How performance recording data can reveal herd animal welfare level: building an useful tool for Italian breeders

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Abstract

An assessment of animal welfare level of a whole herd requires distinct investigation of two different areas:

- Evaluation of farming systems in which an animal can live in wellness
- Evaluation of animal based parameters expressing whether the animal has a condition of wellness

Many scientific papers have been published both about the influence of farming system on animal welfare and about animal based evaluation of animal welfare. Many protocols have been already applied in order to give a support to animal welfare control. Nevertheless, whereas herd evaluation of the first area is easier as it is referred to farm parameters measurements, the latter needs data processing as it is based on animal parameters measurements (often analytical individual parameters). However, final evaluation has to convey the wellness level of all animals of the same herd. Several animal welfare risk factors have been identified by scientific research basing on performance recording data.

The aim of this paper is to present an algorithm which calculates a unique herd animal welfare index from individual performance recording measurements. A set of risk factors have been chosen. Data is previously transformed into standardized values. Afterward, one value for each risk factor is calculated as an index of the animal welfare of the whole herd. An overall index, including all risk factors, is also obtained in order to give a useful information of herd animal welfare level. This final index is an intuitive instrument able to identify animal welfare situations from critical to optimal.

An application using Italian performance recording data is provided.

Keywords: performance recording, welfare assessment

Introduction

In recent animal welfare assessment, animal-based measures are acknowledged as the base for the evaluation of the welfare of dairy cattle on farm. Almost all animals welfare topics can be evaluated by animal-based measures. Furthermore, some animal-based measures are early indicators of health problems and can be used to predict the risk of poor welfare (EFSA Journal 2012; 10(1):2554). However, all these indicators measure the individual condition of welfare. In order to build a herd animal welfare indicator, which supplies an overall classification of dairy cattle in the herd, a mathematical transformation of data is needed. A wide range of parameters can be identified on the basis of scientific evidences, and the choice among them can be guided by specific needs in representing welfare. Performance recording, carried out from breeders associations, are a good opportunity of getting useful data for this purpose. In fact, a lot of fundamental parameters are monthly available for animal welfare evaluation and many studies have confirmed that routinely collected herd data have value for estimating dairy cattle welfare (de Vries *et al.,* 2013). Because farm animal welfare has become a main concern in EU policies, many countries are setting up animal welfare monitoring schemes. The use of routine herd data, such as performance recording, has a high value as a prescreening tool. The chance of highlighting the farms with an estimated lack of animal welfare by routine performance recording leads to remarkable savings due to the possibility of focusing farm visits (in terms of WQ® approach) only in those cases. Moreover, standardization in data collection and continuous monitoring of animals give further value to performance recording data (de Vries *et al.*, 2013).

Many authors are coping with the scientific determination of what parameters are representative of animal welfare according to the 5 freedoms. The aim of this paper is not to fix which is the best set of parameters for animal welfare assessment, but to give a general method capable of summarizing information coming from any type of chosen parameter. The application provided, is based on a five parameters evaluation and their meaning in terms of animal welfare is described. First, simple welfare indicators are calculated, one for each parameter. Afterward, a complex welfare indicator is built on the basis of simple indicators. This is the global herd animal welfare index, an intuitive way of classifying herds that can be used as a highlighter both of critical or good animal welfare conditions. Both the simple welfare indicators and the global index measure the welfare hazard at herd level, that is because the higher the values the higher the lack of welfare level.

The method

The process of transforming information from individual to herd level will be exposed as a seven steps algorithm. In order to obtain the animal welfare level estimation, it is necessary to proceed to a mathematical transformation of raw data. Animal-based measurements are first transformed into distinct animal welfare simple indicators so that each indicator is a synthesis of the overall welfare of all reared dairy cows referred to one welfare aspect. These simple indicators have standardized values so that same assesses have the same meaning in terms of animal welfare and welfare level can be compared among different parameters. After, the simple welfare indicators are combined together in order to get only one value per herd. The method is quite flexible. It allows to include into the assessment any parameter is wanted (as far as it makes sense in term of animal welfare), it allows to specialize threshold values according to peculiar differences (i.e. by breed, breeding system, etc.) and it makes it possible to choose any number of welfare classes into which the farm can be classified. The process schematization is described below, whereas the mathematical process will be detailed in the appendix.

Steps 1 to 5: from raw data to simple indicators

Step 1: Daily representative value of the parameter

The first transformation of measured recorded data consists in calculation of daily representative values for each parameter. Three different kind of values are here considered:

a – breed averages at herd level (e.g., average of days in milk by breed)
b – weighted breed averages at herd level (e.g., weighted average of somatic cell count at herd level by breed)
c – individual values (e.g., fat:protein ratio, fat percentage, etc.)

Other summary measures can be considered depending on the parameter chosen (e.g., maximum or minimum level, total amount, etc.)

The daily representative values have different ranges (e.g., SCC's from 0 to over 1 million, fat percentage from 1.5 to 15, etc.).

Step 2: Standardization of daily values

Standardization of values consists in scaling down the original values to fit a given range. In this particular case, original values are those coming from the previous step 1 and the standardized ranges have to represent various animal welfare levels. In this method, three animal welfare levels have been considered: Good, Attention and Alarm. So, the original range of each daily value has been split into three sub-ranges by the use of suitable threshold values. Every threshold must perform the task to separate values for Good, Attention or Alarm animal welfare level. In this way, each sub-range has a min and max limit so that all daily values within these limits indicate the same animal welfare level. At this point, it is sufficient to apply a continuous linear function over each sub-range in order to scale each [min, max] range into a fixed [A, B] standard range. Performing this process over all sub-ranges, standardized continuous a-dimensional values of every daily values will be obtained. Whereas original ranges (and then min and max values too) are specific of each parameter, standardized final ranges are equal for all of them. In this particular case, standardized final values will range from 0 to 30, being 0 the best value and 30 the worst one in terms of animal welfare; values from 0 to 10 indicate Good animal welfare level, from 10 to 20 Attention level and from 20 to 30 Alarm level. Figure 1 shows how original values are scaled down into standardized ranges.

As the relationship between daily values and animal welfare can be either direct or inverse, the mathematical transformation will take this aspect into account. Figure 1 shows a direct relationship between daily value and standardized value, i.e. when the first increases so does the second. Then, as the effect of the standardization, the higher the animal welfare hazard the higher the standardized value (e.g., an increase in the number of somatic cells leads to an increase of mastitis risk, then the corresponding standardized value is higher meaning an increase in animal welfare hazard). The opposite in figure 2 (e.g., an increase in fat percentage in milk leads to a decrease of acidosis risk, then the corresponding standardized value is lower meaning a decrease in animal welfare hazard).

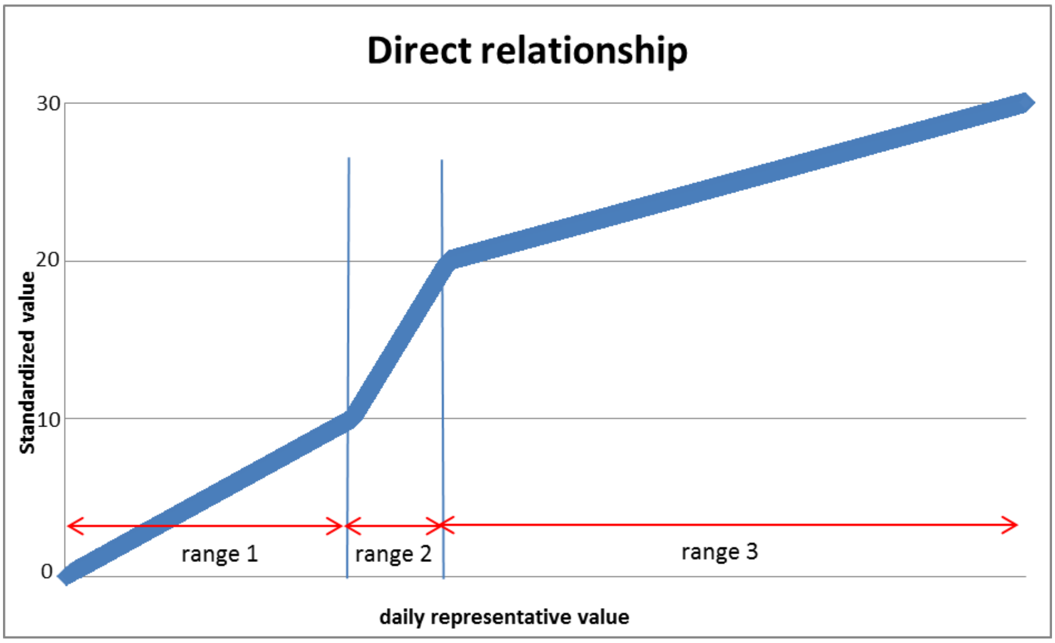


Figure 1. Direct relationship between daily representative value and standardized value.

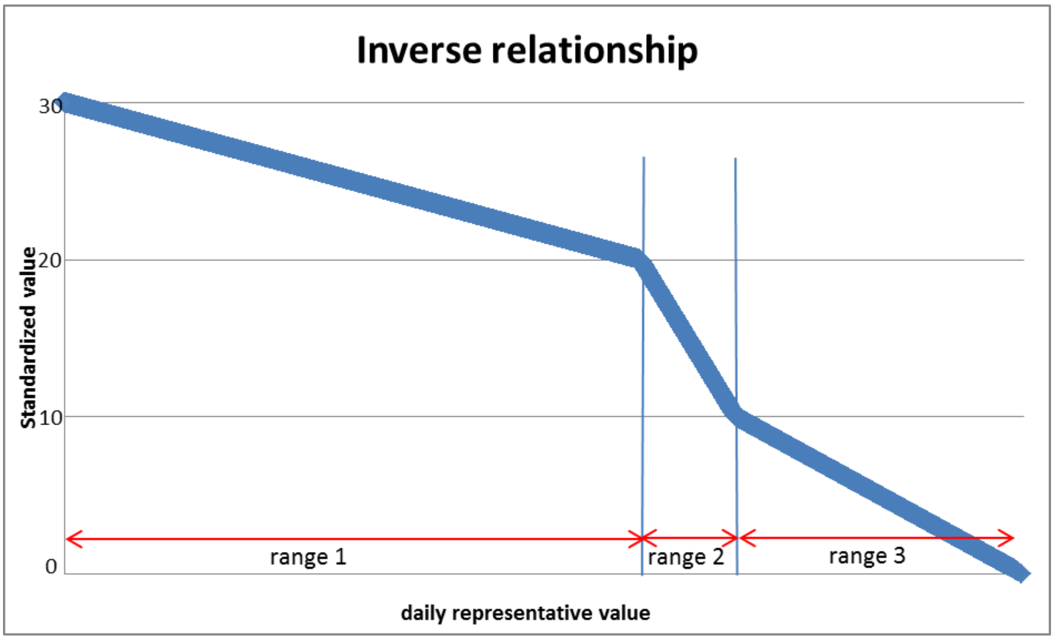


Figure 2. Inverse relationship between daily representative value and standardized value.

According to the kind of daily values defined in step 1 (*a*, *b* or *c*), standardized final values represent an average by breed (*a* and *b* values) or an individual assessment (*c* values). At the end of second step, all values are directly comparable among different parameters.

Step 3: Aggregate standardized values

The daily standardized value is obtained by the calculation of a weighted average for *a* and *b* parameters (e.g. SSC standardized values are averaged and weighted by the number of heads of each breed) or by the calculation of the percentage of heads with high standardized individual values (e.g. Acidosis standardized individual values are used for the determination of the percentage of heads with acidosis risk).

Step 4: Simple animal welfare indicator at herd level for each parameter on test day

On the basis of aggregate standardized values, the herd will be classified into one of the animal welfare classes (Good, Attention, Alarm) for each parameter, then, a mathematical transformation re-assigns a numeric value to the indicator.

The classification process of the herd depends on the kind of parameter:

- for *a* and *b* parameters the numeric value of the daily standardized value is considered, so the herd classification corresponds to the standardized range where the value belongs
- for *c* parameters the percentage of heads with standardized values over 20 (i.e. the heads at risk for animal welfare) is considered, so the herd is classified in the Alarm class if this percentage exceeds a limit (e.g. using an epidemiological limit of 10-15% of animals in Acidosis)

Because the indicator has to summarize the herd animal welfare information, a simple classification of the herd is not suitable. The indicator must be able to distinguish between better and worse farms also within the same welfare class. To satisfy this condition, binding the result to the welfare class previously determined, a farther mathematical transformation is needed. The final value has to depend on daily standardized values coming from step 2. So, taking into account both the worst daily standardized value (i.e. the maximum value from step 2) and the classification of the herd, the final value is calculated (see appendix).

This final value varies into the range corresponding to the herd classification and it is as higher as much as the maximum standardized daily value is higher.

Step 5: Long term Simple animal welfare indicator at herd level for each parameter.

The average over the chosen period is calculated. Other values can be considered such as maximum, median or other percentiles values.

Step 6: Global animal welfare indicator.

This last step provides a single numeric value obtained by the count of the indicators of the various welfare classes. In other words, the frequency of the three classes is transformed into a three digits number so that the number of indicators belonging to the Good class becomes the units digit, the number of indicators belonging to the Attention class becomes the tens digit and the number of indicators belonging to the Alarm class becomes the hundreds digit. If the number of classes are more than three the corresponding number will have more than three digits. The index can assume only some values, that is because the sum of digits is bound to the number of the parameters included in the welfare evaluation.

This global index can represent both one single test day animal welfare assessment and a long period assessment. The higher the value the higher the animal welfare hazard.

An application to Italian performance recording data

According to EFSA recommendation (EFSA Journal 2012; 10(1):2554) and animal welfare issues (deVries *et al.*, 2011), Italian routinely collected herd data have been used in order to make an animal-based assessment of the animal welfare at herd level. With the purpose of summarize animal welfare, five animal-based parameters have been included in the index calculation. They are pertaining to four main areas: reproductive disorders, longevity, udder disorders and metabolic disorders. The EFSA Panel on Animal Health and Animal Welfare has widely examined how animal welfare is related to metabolic and reproductive disorders (EFSA Journal 2009; 1140, 1-75) and to udder diseases (EFSA Journal 2009; 1141, 1-60). Reproductive disorders have been related to different aspects of animal welfare: poor feeding (EFSA Journal 2012; 10(1):2554), poor health (Botreau *et al.*, 2009). Then, a lack of reproductive regularity shows a poor welfare level. Longevity is a fundamental aspect of animal welfare and can be measured by different parameters. High herd replacement rate has been associated with high percentage of very lean cows by de Vries (de Vries *et al.,* 2013). In the same paper, other measures of longevity (such as average age, percentage of cows older than 5 years) have also been analyzed. Even if a more realistic indication of welfare is provided by the ratio of voluntary to involuntary culling (FAWC, 2009, Opinion for the Welfare of the Dairy Cow), longevity itself is a valuable measure. Italian longevity of Holsteins is rather low. In fact, using February 2014 performance recording data, average age at test day is about 58 months, average parity is 2.5 lactations, percentage of primiparous is 34 and average culling age is 62 months. It is clear that low longevity of dairy cows is associated to welfare and health problems. In fact, problematic animals are culled earlier than others. Since not all breeders accurately report the reasons for cows leaving their herd, it is not easy to analyze culling by age and disposal code in order to verify such association. A Canadian report, dated August 2009, shows that reproductive and calving problems have been the major disposal reasons. Considering the average productive life by disposal code, Canadian Holsteins culled for milkability traits (low milk speed/milking temperament) are the youngest (averaging 24 months of production life), cows culled for low production are aged 32 months of productive life. Cows culled for other reasons (such as reproduction, functional conformation, somatic cell count/mastitis and disease) are aged about three years of productive life. Cows being removed from the herd for natural causes (such as death or injury) are the oldest (about 7 years). According to this, longevity can be reasonably considered as an expression of lack of animal welfare.
The five parameters used in this application are:

- DIM: the average Days In Milk of the herd, calculated by breed, as an indicator of reproduction regularity.

- PAR: the average PARity of the herd, calculated by breed, as an indicator of longevity.
- SCC: the average Somatic Cell Count of the herd, calculated by breed, as an indicator of udder health.
- KET: incidence of heads with KETosis risk measured by fat:protein ratio, according to Duffield *et al.* (2002).
- ACI: incidence of heads with ACIdosis risk measured by low fat percentage in milk, according to Oetzel *et al.* (2007).

Many practical applications are possible from the use of the global index, even from the use of single standardized indicators. For example, in technical advice, a continuous monitoring of welfare parameters can help breeders in the animal welfare condition improvement. For this purpose, a report has been developed showing the global index calculated over a year period, together with long term simple indicators. The report exposes also simple indicators calculated at each test day. In the examples, two years of the same herd are compared (figure 3 and 4) for two different farms. According to the global index value, critical herds can be easily highlighted and critical aspects of those herds, in terms of animal welfare, can be immediately focused. Further, simple test day indicators help in analyzing the evolution over the year of those critical aspects.

		Breed
Herd code	xxxxxxx	Cross Breed
Av. n. of cows	80	Holstein
N. of test days	11	Simmental

YEAR		2011					2012				
Global index		032					032				
herd welfare class		Attention					Attention				
Long term simple indicators		DIM	PAR	SCC	KET	ACI	DIM	PAR	SCC	KET	ACI
		18,72	19,66	14,69	9,70	6,75	16,35	19,96	19,37	9,75	2,48
	month										
Test day simple indicators	Jan	18,26	20,00	6,92	9,39	9,07	18,59	19,95	5,12	9,94	0
	Feb	18,75	20,00	19,37	9,46	9,56	18,13	19,98	19,20	9,94	0
	Mar	19,71	20,00	21,80	9,46	0	18,75	19,98	18,83	9,94	0
	Apr	19,98	20,00	19,61	9,46	0	17,20	19,98	17,39	9,94	0
	May	20,00	20,00	12,45	9,46	0	17,59	19,98	25,86	9,94	9,06
	Jun	20,00	20,00	19,21	9,77	9,06	17,90	19,98	30,00	9,58	0
	Jul	20,00	20,00	16,34	9,94	9,56	18,02	19,98	19,87	9,58	9,10
	Aug										
	Sep	17,14	20,00	14,52	9,94	9,35	17,32	19,92	19,03	9,58	9,16
	Oct	18,37	18,75	6,78	9,94	9,11	14,28	19,92	18,13	9,58	0
	Nov	16,07	18,75	5,46	9,94	9,28	7,19	19,93	20,00	9,58	0
	Dec	17,59	18,75	19,10	9,94	9,24	14,88	19,93	19,60	9,58	0

Figure 3. Herd 1 Report for animal welfare assessment.

Herd 1 report shows a stable global animal welfare condition, in fact the value of the global index is 032 in both years. Long term indicators focus the attention on longevity and reproduction regularity, showing a worsening in the somatic cell condition (from 14.69 to 19.37). Also the comparison of SCC indicators at test day between the two years show the same, allowing a deeper analysis. Acidosis and ketosis are classified into the Good level over the two years.

Herd 2 report shows an improvement in the general welfare condition, moving from 401 to 320. In fact, long term ketosis evaluation has changed from 25.88 to 16.90. Acidosis assessment has worsened as it can be seen comparing corresponding long term indicators (2011: 6.66; 2012: 10.50). In fact, the 2012 global index has units digit equal to 0, which means that there isn't any indicator for the digit corresponding to the Good class. Analysing the pattern of single test day indicators, it is easy to catch the evolution of improvement and worsening of single parameter.

		Breed	
Herd code	xxxxxxx	Holstein	
Av. n. of cows	175		
N. of test days	11		

YEAR		2011					2012				
Global index		**401**					**320**				
herd welfare class		Alarm					Alarm				
		DIM	PAR	SCC	KET	ACI	DIM	PAR	SCC	KET	ACI
Long term simple indicators		27,52	20,59	22,13	25,88	6,66	24,08	21,63	20,20	16,90	10,50
	month										
Test day simple indicators	Jan	27,64	20,71	24,29	25,88	8,88	20,34	20,61	15,75	25,88	21,85
	Feb	29,21	20,45	23,20	25,88	9,29	18,02	20,80	20,28	9,78	9,36
	Mar	27,54	20,06	23,78	25,88	8,87	20,98	20,92	20,35	24,44	9,32
	Apr	30,00	20,29	23,31	25,88	0	22,13	20,57	17,60	25,88	9,35
	May	30,00	20,50	27,13	25,88	0	21,57	21,63	17,12	25,38	9,34
	Jun	29,81	20,71	23,19	25,88	0	23,24	22,12	21,44	9,88	9,34
	Jul	29,70	20,93	24,38	25,88	9,20	24,83	22,40	20,90	9,88	9,36
	Aug										
	Sep	25,96	20,80	26,55	25,88	9,33	26,54	22,14	21,32	9,88	9,28
	Oct	25,91	20,91	20,44	25,88	9,25	28,60	22,29	20,23	9,88	9,33
	Nov	25,40	20,72	20,38	25,88	9,18	29,48	22,24	25,94	9,88	9,34
	Dec	21,53	20,40	6,78	25,88	9,31	29,08	22,20	21,24	25,38	9,11

Figure 4. Herd 2 Report for animal welfare assessment.

Another application of this method regards the possibility of supporting the public animal welfare monitoring performed by Governments. By the use of the global animal welfare

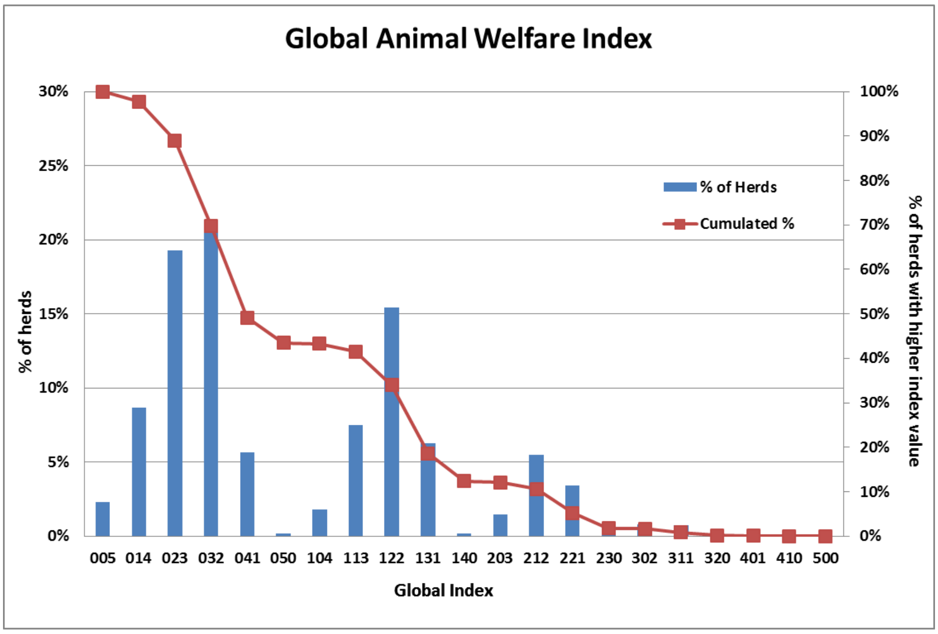


Figure 5. Distribution of 2012 global index.

index, the Government can control the evolution of herd animal welfare and oversee the efficiency of its improvement policies. Figure 5 shows the result of the application of the method on the Italian performance recording data.
The strips indicate the percentage of herds having the corresponding global index value, whereas the line indicates the percentage of herds with the global index greater or equal to the corresponding one, i.e. the percentage of herds with poorer animal welfare compared to the one indicated. The more the line decreases quickly, the better the general animal welfare level is. Figure 6 show the comparison between two Italian regions, where Region 2 has a better welfare level compared to Region 1.

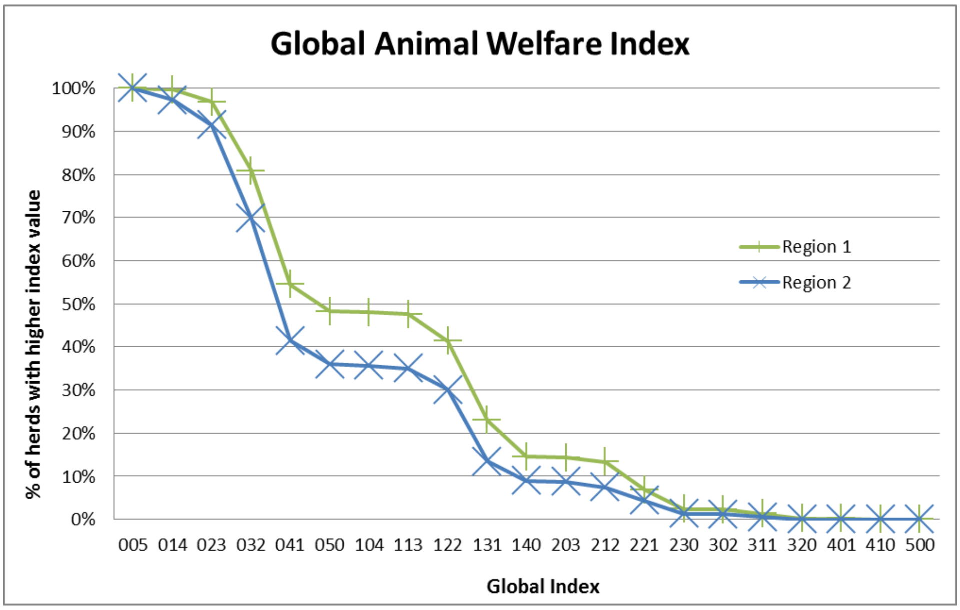
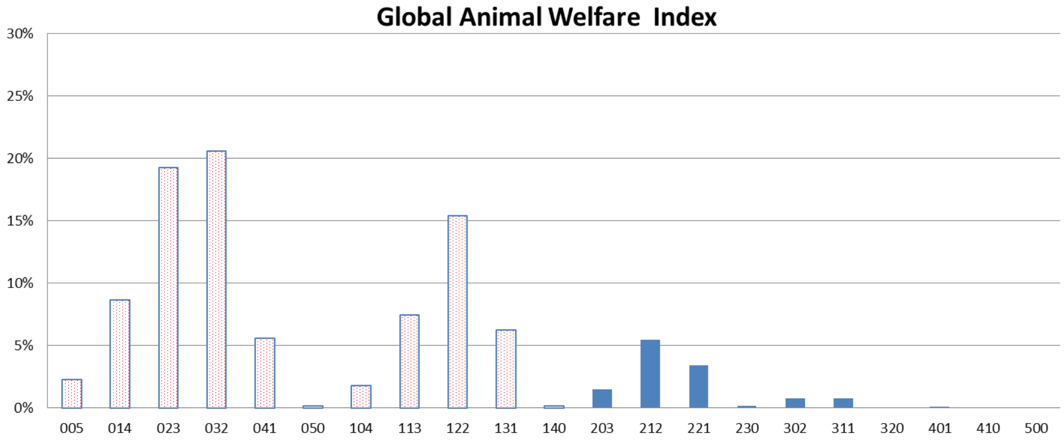
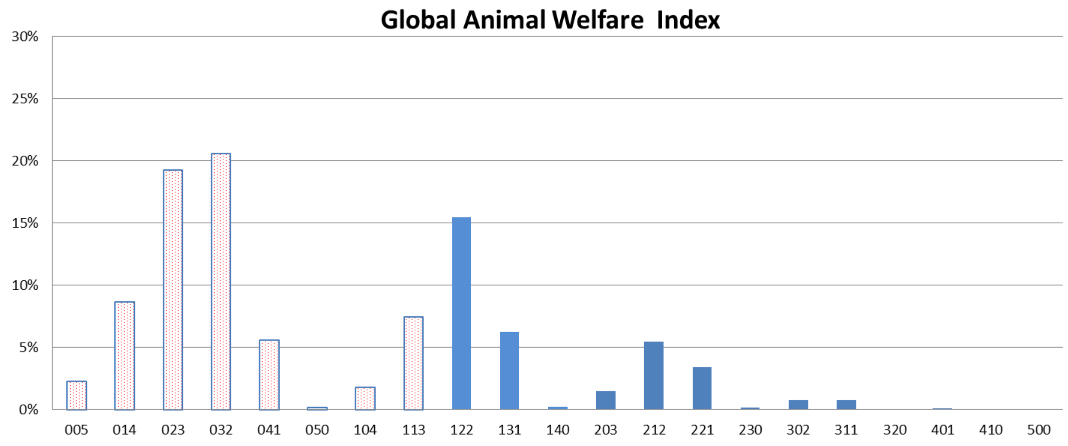


Figure 6. Comparison of welfare level between two Italian regions.

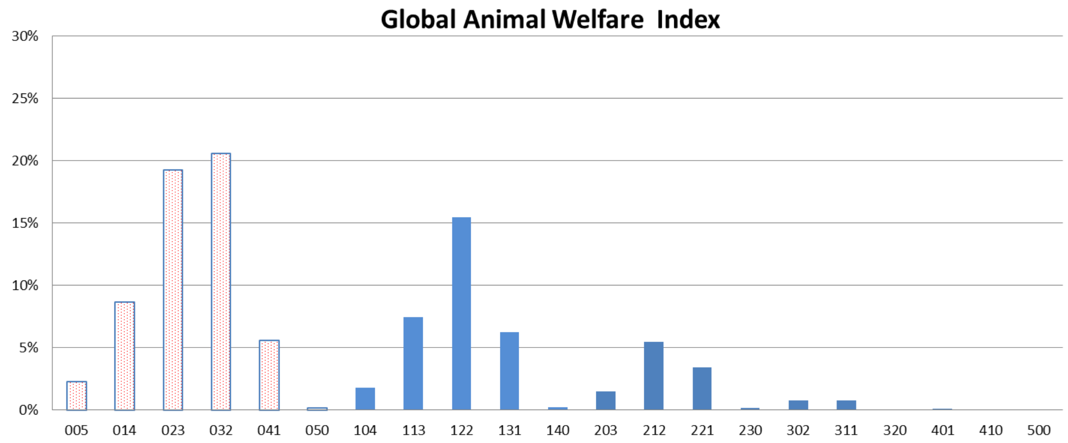
One more application of the global index can be in helping in the study of different scenarios. This can be useful, for example, in programming public funding expenses (figure 7 a-b-c-d).



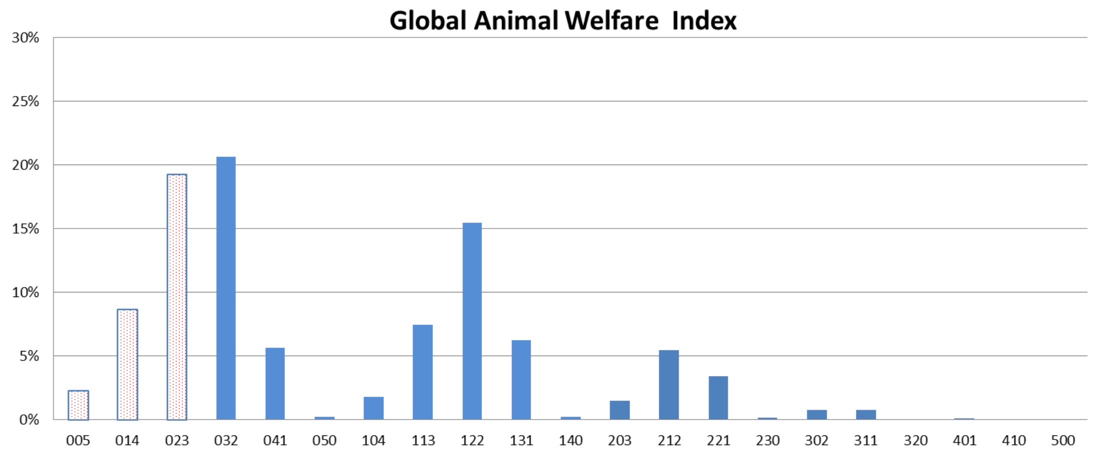
a: Scenario 1 - paying at most 1 indicator in Alarm class: 88% of herds



b: Scenario 2 - paying at most 1 indicator in Alarm class and at least 3 indicators in Good class: 66% of herds



c: Scenario 3 - paying only no indicator in Alarm class: 57% of herds



d: Scenario 4 - paying at most 2 indicators in Attention class: 30% of herds

Figure 7. Analysis of different scenarios for expenses programming

Scenario 1 simulates the payment of all herds that have at most 1 indicator in Alarm class, i.e. all herds with global animal welfare index less or equal then 140. In fact, to have only 1 indicator in Alarm class means that the global index has at most 1 in the first digit.

Scenario 2 simulates the payment of all herds that have at most 1 indicator in Alarm class but at least 3 indicators in Good class, i.e. all herds with global animal welfare index less or equal then 113.

In public animal welfare policies, this method can be also used as a pre-screening for poor animal welfare farms in order to focus the demand of actual on-farm visits mainly in those cases, with a concrete perspective of saving public money.

Conclusion

The global index of animal welfare proposed in this paper is a summary value based only on animal-based measures collected by official performance recording. This index is composed by 5 different indicators related to 4 welfare hazard areas: reproduction, longevity, udder health and metabolic diseases. Longevity is assumed to be the direct consequence of the individual response to risk factors in term of animal welfare.

The importance of this approach is also connected to three main aspects related to performance recording: continues monitoring of herds, long term evaluation, guarantee of objectiveness and homogeneity in data collection. A few applications of the method have been included in the paper.

Appendix

The suggested method is a mathematical process which transforms animal-based measures into a unique herd value. The method is based on the results obtaind in pollution control processes (Albergamo *at al.*, 1997).
The process is later drawn using a six steps mathematical description.

Steps from 1 to 5: **simple welfare indicators calculation**
From animal-based data to *n* animal welfare indicators, one for each key parameter included into the welfare evaluation. The transformation is based on the calculation of a function for every parameter which indicates the reaching of the various animal welfare levels: Good, Attention or Alarm, passing from an evaluation for a single animal or groups of animals, to an aggregated evaluation for all the farm referred to the survey day. The calculation of the single parameter ends with a further aggregation on long period (year or year fraction). At the end of the fifth step, each parameter has a corresponding indicator representing the welfare level of the farm over the year.

Steps 6: **global indicator**
The information that comes from each indicator is bound through a function, providing the total animal welfare level indicator.

Choise of key parameters
The following description considers 5 parameters:
1 – DIM: the average Days In Milk of the herd, calculated by breed, as an indicator of reproduction regularity.
2 – PAR: the average PARity of the herd, calculated by breed, as an indicator of longevity.
3 – SCC: the average Somatic Cell Count of the herd, calculated by breed, as an indicator of udder health.
4 – KET: incidence of heads with KETosis risk measured by fat:protein ratio.
5 – ACI: incidence of heads with ACIdosis risk measured by low fat percentage in milk.

This method can be generalized to any set of parameters and can be customized to different national scenarios in order to adapt the values of the thresholds, corresponding to the reaching of the welfare levels, for every single parameter.

Choice of welfare classes
In the following exposure 3 risk classes are considered for animal welfare:
GOOD → (0, **a**)
ATTENTION → (**a**, **b**)
ALARM → (**b**, **SUP**)

The number of classes can be different from three, depending on how welfare levels are required to be accurate. In this case the method needs to be reformulated. **a**, **b**, **SUP** values can be customized as needed.

STEP 1
Daily representative value of the parameter: $\mathbf{Y}_{itr}$
A representative value of the welfare state of the animals of the stable must be estimated at the day of survey. This value keeps the same unit of measurement and variation range as animal-based data involved in the calculation.

Three kinds of representative values are considered:

a – herd average values, calculated by breed

b – herd weighted average values, calculated by breed

c – individual values

For exposure comfort, every parameter inserted in the welfare evaluation is associated with a number. With reference to the chosen parameters, let:
DIM=1; PAR=2; SCC=3; KET=4; ACI=5.

Let $\mathbf{x}_{ijt}$ be the row measured value for the *i*-th parameter of the *j*-th head on *t*-th day.

where

i= 1, …, k – *i*-th parameter inserted in the welfare evaluation
j= 1, …, n – *j*- th head
t= 1, …, T – *t*-th survey day
k total number of parameters included in calculation (in this case k=5)
n total number of heads
T total number of survay days in the long period

Let $\mathbf{Y}_{itr} \rightarrow f(\mathbf{x}_{ijt})$ be the calculated value for the *i*-th parameter on the *t*-th day of all the heads belonging to the same *r*-th breed. The f function is afterward defined according to the above classification of representative values (***a***, ***b*** or ***c***).

Definition of the f function for *a* representative values

$\mathbf{Y}_{itr}$ is the arithmetic average of *i*-th parameter on *t*-th day for all heads belonging to the *r*-th breed (in this case ***a*** parameters are *i*= 1 - DIM and *i*= 2 - PAR):

$$\mathbf{Y}_{itr} = \frac{1}{n_{rt}} \sum_{j=1}^{n_{rt}} x_{ijt} \qquad (1)$$

where

n_{rt} number of heads of the same *r*-th breed on *t*-th day
(when *i*=1 recorded heads; when *i*=2 total mature heads)
x_{ijt} when *i*=1 Number of days in milk of the *j*-th head on *t*-th day
when *i*=2 Lactation order of the *j*-th head on *t*-th day

Definition of the f function for *b* representative values

$\mathbf{Y}_{itr}$ is the weighted average of *i*-th parameter on *t*-th day for all heads belonging to the *r*-th breed (in this case ***b*** parameters are *i*= 3 - SCC)[1]:

$$\mathbf{Y}_{itr} = \frac{\sum_{j=1}^{n_{rt}} x_{ijt} * p_{jt}}{\sum_{j=1}^{n_{rt}} p_{jt}} \qquad (2)$$

where

x_{ijt} when *i*=3 Number of Somatic Cell Count of the *j*-th head on *t*-th day
p_{jt} weight of the *j*-th head on *t*-th day
(when *i*=3 *p*=milk yield of the *j*-th head on *t*-th day)

[1] ***a*** type can be considered as a special case of ***b*** type being *p*=1.

Definition of the *f* function for *c* representative values

In this case the *f* function is the identity function. Then, the representative value is the row value of *i*-th parameter of the *j*-th head on *t*-th day (in this case ***c*** parameters are *i*= 4 – KET and *i*= 5 – ACI):

$$\mathbf{Y}_{ijt} = x_{ijt} \qquad (3)$$

where

x_{ijt} when *i*=4 milk Fat:Protein ratio of the *j*-th head calculated on the first performance record of the current lactation on *t*-th day (the value being valid only if the first performance record has been performed within 60 days from breeding)

when *i*=5 milk fat percentage of the *j*-th head on *t*-th day

Thresholds setting

Let respectively X_{ai} e X_{bi} be the threshold values either for $\mathbf{Y}_{itr}$ or for $\mathbf{Y}_{ijt}$ which determine the reaching of the attention and alarm animal welfare state for the representative value of the *i*-th parameter. Furthermore, let X_{INFi} e X_{SUPi} be opportune extreme values, respectively inferior and superior, that are required in order to delimitate herd animal welfare classes.

STEP 2

Standardized values of $\mathbf{Y}_{itr}/\mathbf{Y}_{ijt}$: $\mathbf{YStd}_{itr}/\mathbf{YStd}_{ijt}$.

All $\mathbf{Y}_{itr}/\mathbf{Y}_{ijt}$ values are standardised in order to make them comparable and uniquely interpretable. This way, standardised values of different parameters can be directly compared. Standardisation consists in the application of a linear spline function (i.e. a continuous piecewise degree-1 polynomial) which pairs thresholds values {X_{INFi}, X_{ai}, X_{bi}, X_{SUPi}} to corresponding conventional values, named {**INF**, **a**, **b**, **SUP**}. X_{ai} e X_{bi} values are set depending on *i*-th parameter considered. Let **INF**=0, equal width intervals are defined as (0, **a**), (**a**, **b**) e (**b**, **SUP**). Two different typologies of relationships between $\mathbf{Y}_{itr}/\mathbf{Y}_{ijt}$ values and corresponding animal welfare levels must be considered:

d – animal welfare level decreases as $\mathbf{Y}_{itr}/\mathbf{Y}_{ijt}$ increases

e – animal welfare level increases as $\mathbf{Y}_{itr}/\mathbf{Y}_{ijt}$ increases

Considering the above intervals, type ***d*** values are standardised into $\mathbf{YStd}_{itr}$ values as follows:

$$\mathbf{YStd}_{itr} = \begin{cases} 0 & \text{se } \mathbf{Y}_{itr} \leq X_{INFi} \\ \dfrac{(Y_{itr} - X_{INFi})}{(X_{ai} - X_{INFi})} * \mathbf{a} & \text{se } \mathbf{Y}_{itr} \in (X_{INFi}, X_{ai}] \\ \dfrac{(Y_{itr} - X_{ai})}{(X_{bi} - X_{ai})} * (\mathbf{b}-\mathbf{a})+\mathbf{a} & \text{se } \mathbf{Y}_{itr} \in (X_{ai}, X_{bi}] \\ \dfrac{(Y_{itr} - X_{bi})}{(X_{SUPi} - X_{bi})} * (\mathbf{SUP}-\mathbf{b})+\mathbf{b} & \text{se } \mathbf{Y}_{itr} \in (X_{bi}, X_{SUPi}] \\ \mathbf{SUP} & \text{se } \mathbf{Y}_{itr} > X_{SUPi} \end{cases} \qquad (4)$$

for type ***e*** values:

$$\mathbf{YStd}_{itr} = \begin{cases} \mathbf{SUP} & \text{se } \mathbf{Y}_{itr} \le \mathrm{X}_{INFi} \\ \dfrac{(\mathrm{X}_{ai} - \mathrm{Y}_{itr})}{(\mathrm{X}_{ai} - \mathrm{X}_{INFi})} * (\mathbf{SUP}–\mathbf{b})+\mathbf{b} & \text{se } \mathbf{Y}_{itr} \in (\mathrm{X}_{INFi}, \mathrm{X}_{ai}] \\ \dfrac{(\mathrm{X}_{bi} - \mathrm{Y}_{itr})}{(\mathrm{X}_{bi} - \mathrm{X}_{ai})} * (\mathbf{b}–\mathbf{a})+\mathbf{a} & \text{se } \mathbf{Y}_{itr} \in (\mathrm{X}_{ai}, \mathrm{X}_{bi}] \\ \dfrac{(\mathrm{X}_{SUPi} - \mathrm{Y}_{itr})}{(\mathrm{X}_{SUPi} - \mathrm{X}_{bi})} * \mathbf{a} & \text{se } \mathbf{Y}_{itr} \in (\mathrm{X}_{bi}, \mathrm{X}_{SUPi}] \\ 0 & \text{se } \mathbf{Y}_{itr} > \mathrm{X}_{SUPi} \end{cases} \quad (5)$$

With reference to the 5 key parameters set above, the (4) function will be used when *i*=1, 3, 4, whereas the (5) function when *i*=2, 5. Type ***c*** representative values will have an individual standardised value named $\mathbf{YStd}_{ijt}$.

STEP 3

Aggregated standardised values on *t*-th day: $\overline{\mathrm{Y}}\mathrm{Std}_{it}$

Both $\mathbf{YStd}_{itr}$ and $\mathbf{YStd}_{ijt}$ values have to be aggregated in order to get one standardised value for the *i*-th parameter on *t*-th day. Type ***a*** and ***b*** parameters aggregation is performed by a weighted average calculation, whereas type ***c*** aggregation according to the percentage of heads whose standardised values are over the **b** value, i.e. those with $\mathbf{YStd}_{ijt} > \mathbf{b}$. Then:

for *i*=1, 2, 3

$$\overline{\mathrm{Y}}\mathrm{Std}_{it} = \frac{\sum_{r=1}^{R} \mathrm{YStd}_{itr} * p_{rt}}{\sum_{r=1}^{R} p_{rt}} \quad (6)$$

where

p_{rt}	weight of the *r*-th breed on *t*-th day (*p*=number of heads of the *r*-th breed on *t*-th day)
R	total number of breeds

for *i*=4, 5

$$\overline{\mathrm{Y}}\mathrm{Std}_{it} = \frac{\sum_{j=1}^{n} \mathrm{I}_{(\mathrm{b},\mathrm{SUP}]}(\mathrm{YStd}_{ijt})}{n} *100 \quad (7)$$

where

$\mathrm{I}_A(x)$ is the indicator function of a subset A. It is a function defined as:
$\mathrm{I}_A(x) = 1$ if $x \in A$
$\mathrm{I}_A(x) = 0$ if $x \notin A$

STEP 4

Final value for the indicator of the *i*-th parameter on *t*-th day: $\mathbf{IND}_{it}$

The final value for the indicator of the *i*-th parameter on *t*-th day has to be representative of the overall welfare level of all present animals on *t*-th day. Therfore, its numerical values have to vary within the representative herd welfare class, even though they are wanted to be dependent from initial standardised values $\mathbf{YStd}_{itr}/\mathbf{YStd}_{ijt}$. To get the result, first the herd has to be classified into one of the welfare classes (WC) for the *i*-th parameter on *t*-th day, afterward the i-th indicator (IND) has to assume numerical values depending on initial standardised values.

According to $\overline{Y}Std_{it}$ value, the herd is classified by a step function given by $WC_{it} \rightarrow f(\overline{Y}Std_{it})$ such that its image is the set {1, 2, 3}. For type ***a*** and ***b*** parameters, the step function is given by:

$$WC_{it} = I_{[0,\,a]}(\overline{Y}Std_{it}) + 2 * I_{(a,\,b]}(\overline{Y}Std_{it}) + 3 * I_{(b,\,SUP]}(\overline{Y}Std_{it}) \qquad (8)$$

for ***c*** type parameters:

$$WC_{it} = I_{[0,\,lim_i]}(\overline{Y}Std_{it}) + 3 * I_{(lim_i,\,100]}(\overline{Y}Std_{it}) \qquad (9)$$

where

$lim_i \in [0, 100]$ is the limit value. If the percentage is over this limit the whole herd has to be considered at risk for the i-th parameter.

I is the indicator function as specified above.

WC_{it} will only assume values in {1, 2, 3} depending on which range standardised daily value $\overline{Y}Std_{it}$ fits.

In order to obtain the final value for the indicator (IND_{it} for the i-th parameter on t-th day), which must assume a continuous value within the interval (0, **SUP**), a new function is needed. This function has to link initial standardised values $\mathbf{YStd}_{itr}$ (the domain of the function) with final values (the image of the function), bounding them into welfare intervals as defined above ([0, **a**], (**a**, **b**], (**b**, **SUP**]). The wished function must have opportune properties to ensure the above.

let $z_{it} = \max_r \{\mathbf{YStd}_{itr}\}$ when i=1, 2, 3 and r=1, …,R (10)

$z_{it} = \max_j \{\mathbf{YStd}_{ijt}\}$ when i=4, 5 and j=1, …,n (11)

and let

$$IND_{it} = I_{\{1\}}(CB_{it}) * f_1(z_{it}) + I_{\{2\}}(CB_{it}) * f_2(z_{it}) + I_{\{3\}}(CB_{it}) * f_3(z_{it}) \qquad (12)$$

be the function for the i-th parameter on t-th day which satisfies the following properties:

$IND_{it} : [0, \mathbf{SUP}] \rightarrow [0, \mathbf{SUP}]$

$IND_{it} = \mathbf{a}$ when the attention state is reached

$IND_{it} = \mathbf{b}$ when the risk state is reached

$f(z)$ functions must be such that:

$f_1(z_{it}) : [0, \mathbf{SUP}] \rightarrow [0, \mathbf{a}]$

$f_2(z_{it}) : [\mathbf{a}, \mathbf{SUP}] \rightarrow [\mathbf{a}, \mathbf{b}]$

$f_3(z_{it}) : [\mathbf{b}, \mathbf{SUP}] \rightarrow [\mathbf{b}, \mathbf{SUP}]$

f (z)'s are monotonically increasing functions given by:

$$f_1(z_{it}) = \left(\frac{a}{SUP^3} * z_{it}^{\ 3} - \frac{3*a*SUP}{SUP^3} * z_{it}^{\ 2} + \frac{3*a*SUP^2}{SUP^3} * z_{it} - \frac{a*SUP^3}{SUP^3} \right) + a \quad (13)$$

$$f_2(z_{it}) = \left(\frac{(b\text{-}a)}{(SUP\text{-}a)^3} * (z_{it} - a)^3 - \frac{3*(b\text{-}a)*(SUP\text{-}a)}{(SUP\text{-}a)^3} * (z_{it} - a)^2 + \frac{3*(b\text{-}a)*(SUP\text{-}a)^2}{(SUP\text{-}a)^3} * (z_{it} - a) - \frac{(b\text{-}a)*(SUP\text{-}a)^3}{(SUP\text{-}a)^3} \right) + b \quad (14)$$

$$f_3(z_{it}) = z_{it} \quad (15)$$

The graphic representation of IND_{it} is provided in figure 1.
Thus, IND_{it} values are the final representation of herd animal welfare with regard to the *i*-th parameter on *t*-th survey day.

STEP 5
Long term indicator: IND_i
The long term *i*-th indicator is calculated by the arithmetic average over the chosen period (year or fraction of year):

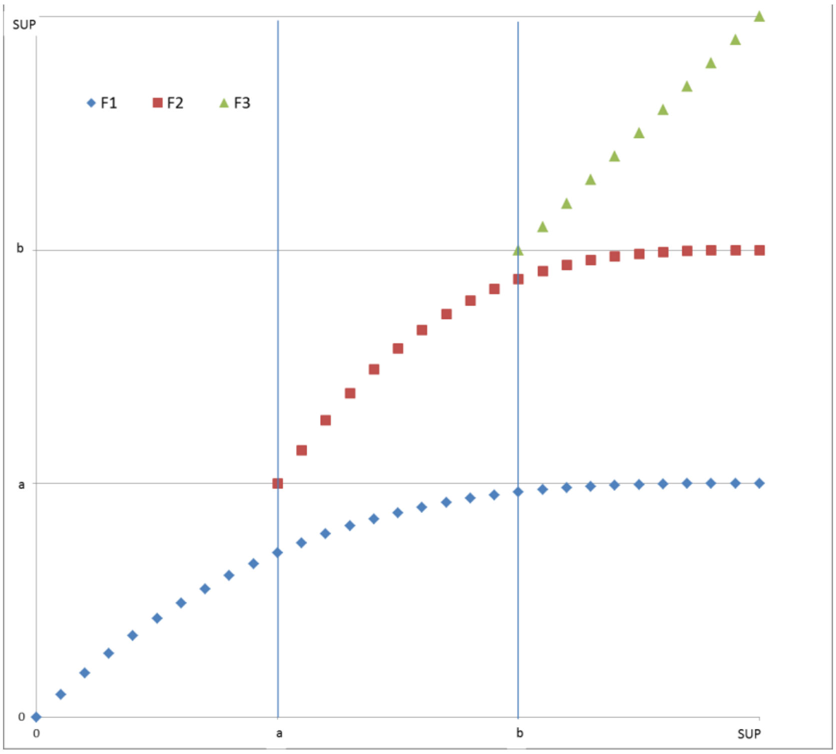
$$IND_i = \sum_{t=1}^{T_i} \frac{IND_{it}}{T_i} \quad (16)$$

where

T_i number of valid indicators for the *i*-th parameter on reference period

IND_i is the annual animal welfare indicator of the *i*-th parameter.

Figure 1. *Graphic representation of* IND_{it} *function.*



STEP 6

Global animal welfare indicator: WI

Both IND_{it} and IND_i are directly comparable values (the first at the survey day, the latter over a long term period) that supply an exhaustive picture of the herd welfare level separately for each parameter inserted in the evaluation.

However, the determination of a single herd value represents a good chance to express in synthetic format the level of the animal welfare of the whole breeding on the chosen period, as regards to the set of selected parameters.

From a mathematical point of view, an aggregation function of the final IND_i values has been built such that: WI → $f(IND_i)$. The f function is required to show, with a single value, the reaching of attention or alarm levels by at least one of the indicators considered. The domain of this function is the interval [0, **SUP**], and the image is a discrete set whose values depend on the number of indicators and the number of welfare classes chosen. The same function can be considered on the survey day, having WI_t → $f(IND_{it})$. For this

The global Welfare Index is given by:

$$WI = \sum_{i=1}^{k} I_A(IND_i) + 10 * \sum_{i=1}^{k} I_B(IND_i) + 100 * \sum_{i=1}^{k} I_C(IND_i) \qquad (17)$$

where

A	[0, **a**] interval – referred to GOOD animal welfare state
B	(**a**, **b**] interval – referred to ATTENTION animal welfere state
C	(**b**, **SUP**] interval – referred to ALARM animal welfare state

According to the number of indicators chosen and to the number of animal welfare classes adopted, WI can only assume 21 integer values between 5 and 500. WI indicates the frequency of the three classes so that the units digit is the number of indicators belonging to the Good class ($IND_i \in (0, a)$), the tens digit the number of indicators belonging to the Attention class ($IND_i \in (a, b)$) and the hundreds digit the number of indicators belonging to the Alarm class ($IND_i \in (b, SUP)$).

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