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Animal Welfare and Economics in Beef Production

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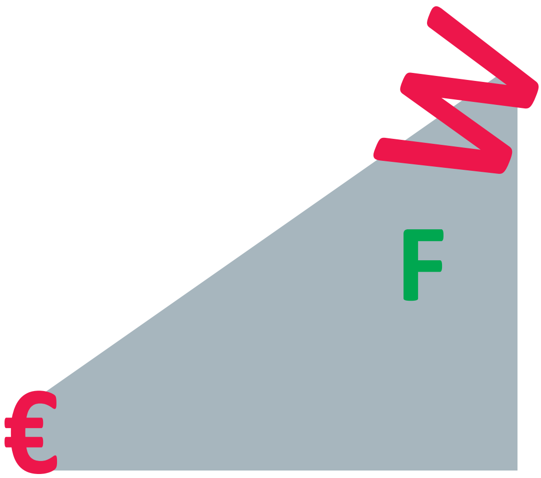

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Animal welfare and economics in beef production

Academic Dissertation

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Contents

1. Abstract

Animal welfare (AW) is an issue of growing concern in Finland as well as in other developed countries. A public debate has focused on the potential AW problems resulting from current production systems. Possibilities to find mutual benefit for animals, farmers, industry and society have received less attention.

The main objective of the study was a thorough understanding of relationships between AW and beef production economics to find barriers and opportunities for enhanced AW. The study consisted of on farm AW assessments by a version of the ANI/TGI 35L AW assessment system, modified for Finnish beef production, calledA-index, validation of the index, building a best subset of the A-Index items to be used as welfare score (WFS), epidemiologic studies to establish the associations between the A-Index and production parameters as well as economic modelling to evaluate the relationship between housing, AW and farm net income.

The A-Index was modified and evaluated based on Test Theory. On-field associations between A-index, daily gain, carcass fat score and carcass conformation score were determined using statistical multilevel models. Mortality was studied by one-level model designed for the excess zero-count data type. Confirmed associations were used to evaluate the criterion validity and sensitivity of the A-Index and to build a bio-economic simulation model. Economic evaluation of AW was based on comparison between cold and warm housing. The model consisted of a stochastic part predicting production results by given welfare score and A-Index. A deterministic part was built in to calculate costs, revenues and economic results by given input values and predicted production results.

WFS was associated to the decreased mortality and the declining proportion of high fat scores at slaughter but to the increased proportion of high conformation scores at slaughter. Daily carcass gain was increasing in association with the A-Index. Due to these findings, criterion validity of the measures was concluded to be reasonable.

Good AW was found to favour animal performance. Cold housing with enhanced welfare and bedding based on own straw at a reasonable price was economically favourable. Profitability of cold housing was sensitive to fluctuation in bedding price. Developing a reasonably priced market for bedding material would be a major way to enhance AW.

Restricted space allowance and increased number of animals were calculated to favour economic performance, although effects on production parameters were negative due to lower AW. Calculated results were in conflict with preliminary on-farm findings. More information about interactions between AW and production costs should be sought for adequate farm budgeting calculations to resolve the conflict between space allowance, AW and profitability. A reform of the subsidy system was suggested to be needed to fulfil the aims of the subsidy regime to support AW.

Conflicts between AW, performance and profitability can be solved by developing production systems and reforming subsidies. The inconsistency of determination and perception of AW can be a greater problem from the economic point of view. There is also a great uncertainty as to whether any AW-enhancing measure in commercial farms could alleviate public concern over AW in food production as long as there is an unrealistic picture of AW in traditional animal husbandry. Although there was a positive relationship between WFS and performance, another

AW evaluation system could give very different results. A sustainable welfare scheme should give sufficient production benefits or added value to cover the extra costs of the measure. Costs and benefits of the measures should be available before risk-averse farmers can be expected to join the schemes. Possibilities for farmers to enhance AW are limited if they can't be confident that their efforts meet their economic or personal goals and alleviate public concerns of AW. A thorough understanding of farm economics is essential to find practicable ways to enhance on-farm AW.

2. Publications

This thesis is based on four original articles. They are referred in the text by Roman numerals.

I. Herva, T., Peltoniemi, O.A.T., Virtala, A.-M., 2010. Validation of an Animal Needs Index for cattle using Test Theory. Animal Welfare. 18, 417-425.

II. Herva, T., Virtala, A.-M., Huuskonen, A., Saatkamp, H., Peltoniemi, O.A.T., 2009. On-farm welfare and estimated daily carcass gain of slaughtered bulls. Acta Agriculturae Scandinavica. A. Animal Science. 59, 104-120.

III. Herva, T., Huuskonen, A., Virtala, A.-M., Peltoniemi, O.A.T, 2011. On-farm welfare and carcass fat score of bulls at slaughter. Livestock Science. 138, 159-166.

IV. Herva, T., Niemi, J., Peltoniemi, O.A.T., Saatkamp, H., (Livestock Science. submitted in 2014) Welfare of beef cattle and farm net income: the complex relationship among housing, space allowance and subsidies

These original publications have been reprinted with the kind permission of their copyright holders. In addition, some unpublished material is presented.

3. Abbreviations

A-Index	An animal welfare index constructed by Atria in 2003
ANI	Animal needs index (TGI/ Tiergerechtheitsindex)
AW	Animal welfare
BRD	Bovine respiratory disease
CH	Cold housing
EU	European Union
QBA	Qualitative behavioural assessment
QoL	Quality of life of human beings
SEUROP	European classification system for carcass conformation
WFS	Welfare score, a subset of A-Index
WH	Warm housing
WQ®	Welfare Quality project®

4. Introduction

Animal welfare (AW) is an issue of growing concern in Finland as well as in other developed countries (Kupsala, 2011). A public debate has focused on the potential AW problems resulting from current production systems. Large-scale, confined production systems for hens, chickens, pigs, veal calves and fur animals have been of particular interest. Milk and beef production has not attracted major criticisms.

Due to better understanding of animals and increased citizen interest in ethical issues, farms, industry and the whole of society have paid increased attention to AW, but consumer interest in AW has been limited. Among all the citizens of the European Union (EU), Finnish consumers are the least willing to change their usual place of shopping to buy more animal-friendly products (Eurobarometer, 2009). Welfare labels do not play a major role in the Finnish beef market. The Finnish beef market is based largely on minced meat, which is partly sold at low prices in supermarket marketing campaigns, to tempt customers to purchase. These circumstances are generating a pressure to keep market prices down despite domestic production decreasing and costs of fuel, fertilizers and feed increasing.

The aim of the Finnish co-operatively owned meat industry is to support farmers' conditions for production. Domestic industry is trying to maintain competitiveness in the meat market in a changing business environment. As part of corporate responsibility programmes, the Finnish beef industry supports AW in connection with other issues, like membership of the national herd health register, daily gain, carcass fat and conformation scores, as well as increasing the market price of meat (Atria Plc, 2012).

The industry delivers calves from dairy and suckler herds to calf-rearing units and finishing farms (TNS Gallup, 2013). Most dairy calves are delivered at around two weeks of age. Some calves are delivered from dairy farms directly to finishing farms, but most are reared first on specialised calf stations. Slaughtered milk cows are an important component of the meat market. The industry is developing its own delivery systems and providing farms with appropriate advice to develop their production.

The industry is able to affect farms by price fixing, quality demands for calf delivery or slaughtered animals and extension work. Prices are set mainly from a commercial point of view. Extension work in the industry is targeted to improve productivity and sustainability of the beef chain. The main goals have been to increase the number of suckler cows and to improve productivity of beef producers, and the main efforts are directed to farm expansion. Calculation of gross margins in existing and planned production is the main part of the advisory process. The A-Index, was developed in 2003 to support animal welfare and productivity in the beef chain (Munsterhjelm and Herva, 2003). It was based on an Austrian Animal Needs Index (ANI) (Bartussek, 1999), which was the only widely used AW score in those days.

In Finland, domestic origin still represents added value for products, but imported meat remains a major competitor. The added value is probably going to decrease in the future if it is not supported by facts and marketing efforts. Production scandals are a major threat to the industry, which is looking for strategies to maintain the added value. Finland has been able to avoid scandals better than other EU countries, which has helped the country to maintain reasonably high self-sufficiency in food after the EU membership despite unfavourable production conditions (Tomšík and Rosochatecka, 2007).

However, Finnish membership of the EU in 1995 has been a challenge for domestic agriculture. Finnish farms have become highly dependent on subsidies based on the common agricultural policy, which aims to guarantee the quality, including AW, and quantity of agricultural products for European consumers.

In beef production, there could be an opportunity to change the view from problems to mutual benefit between AW and animal production. There could be several possibilities to enhance AW and profitability in beef production simultaneously by farmers, society and industry. Thorough understanding of AW and relationships between AW and beef production economics are needed to establish a common ground for further farm development. The current study is reviewing different aspects of AW, studying the association between animal welfare, production parameters and farm economics and trying to identify the best interventions to change the business environment towards a more AW-oriented direction.

5. Reviewed literature

5.1. Concern about animal welfare

We, as human beings, have always been morally concerned about animals (Fraser , 2008). There seems to be a universal ethical conflict between our similarities with animals and our rights to utilize them. We treat animals according to our cultural beliefs concerning the nature of animals.

The modern concern of animal welfare has many similarities with the debate in ancient Greece, the medieval Christian Church and the English Enlightenment during the 18th and 19th centuries (Fraser , 2008). Animal welfarism started as a part of general trend against widespread brutality to both humans and animals in Britain in those days. Sensibility was a key issue in the new attitude (Cooper, 1711). In 1789 Bentham (1988) developed a utilitarian philosophy where acts should be judged by the consequences for all concerned, for humans as well as for animals, which were regarded as sensible beings.

Western animal protection societies and acts are based mainly on this tradition. They were originally targeted towards cruelty to animals. In 1964, Ruth Harrison shocked readers by publishing Animal Machines, in which she described the living conditions of farm animals in intensive confinement systems (Fraser , 2008). The book created a remarkable debate. Some professionals tried to emphasize the advantages of efficient farming with good care and feeding compared with lack of feed, shelter and other resources in traditional farming. Nevertheless, the public concern shifted to industrialized farming systems. Prejudices are strengthened by food advertisements exploiting traditional animal husbandry and video clips published by animal rights activists showing mistreated animals in intensive production systems (Kupsala, 2011).

Influenced by Animal Machines, the animal rights movement arose in the 1970s among post-graduate philosophy students at Oxford University to criticize the status of animals as purely sensitive beings (Godlovitch, et al., 1972). The movement aimed to include animals in the moral community, give them legal rights and stop using them as a commodity for people. Although a fundamental part of the movement is regarded as a terrorist group, for example by the FBI (Lewis, 2004), other parts have been quite influential; animal law courses are taught in many universities (Animal Legal Defence Fund, 2014), great apes have revived basic rights in New Zealand (Taylor, 2001) and animal rights are protected by the constitution in Germany (Federal Republic of Germany, 2010).

Based on late urbanization, Finnish consumers have traditionally had wide experience of animal production and, consequently, a non-problematized attitude towards AW. The situation has changed in recent decades due to progressive urbanization and intensified animal production, also in Finland, although Finnish consumers trust in livestock farming more than consumers in other EU countries (Jokinen, et al., 2012). Surveys from Finland (Kupsala, et al., 2011) show that people are trusting in traditional extensive animal husbandry, but there are major prejudices towards intensive commercial farming systems. Welfare of reindeer was perceived to be good or excellent by 79% of respondents. Respective figures were 69% for milking cows, 57% for beef cattle, 42% for pigs and only 28% for broilers produced under the most intensive production systems. Eighty five per cent of respondents agreed that animals should have possibilities to behave naturally and 96% agreed that cattle need to graze. Only 16% thought that tied stalls were appropriate for cows, and only 13% considered broilers as having enough space. Almost half of respondents perceived that a farmer should know individually all his/her animals. Beef production has been apart from the public AW debate, where the focus has been on large-scale confinement systems used in egg, broiler, pig and veal production (Kupsala, 2011).

Farmers' views have been set aside in the ongoing debate, although farmers are responsible for looking after animals (Kauppinen, et al., 2010). Farmers' identity has changed during structural development of agriculture in Finland and traditional values emphasizing the family farm and food security have been switched to one more of a business-oriented entity. Profit maximization is not the number one value for most of the farmers. Sustainable economy, autonomy, societal values and a respect for nature are more important to a current Finnish farmer (Niska, et al., 2012). In Finland, farmers see an important correlation between their own well-being and AW (Kauppinen, et al., 2010). They regard AW as having an intrinsic as well as an instrumental value. They view welfare as an important way to keep animals healthy, reduce work demand and increase productivity. They also consider consumers not to be sufficiently knowledgeable to gauge AW. Kauppinen divided farmers into reward-seeking and empathic groups. This is quite in line with earlier divisions into welfare and business orientations (Austin, et al., 2005), which are affected by age, education and some personality traits like conscientiousness. Intrinsic values seem to be somewhat more important for Finnish farmers compared with the quite common argument made by professionals that AW is always good when animals are producing well (Lusk and Norwood, 2011).

5.2. Scientific views on animal welfare

The British government set up "the Technical Committee to Enquire into the Welfare of Animals kept under Intensive Livestock Husbandry Systems" as a political answer to the public debate in the 1960s. The committee concluded that animals have freedom to stand up, lie down, turn around, groom themselves and stretch their limbs (Brambell, 1965). These were later transformed into the five freedoms of animals (Farm Animal Welfare Council, 1992): freedom from thirst and hunger, freedom from discomfort, freedom from pain, injury, and disease, freedom to display normal behavioural patterns and freedom from fear and distress.

The Farm Animal Welfare Council introduced a wide variety of issues concerning stress physiology, veterinary medicine, animal science and animal behaviour to be addressed. Researchers from different backgrounds stressed their own approaches, which led to various definitions of AW (Fraser , 2008). A wide definition describes AW as complete physical and mental health, where the animal is in harmony with its environment (Hughes, 1976). Many scientists emphasized an ecological approach with impaired longevity or productivity, reproductive success and general fitness (Barnard and Hurst, 1996, Curtis, 2007, Hurnik, 1993, McGlone, 1993). Other contributors focused on the ethologic and typical species-specific natural behaviour (Kiley-Worthington, 1989, Waiblinger, et al., 2004) as the best indicator of feelings (Dawkins, 1980, Duncan, 1996).

Broom (1991) defined AW as animals' success in coping with the environment to make AW a more useful concept when considering animal management or legislation. Rushen (2003) criticized this, saying that the approach did not address many of the issues of concern to the public, especially, suffering. From a welfare-economic point of view AW can be defined as a net happiness minus suffering (Ng, 1995). However, it has become most common to define AW as a prolonged mental state, resulting from how the animal experiences its environment over time (Bracke, et al., 1999b, Dawkins, 1980, Duncan, 1996). This definition is the base for the current study as well.

Traditionally, animal behaviour and stress physiology have been of principal interest in welfare studies. A prepathological state caused by stress has been noted to be a threat for AW (Moberg, 1985). Rushen (2003) emphasized the use of health and performance in addition to behaviour as AW measures. Bracke et al. (1999b) listed 13 basic needs on which AW is based. This multidimensionality of AW is generally accepted as a part of the multidisciplinary Welfare Quality® (WQ®) project (Botreau, et al., 2007b). A widely known welfare assessment protocol for cattle was published by the Welfare Quality project funded by the EU (Welfare Quality, 2009). Assessment was based on 4 principles: good feeding, housing and health together with an appropriate behaviour.

5.3. Welfare assessment

The tradition in animal welfare science has been to measure different behavioural, physiological and health parameters under experimental conditions (Bracke, 2007). Conclusions concerning general welfare status under different housing arrangements have been drawn from the particular results.

Boutreau (2007b) described different ways to assess on-farm AW. Data concerning a farm can be (1) analysed by an expert who draws an overall conclusion; (2) compared with minimal requirements set for each measure; (3) converted into ranks, which are then summed; or (4) converted into values or scores compounded in a weighted sum (e.g. TGI35L) or using ad hoc rules.

Fraser (2006) evaluated different assurance schemes and their applicability from various points of view. He divided schemes into five formats: non-mandatory codes, government regulations, inter governmental agreements, corporate programmes and product differentiation programmes. He divided the requirements included in schemes into four classes: basic health and function, affective states, natural behaviour and natural environment. Applicability of formats and requirements are dependent on the aims of the scheme. For an example, industry with commercial aims is likely to accept non-mandatory codes of conduct that emphasize animal health and affective states, whereas, the public, with its common Western values, would favour product differentiation programmes based on the natural environment. From the AW point of view, intergovernmental agreements, including health, affective state and behaviour, would likely be the most progressive.

Rushen (2003) criticized the traditional approach as being too focused on the type of housing and paying less attention to other important factors such as the quality of stockmanship, nutritional effects and the effects of breeding. He criticized assumptions behind experimental welfare studies because it is unlikely that the effects of housing type on animal welfare can be isolated from the effects of nutrition and management. He recommended taking an epidemiologic approach to identify the main threats to welfare. He also pointed out a need for adequate understanding of underlying biological mechanisms of physiological, immunological and behavioural measures before using them as AW indicators.

Summated scales are considered to be the most suitable for overall welfare assessment despite having been criticised for many reasons (Botreau, et al., 2007a). They also provide a possibility to compensate worse measures with better measures, which is important for farmers (Bartussek, 1999).

Summated scales are very popular tools to assess overall welfare and are easily understood by non-scientists. Partial scores can be used to point out strong and weak points of each farm assessed, and thus can be used for animal welfare advisory purposes. The overall score allows comparisons between animal units while an absolute judgement of a farm, independently of the others, can still be made (Botreau, et al., 2007a). Overall scores offer an opportunity to use a wide range of parameters enabling study of the multidimensional nature of AW.

The Animal Needs Index (ANI) "TGI 35 L" (Tiergerechtheitsindex) (Bartussek, 1999) was the first widely used tool for overall on-farm AW assessments. It has been used regularly in Austria and Germany. The ANI was criticized because summated scales suffer from several limitations. It comprised mainly environment-based measures. Resource-based measures are considered to be less valid AW indicators than animal based ones (Keeling, 2005). Animal-based measures such as behavioural and health parameters are generally considered to be more closely linked to the welfare of animals (Capdeville and Veissier, 2001, Whay, et al., 2003, Winckler, et al., 2003). Bracke (2007) suggested combining environment- and animal-based methods to guarantee that animal-based measures would be interpreted correctly and all those aspects of public interest would be considered in AW statements. Summated scales may allow compensation where compensation should be restricted and they do not favour situations of compromise (Botreau, et al., 2007a). A farm that obtains an average overall score may still have very low scores in certain measures, and thus problems regarding some animal welfare measures. However, from an animal's point of view, it may be preferable to live on a farm with a moderate overall score than to be subjected to very poor environmental conditions in some respect despite other conditions being excellent. Furthermore, scaling of selected measures should be based on discriminative techniques, not only on subjective methods (Scott, et al., 2001).

Despite these limitations, a Finnish beef production company Atria ltd. (Munsterhjelm and Herva, 2003) decided to use ANI as a basis for its own welfare measure, the A-Index, because it was the only practical AW measure with a compensatory mechanism available during the construction of the A-Index (Munsterhjelm and Herva, 2003). To avoid problems associated with over-compensation, minimum requirements based on legislative or quality requirements following previous studies (Keeling, 2005) were included in the A-Index.

Later, the theoretical basis for overall assessment of animal welfare is thoroughly discussed (Botreau, et al., 2007b). A set of 12 criteria was proposed to monitor the principles in the WQ®: absence of prolonged hunger, absence of prolonged thirst, comfort around resting, thermal comfort, ease of movement, absence of injuries, absence of disease, absence of pain induced by management procedures, expression of social behaviour, expression of other behaviour, good human-animal relationship, and absence of general fear (Botreau, et al., 2007b). Parameters suggested to be included in overall welfare assessment schemes for cattle are summarized in Table 1. Mortality is not included in these suggestions, but reduced life expectancy indicates that the animal has been stressed and that its welfare, at some time or times during its life, has been poor (Broom, 1991). Repeatability of suitable welfare parameters (Winckler, et al., 2003) and strategy (Botreau, et al., 2007b) for overall welfare assessment tools have been described. Welfare assessment protocols for cattle, pigs and poultry have been published (Welfare Quality, 2009). WQ® classifies farms to excellent, enhanced, acceptable or not classified, based on four principle scores. To avoid overcompensation there is minimum and upper requirement for all three classifications. Excellent farms have to get all principal scores over 55 and at least two of them over 80. Respective values for enhanced farms are 20 and 55. Whereas, acceptable farm have to get all principal scores over 10 and at least three of them over 20.

Table 1. Parameters suggested to be included (marked by X) in welfare assessment schemes for dairy cows and cattle in two separate studies.

	Parameters for epidemiologic on-farm assessment schemes for dairy cows Waiblinger et al. (2001)	Overall welfare assessment scheme for cattle Winckler et al. (2003) Winckler et al. (2003)
Body condition scores	X	X
Cleanliness	X	X
Prevalence of leg disorders / lameness	X	X
Skin lesions / injuries	X	X
Mastitis	X	-
Cell counts	X	-
Social interactions	X	X
Time budgets for lying, standing and feeding	X	-
Standing up behaviour	X	X
Avoidance distance towards humans	X	X
Stockman ship	-	X
Culling rate due to disease	X	valid but unavailable

The evaluation of WQ-protocol for cattle on commercial farms was not yet available in the reviewed literature but the protocol for pigs was evaluated in 30 conventional pig farms in Spain (Temple, et al., 2011). Testing was time consuming (6 hours and 20 minutes per visit) and there was too little variation in most animal-based measures to differentiate farms. Levels of moderate and severe bursitis, cleanliness of animals, expression of positive and negative social behaviours, and exploration varied enough to enable discrimination among farms.

5.4. Test theory

Animal welfare science is largely based on applied ethologic and veterinary science. Separate welfare factors like cortisol level, altered gait, scoring of body condition or fear reaction towards humans have been studied in detail. Efforts have been made to find repeatable on-farm measures to cover all aspects of AW before forming an overall AW assessment scale (Knierim and Winckler, 2009, Winckler, et al., 2003).

In social and educational science, psychometrics has been developed to measure knowledge, abilities, attitudes and personality traits (DeVellis, 2003, Nunnally and Bernstein, 1994). These can be conceptually compared with AW. They are not directly measurable quantities, but rather concepts, which can be estimated by Test Theory methods described by Nunnally and Bernstein (Nunnally and Bernstein, 1994). The concept of interest, such as the level of AW, can be seen as a directly immeasurable latent variable, which can be assumed to vary in different situations.

Methods to estimate the magnitude of a latent variable in time and space by summated scales are well described in the handbooks of psychometrics (DeVellis, 2003, Nunnally and Bernstein, 1994). Individual measures or questions are termed items in the Test Theory. Construction of a summated scale includes clear specification of the study concept, generation of a pool of items to be tested, specification of the format of the items including scaling procedures, expert analysis of the item pool, testing the item pool in a sample group, item evaluation and optimization of the scale length. In general, a short scale including a limited number of items is more convenient to use but less repeatable than a longer scale.

Items can be scaled using subjective or discriminative estimation techniques (Nunnally and Bernstein, 1994). Discriminative techniques are preferred to provide interval-level measurement. Paired comparison (Thurstone, 1927) is a most commonly used discriminative scaling technique. It assumes that the items included in a scale are correlated with the intensity of the attribute of interest and that the intensity associated with each item follows a normal distribution. The average welfare intensity associated with an item is regarded as the best estimate for the weight of an item. This issue is estimated by judging rating items. The mean rate is calculated for each item and used as a weight for the item.

Item difficulty, correlation between each item and sum of the scale (Item test correlation), correlation between each item and total score excluding the particular item (Item rest correlation, r) and Cronbach's alpha are commonly used parameters in item analysis (Cronbach, 1951). Items can be evaluated qualitatively, comparing item rest correlation with item difficulty. An item is excluded from a final scale if it does not differentiate objects or does not occur consistently with the other items. These items are so called easy items. Exact value for difficulty or item rest correlation, in which an item is excluded, depends on the case and aims of the scale builder. Difficult items separate best objects from good ones. Items with moderate difficulty differentiate average objects from each other and easy items are used for the worst objects. Exclusion of an item is always a trade-off between convenient length of the scale and reliability, which is described by Cronbach's alpha. It is based on the number of items used in a scale, sum of variance of each item and variance of the summated scale.

The concept of reliability in the Test Theory differs from the conventional context of life sciences. The reliability of a measurement scale quantifies the internal consistency of the scale. In the life sciences inter-observer reliability measures the agreement between different observers. Intra-observer reliability measures agreement between the same observer on different occasions and a test-retest reliability measures the agreement between observations made on the same individual on at least two different occasions (Scott, et al., 2001). Different approaches are needed because psychometrics is largely based on individual tests or questionnaires, which can't be repeated on the same individual due to the learning effect. There are two previous reports concerning repeatability using internal consistency of on-farm welfare measurements, one on pig farms (Munsterhjelm, et al., 2006) and another one for horses (Beyer, 1998).

Factor analysis, principal component analysis and item response analysis are more advanced regularly used methods to select items for certain latent variables (DeVellis, 2003). They are also used to find multiple latent variables from the studied sample. Items have to be formatted to be divided at least into three classes, to allow the use of these more complex methods.

The best set of items depends on the measured population (Nunnally and Bernstein, 1994). Although an item might theoretically be a good welfare indicator, it can be inappropriate for a studied population if it does not occur consistently with other indicators or it is not stringent enough to differentiate farms. For example, in the case of a mathematical test, a very easy set of items does not differentiate skilled pupils at all and a difficult item does not measure mathematical skills if the pupils have seen the correct answers in advance. Similarly, we may ask whether fear of humans is an important part of animal welfare assessment in Finnish beef farms. If animals received full score for this indicator on most of the farms, fearfulness would not differentiate farms in respect to the overall welfare status, although fear shown towards humans can represent major welfare problems for animals.

Construct validity means the measurements ability to measure what it is constructed to measure. It can be divided into several types of the validity. Coverage or content validity depends on the scale's ability to cover all aspects of the latent variable (DeVellis, 2003). Criterion validity or responsiveness refers to the empirical association between the scale and some other criterion for the issue (DeVellis, 2003, Testa and Simonson, 1996). Convergent validity refers to correlation of results of two measurements theoretically supposed to measure the same phenomenon. Discriminant validity describes the difference between measurements not intended to measure the same phenomenon (Fayers and Machin, 2007). For example, a welfare score would be expected to correlate with low mortality but a score evaluating good feeding would not be supposed to correlate with a score evaluating good housing.

In the context of the Test Theory sensitivity refers to the ability of a scale to reflect true changes in the latent variable (Testa and Simonson, 1996). Criterion validity and sensitivity can be driven from a statistical comparison of a scale and some other indicators of the issue

Measures used to assess animal welfare are not direct measures of mental state but only indices that need to be interpreted in terms of welfare (Botreau, et al., 2007b). These indices are human constructs that are inherently loaded with many of our values (Fraser, 1995). In this respect, methods used widely in psychometrics and social sciences would represent a substantial advantage in choosing the most appropriate parameters, that is, items for overall assessment scales. These methods are widely used for the quality of life (QoL) assessments for human beings (Testa and Simonson, 1996).

In the context of AW, a psychometric approach is used mainly in Qualitative Assessment of Behaviour (QBA) (Wemelsfelder, 2007). It is based on the idea that animals express their emotional stages and we, as human beings, have skills to identify them. QBA uses Free Choice Profiling methodology as used previously in food and consumer science to prevent a bias caused by a pre-fixed list of animal expressions. Profiles given by a panel of professionals using their own descriptions for the expressions of animals are analysed using a multivariate statistical technique termed Generalised Procrustes Analysis. It identifies commonly perceived dimensions of the expressions of animals and determines agreement among observers. QBA is included in WQ® protocols as a pre-fixed list of animal expressions (Welfare Quality, 2009). Inter- and intra-observer reliability of QBA has been found to be insufficient (Bokkers et al., 2012).

5.5. Performance, health and animal welfare of beef cattle

To date, nothing has been published on the association between beef cattle AW and performance. Hence, the current chapter is restricted to describe the most important aspects of performance and health of beef cattle and AW related factors affecting them. The use of performance as a welfare indicator is discussed as well.

Daily gain is an important production parameter affecting profitability of the finishing farms. It is defined by the increase of body tissue mass, which is increased by hyperplasia early in life and hypertrophy later in life (Owens, et al., 1993). It depends on individual growth potential, availability of energy and nutrients and physiological stage affecting energy utilisation (Lawrence and Fowler, 2002). Variation in the performance of ruminants is more closely related to feed intake than to diet digestibility or efficiency of converting digestible energy into metabolizable or net energy (Mertens, 1994).

Adipose tissue is a component of growth (Lawrence and Fowler, 2002) and different tissues grow at certain ages. In contrast to the case for lean tissue, hyperplasia of adipose tissue continues throughout life. Mature weight is generally considered to be the point at which muscle mass reaches a maximum. It is determined mainly by genotype, but it is also affected by nutritional and hormonal factors (Owens, et al., 1993). Fat deposition is steady until the growing animal reaches approximately half of its physiological maturity. Later on, live weight gain is associated with a dramatic increase in body fat, when nutrient availability exceeds the capacity for skeletal and muscle growth (Trenkle and Marple, 1983). Carcass fat content depends on slaughter weight in relation to mature body size and daily gain (Owens, et al., 1993, Steen and Kilpatrick, 1995). In the EU fat content of carcasses is scored at slaughter from 1 to 5 (Comission of the European Communities, 1982). Different concentrate formulations do not seem to affect carcass fat content as long as energy and protein intake are kept constant. In general, it appears that added protein has no effect on carcass characteristics (Huuskonen, et al., 2007, Huuskonen, 2009, Solomon and Elsasser, 1991).

In the EU (Comission of the European Communities, 1982) carcass conformation is estimated by the SEUROP-score system. The best carcasses are assigned the grade S, followed by E, U, R, O and P (worst). In Finland grade S is not used, and most dairy breed bull carcasses are classified as P+, O- or O. Carcass conformation of cattle can be modified by breeding, feed ratio and management. McGee et al. (2007) reported over one SEUROP-score difference between pure Holstein and Charolais-Holstein cattle. Keane et al. (1998) found that intensive feeding with fast growth favours high carcass scores. In contrast, slaughter weight was not found to affect the conformation score (Keane and Allen, 1998).

Reduced space allowance decreases growth rate according to many studies (EFSA Panel on Animal Health and Welfare (AHAW), 2012). It is mainly due to a poorer feed conversion ratio (Andersen, et al., 1997). The decrease in feed conversion efficiency at lower space allowance may partly be due to an increased energy cost associated with longer periods of standing, as suggested by Fisher et al. (1997). According to Ingvartsen (1993), poor performance due to decreased space allowance is probably caused by stress, which leads to altered hormone secretion, nutrient absorption and metabolism. It is hypothesised that stress caused by low space allowance increases the proportion of energy retained as fat instead of muscle tissue (Webster, et al., 1972). In rats and humans, stress has a well-known effect on promoting abdominal fat accumulation (Dallman, et al., 2003).

In reviewed feeding experiments tethered ate approximately 4% less and had an approximately 4% higher feed conversion compared with loose-housed animals allowed more exercise (Ingvartsen and Andersen, 1993, Tuomisto, et al., 2009). Loose-housed animals tended to have a higher conformation score and less fat. Looking at loose-housed animals, no singificant differences in performance have been identified comparing warm and cold housing (Ingvartsen and Andersen, 1993, Lowe, et al., 2001, Mossberg, et al., 1993).

In reviewed controlled experiments housing factors other than space allowance and tethering have had little effect on performance (Tuomisto, et al., 2009). Housing effects have been clearer in field studies with more statistical power. In studies based on cattle auction databases, Koknaroglu (2005) found that daily gain and feed efficiency were highest in the open lot with overhead shelter compared with cattle fed in the open lot without overhead shelter or in confinement systems. In addition, Pastoor et al. (2012) reported better performance in bedded confinement than in open lot facilities without access to shelter. Some differences between studies could be explained also by variable environmental factors during experiments. Mader et al. (2003) reported that wind protection had no effect on performance in an experiment with yearling steers during a mild winter, but the protection gave clear benefit to heavier steers in harder conditions in the following winter. They also found that fat deposition was enhanced under moderate cold stress and maintained under more severe cold stress, although performance was reduced.

There are also some experimental studies in which AW-favouring environments decrease carcass fat content and increase conformation scores. These findings provide some evidence for a theory that exercise can explain differences in carcass characteristics (Huuskonen, et al., 2008). It was reported that Ayrshire bulls were fatter with worse conformation scores when housed in tied stalls compared with when housed in pens or enclosures (Tuomisto, et al., 2009). Huuskonen (2008) reported a 23% better conformation score in Hereford bulls in a forest paddock compared with the tied stalls in insulated buildings. Mossberg et al. (1993) compared different housing types for bulls and found that bulls in uninsulated buildings with bedding were leaner compared with those kept in insulated buildings on slatted floors. Pen type had no effect on daily carcass gain, feed intake or feed conversion ratio. They concluded that lower fat content in uninsulated buildings was caused by higher activity and energy expenditure due to a larger space allowance and a non-slip floor. Andrighetto et al. (1999) reported better performance in veal calves in groups vs. individual crates. Carcass conformation score was higher in calves housed in groups, but there was no difference in proportion of muscle in the whole carcass. They suggested that the better conformation in groups was due to a more pronounced hypertrophy of the muscle directly involved in exercise. This hypothesis is supported by previous findings in sheep (Aalhus and Price, 1990). They found that moderately endurance-exercised sheep did not show any change in the proportion of muscle, fat and bone in total carcass composition, but they had significantly larger muscles in the proximal pelvic limb.

Feed efficiency decreases with increased live weight (Huuskonen, 2009). Economic efficacy depends also on proportional cost between calf price and feed as well as carcass pricing by weight. Faster growth decreases fixed costs of gain. On the other hand, it can increase variable costs due to more expensive feed needed. To maximize farm level profitability, growth rate should be adjusted to fixed costs due to buildings, machines and labour as well as to prices of available feed. Pihamaa et al. (2002) reported that total mixed ratio fed bulls on 70% concentrate grew 88g/d faster with €0.51/d greater gross margin compared with bulls on 30% concentrate. However, Koknaroglu (2005) found that cattle receiving increasing levels of concentrate ate less and gained more but were less profitable than animals receiving lower levels of concentrate. These contradictory results are understandable because optimal daily gain depends on forage quality and prices of forage vs. concentrate.

The cost of live weight gain tends to increase with days on feed, but the economics of days on feed depend also on carcass pricing. This is based on SEUROP classification in the EU (Comission of the European Communities, 1982) and the carcass grading system in the United States. In both systems, carcass classification is related to slaughter weight. In Finland, heavy carcasses with good conformation are supported by pricing to increase domestic supply to meet market demand. In contrast, there are price penalties for carcasses under 320 kg with fat scores 3-5 and for carcasses over 320 kg with fat scores 4-5. High fat carcasses cause extra costs for the industry. Carcass fat score is an important but controversial issue also from the economic perspective. Fat-increasing fast growth is reported to favour palatability of beef (Fishell, et al., 1985), but consumers generally favour low fat minced meat for health reasons (Koistinen, et al., 2013). Fat carcasses are also supposed to be more expensive to produce because fat production in animal tissues requires more energy per kilogram than lean meat production (Lawrence and Fowler, 2002, Lawrence and Fowler, 2002). These factors have created a conflict between the need for heavy carcasses, farm productivity and low carcass fat content. Additional knowledge is needed to find an optimal solution to the dilemma.

Economic losses caused by mortality are due to the purchase price of the animal, the cost of feeding the animal until death, treatment and cadaver disposal costs, costs for extra labour associated with deaths and interest on invested money (Loneragan, et al., 2001). However, indirect costs due to decreased performance associated with the underlying diseases or management problems can have an even greater economic effect. For example, animals treated for bovine respiratory disease have had 0.06 – 0.33 kg worse average daily gain compared with untreated animals (Smith, 1998).

Mortality varies greatly depending on the age of animals and other production factors. Loneragan et al. (2001) reported that the annual mortality ratio was, on average, 1.26% in animals entering feed lots in the US between 1994 and 1999. In a study conducted in France in 1983, the total mortality of bulls was 1.95% on straw bedding and 5.99% on slatted concrete floors with culling rates of 0.70% and 1.47% respectively (ITEB, .1983). Based on the national data for 2008 in Italy, Fiore et al. (2010) reported an average monthly mortality rate of 0.26% for all registered cattle. Monthly mortality rate for transported animals was 0.50% within 30 days from transport. The mortality rate was highest (1.4%) for calves under 6 months of age, showing a peak at the 2nd week after the transport, under 0.4% for cattle between 6 and 12 months and lowest for cattle between 12 and 20 months. For older animals the mortality increased, with a peak within the first week after transportation.

The factors involved in diseases explaining mortality have been summarized as: 1) stress caused by co-mingling, transport, weaning, mutilations, overstocking and human handling; 2) flooring, ammonia, humidity, dust, high temperature, insects; 3) genetics that affect temperament and susceptibility to different diseases; and 4) infectious agents (viruses and bacteria) (AHAW, 2012). Increasing farm size seems to increase mortality and incidence of BRD. Laiblin et al. (1996) reported that calf losses in free range suckling herds were less than 10% in 97% of herds with fewer than 20 suckling cows, but in herds with more than 300 cows, calf losses were higher than 10%. Increasing group size from less than 10 animals to over 15 animals has been found to increase BRD in many studies (EFSA Panel on Animal Health and Welfare (AHAW), 2012).

Respiratory disease is globally the most important reason for premature deaths, causing 70-80% of feedlot morbidity and 40-50% of total mortality (Edwards, 2010). Despite great advances in the technology of vaccines, anti-microbial, and anti-inflammatory agents, morbidity and mortality have not declined. The primary effort should be targeted to herd health programmes to minimize the incidence and costs associated with morbidity and mortality caused by Bovine Respiratory Disease (BRD) and other diseases through designated prevention and control programmes, and thus maximize feeding performance and carcass value (Edwards, 2010). The focus is to minimize pathogen exposure effectively, stimulate herd immunity, and manage risk factors that potentiate the spread of BRD, especially during the first 45 days after the arrival of calves to a farm.

On a slatted floor lameness is an important problem contributing to elevated mortality. Murphy (1987) reported lameness incidence of 4.75% on slatted floors compared with 2.43% on straw. Incidence of all diseases was 9.73% and 5.42%, respectively. Septic traumatic pododermatitis explained 42.6% of lameness and cellulitis 21.5%.

Some animal scientists (for example Curtis (2007)) are in favour of regarding animal performance and productivity as a practical and the best indicator of overall AW. In contrast, although impaired growth is regarded as a sign of decreased AW in animal welfare science, good performance is not seen as a guarantee of good welfare (Broom, 1991). Moynagh (2001) stated that production indicators need to be interpreted carefully. For example, the productivity of broiler chickens has increased dramatically over recent decades, but AW of broiler chickens has decreased over the same time period. On the other hand, there are many facts supporting the use of animal performance as an AW indicator. Food is considered to be a basic need of animals (Bracke, et al., 1999b) and body condition scores are suggested to be a part of overall welfare assessment. Additionally, eating is known to give direct pleasure mediated by leptin and insulin (Boissy, et al., 2007, Figlewicz and Benoit, 2009), which could possibly be used as an indicator of a positive affective state. On the other hand, Bartussek (1999) did not include any production parameters in ANI because he wanted to exclude all parameters that affected productivity of animals, to keep the index as a pure quality statement.

Based on previous discussion, production data for daily gain, carcass fat and conformation scores at slaughter and on-farm mortality are available and probably quite valid to be used as AW indicators. Factors affecting cattle performance are usually studied in controlled feeding trials (Hickey, et al., 2003, Lowe, et al., 2001). Few studies have been published on feeding and management procedures under farm conditions (Cozzi, et al., 2008, Niemelä, et al., 2008). Field studies could provide essential knowledge about effects of interactions on commercial conditions. Results based on controlled trials are not always applicable in commercial conditions with various interacting effects (Rushen, 2003). A-Index measurement can be expected to elicit interesting information on on-farm effects and interactions.

5.6. Economics of cattle farms in Finland

Economics concerns the use of limited resources. Farmers have to decide how to achieve their financial and personal goals on their farm. Optimal solutions are farm specific due to varying goals, input prices and available resources (Kay, 2008). Although a farmer is a principal decision maker concerning beef production and animal welfare, other stakeholders have a marked influence, especially in Finnish circumstances. The EU and the government of Finland set the legal framework and subsidy regimes under which farmers operate. Industry delivers calves and sets prices for carcasses with varying validities. Advisors translate complex frameworks for farmers and try to find optimal solutions for each of them. The public discussion can be supposed to influence gradually the opinions, attitudes and behaviour of farmers as well.

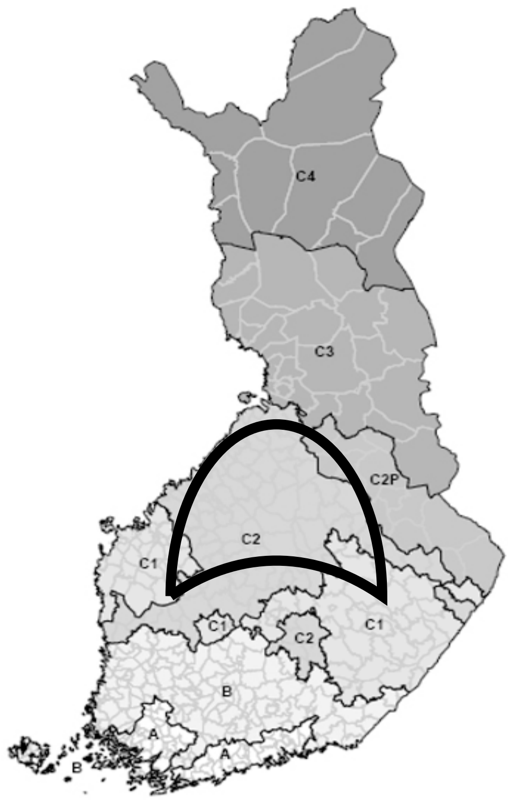
Beef production in Finland has been strongly related to the dairy industry. There has been a big structural change in beef production in Finland. The number of milking cows has decreased over recent decades by 40%. Decreasing numbers of dairy cows have been partly compensated for by suckler cows and increased slaughter weight (Information Centre of the Ministry of Agriculture and Forestry, 2013).

In Finland bulls are raised from approximately half a year of age up to the slaughter age mainly in WH with insulated barns on a slatted concrete floor. However, a proportion of them are also kept in CH systems with straw, peat, wood chip or sand bedding. In WH there has been a tendency towards restricted space, perhaps due to high investment costs. Contrary to the published studies (Fallon and Lenehan, 2003), many farmers also believe that high animal density favours cleaner animals by forcing manure through a slat. CH is not as common although it is less expensive to construct. Availability of bedding material at a reasonable price is not guaranteed, especially in the main cattle producing areas dominated by pastures. However, there are a lot of potential resources available in the form of straw, peat, wood and sand, although the availability of different materials varies among areas. Rubber covered slats are not yet common in Finland, although they are a recommended way to enhance AW (EFSA Panel on Animal Health and Welfare (AHAW), 2012).

After Finnish membership of the EU in 1995 direct subsidies have become an essential part of Finnish beef production. Subsidies are based on the common agricultural policy of the EU, but they are partly financed by the Finnish government. The EU policy aims to guarantee the quality and quantity of agricultural products for European consumers. Rural development, environmental care and animal welfare are additional objectives of the policy (European Commission, 2013). Agri-environmental support is paid to Finnish livestock producers due to Finland being a less favourable area. Animal welfare is promoted by a special subsidy incorporated into agri-environmental support. Some investment supports are paid to farmers investing in a new, more animal-friendly production facility. Most subsidies are paid according to arable land area. A part of the subsidies, such as the animal welfare support, is paid according to animal units or as a production premium by output. Finland is divided into A, B and C1 to C4 regions from south to north. The total available support per farm varies depending on region, farm characteristics and adopted production practices. Each form of support has its own regulations. The profitability ratio was calculated by dividing family farm income by the sum of the wage claim and the interest claim of agriculture. It is best in the C2 region and 40% of that in the B region (MTT Agrifood Research Finland, 2013).

Over half of the beef in Finland is produced in C1 and C2 regions (Figure 1). The province of Northern Ostrobothnia is the biggest producer, whereas the grain is produced mainly in southern parts of the country (Information Centre of the Ministry of Agriculture and Forestry, 2013). For this reason, there seems to be a lack of straw as a bedding material in cattle intensive areas.

Figure 1. Subsidy regions and most intensive cattle rearing area (rounded by a thick black line) in Finland.



After Finnish membership of the EU in 1995, the herd size of cattle farms has grown and farms have specialised. The number of farms has dropped to one third of the original number, while the number of cattle has decreased only by 20% (Information Centre of the Ministry of Agriculture and Forestry, 2013). Eighty four percent of fattened cattle are delivered from milk farms or suckler herds for fattening, which is 24% units more than in 2000. Also, the total percentage of slaughtered cattle, including dairy cows sold by milk farms, has decreased from 60% to 35%. However, cattle farms are still diverse in Finland. There are specialized milk farms, suckler herds, calf rearing units and heifer or bull slaughtering farms. Also different combinations of cattle are still common (TNS Gallup, 2013).

In response, the average size of a farm slaughtering fattened heifers or bulls has grown from 20 head per year in 2000 up to 60 head per year in 2013. The proportion of large farms has been growing faster. In 2000, 20% of cattle fattened on specialized units were from farms selling over 100 animals. Twelve years later the proportion was over 60% (TNS Gallup, 2013). Increasing farm size is enhancing profitability by allowing the use of all available resources and the most efficient technology. Specialisation possibilities and pricing power are other economies of size, but management difficulties and long within farm distances can cause diseconomies of size (Kay, 2008).

The structural change has improved productivity of beef farms, although farm structure and economic results vary greatly among farms. However, profitability of cattle farms seems to be poor (Table 2) and the production decline after EU membership has been greatest in the beef sector. However, the self-sufficiency of beef has remained quite high (83%) (Finfood, 2013) compared with the case in Sweden (55%) (Finfood, 2013, Strand and Salevid, 2008). Consequently, a combination of domestic support mechanisms and production adjustments with the common agricultural policy of the EU has been important factors in the reasonably successful adaptation of Finnish agriculture to EU membership (Tomšík and Rosochatecka, 2007).

Table 2. Economic figures of cattle farms in Finland by size (MTT Agrifood Research Finland, 2013).

Economic size (€)	25 000-50 000	50 000-100 000	100 000-250 000
Livestock units in average (LU), #	31	51	115,3
Subsidies, €/LU	1381	1457	1243
Total incomes, €/LU	2413	2625	2833
Variable costs, €/LU	-1541	-1616	-1790
Labour costs, €/LU	-873	-842	-447
Fixed costs excluding labour, €/LU	-864	-1055	-913
Net profit, €/LU	-852	-857	-240
Net revenues for labour and management, €/LU	6	-43	129

LU = livestock unit, # = number

Patjas (2004) compared beef production costs in Finland and some other EU countries. He used the EU regulated Farm Accountancy Data Network (FADN). Production costs in Finland were €1 173/ livestock unit and €3.94/kg. In Sweden beef production cost per livestock unit was 19% and in Germany 39% lower than in Finland. In Germany fixed costs, excluding labour, were only 49% and work costs 61% the cost levels in Finland. Different farm structure affected the results, the average total number of cattle per farm being 69 in Finland, 76 in Sweden and 131 in Germany.

The most intensive farms are invisible in public statistics since they are few. Rantala (2005) studied beef production cost in 13 intensive beef cattle fattening farms, eight of which were AW scored according to the A-Index. The study included 13 farms and A-Index scorings were done on eight of them. Production volume and costs were collected and production cost per kilogram of beef was calculated by farm (Table 3). There was no significant correlation between growth rate and production cost, and cost relationships and structure varied considerably among farms (Rantala, 2005). The main factors affecting the farm profitability are reported to be efficiency of silage production (Pihamaa and Pietola, 2002), fixed costs from machinery and labour cost (Patjas, 2004).

Table 3. Production results on 13 intensive cattle-fattening farms in Finland. Modified from Rantala (2005).

	Average	Median	Minimum	Maximum
Slaughter weight, kg	338	338	325	358
Carcass daily gain on farm, g/d	626	634	559	661
Number of slaughtered animals	277	247	144	619
Culling, %	2.98	1,9	0	12.4
Production cost, €/kg	4.24	4.24	3.34	4.89

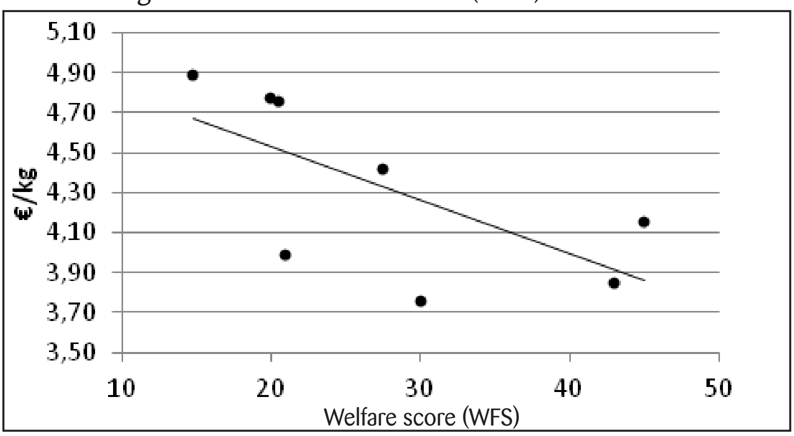
5.7. Animal welfare and economics

Although McInerney (2004) thoroughly discussed economic aspects of animal welfare, there appears to be limited information about the relationship between welfare as such and production parameters, although various threats of intensive animal production to AW are thoroughly discussed in AW textbooks (Appleby and Hughes, 2011, Broom and Johnson, 1993).

The costs of AW (Den Ouden, et al., 1997, Hudson, 2010, Vosough Ahmadi, et al., 2011), as well as the relationship between AW and farm profitability (Stott, et al., 2005), have been studied in a few cases. Enhanced welfare due to better human-livestock interaction has been shown to be beneficial for productivity (Hemsworth and Coleman, 1998, Hemsworth, et al., 2002). However, research based on data collected from commercial farms to examine the relationship between AW, outputs of livestock production and farm economics is scarce.

In a survey concerning beef production costs in intensive cattle fattening farms in Finland farms with good welfare seemed to have a better growth rate but also lower production (Rantala, 2005; Figure 2).

Figure 2. Association between animal welfare score (WFS) and production cost (€/kg) in eight intensive cattle-fattening farms. Modified from Rantala (2005).



In decisions made by farmers regarding AW, the trade-off between farmers' wellbeing and the welfare of animals is of central importance. This is a complex trade-off in which farmers' financial and non-financial goals appear to conflict with each other. Both financial and non-financial goals can represent barriers that farmers face in improving on-farm AW (Gocsik, et al., 2013). Adequate information concerning interactions among welfare, productivity and external incentives are needed to find the most efficient ways to support both the farm economy and AW.

6. Objectives of the study

An aim of the study was to explore the association of on-farm AW on animal performance and farm economics . The study had multiple objectives, which are reported in the four original articles (I-IV):

1. to explore association between AW and cattle performance in beef production (I-IV)
2. to validate the A-Index using test theory and the association between AW and performance (I)
3. to study major factors affecting the association between AW and performance (I-IV)
4. to model farm economics in different housing conditions with varying AW (IV)
5. to find appropriate tools to utilize the information gathered in regular trade operations of the meat industry to support AW and farm productivity by farms and other stakeholders (I-IV).

Additional objectives of the thesis were to find any conflicting interest between stakeholders concerning AW and to evaluate the value of A-Index as a quality statement.

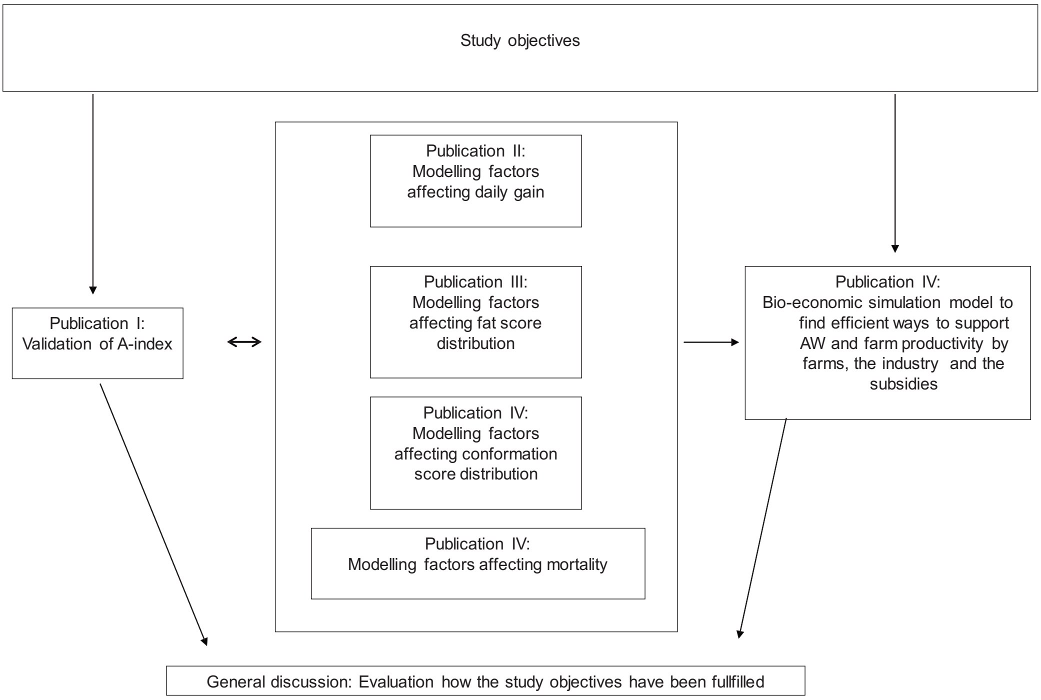
It was hypothesized, that 1) the A-index is a valid tool to measure on-farm AW, 2) AW increases daily gain and reduces carcass fat and mortality by reduced stress, 3) increased exercise related to good AW reduces carcass fat and increases carcass conformation, 4) AW affects profitability of beef production and 4) multilevel models and economic simulations are appropriate tools to utilize data gathered in regular business operations to generate valuable information for farm development.

7. Material and methods

7.1. Overview of the study design

The study is overviewed in Figure 3. The A-Index was modified and evaluated based on Test Theory. On-field associations between A-index, mortality, daily gain, carcass fat score and carcass conformation score were determined using statistical multilevel models. Confirmed associations were used to evaluate the criterion validity of the A-Index and to build a bio-economic simulation model.

Figure 3. Schematic overview of the contents of the study.



7.2. Animal welfare measurements, A-Index modifications and validation

In this study AW was regarded as a prolonged mental state, resulting from how the animal experiences its environment over time (Bracke, et al., 1999a, Dawkins, 1980, Duncan, 1996). Inclusion of items needed to ensure coverage and content validity (Scott, et al., 2001) of the A-Index as a welfare indicator was considered before the study during the development process by a farm advisory group of Atria. In this process the group discussed each item until consensus concerning weights and formulations for different values of the item was reached. Items, scoring-space, social environment, resting area, technical environment, feeding, management and health of the animals were included to cover all aspects of animal welfare. Modifications of the ANI were based on the literature and practical plausibility. Applicability in the local commercial production environment was the main development criterion. Separate indices for suckling calves (≤2 months), fattening calves (>2 to 6 months) and bulls or heifers (>6 months) were developed (I-II) (Table 5 and 6). In total, 43 items were included in the A-Index, with a maximum score of 100, to assure content validity. Used references were included in the A-Index. There were minimal requirements set for certain items to be used in a farm quality programme. Those limits were not included in the analyses for this study.

One hundred farms slaughtering over 40 bulls a year were randomly selected for the study to guarantee adequate participation. Additional scorings were done on voluntary farms on advisory request. Welfare scorings were performed by advisory personnel of Atria. Suckling calves were scored at 155 farms, fattening calves at 131 farms and bulls or heifers at 237 farms (I-II).

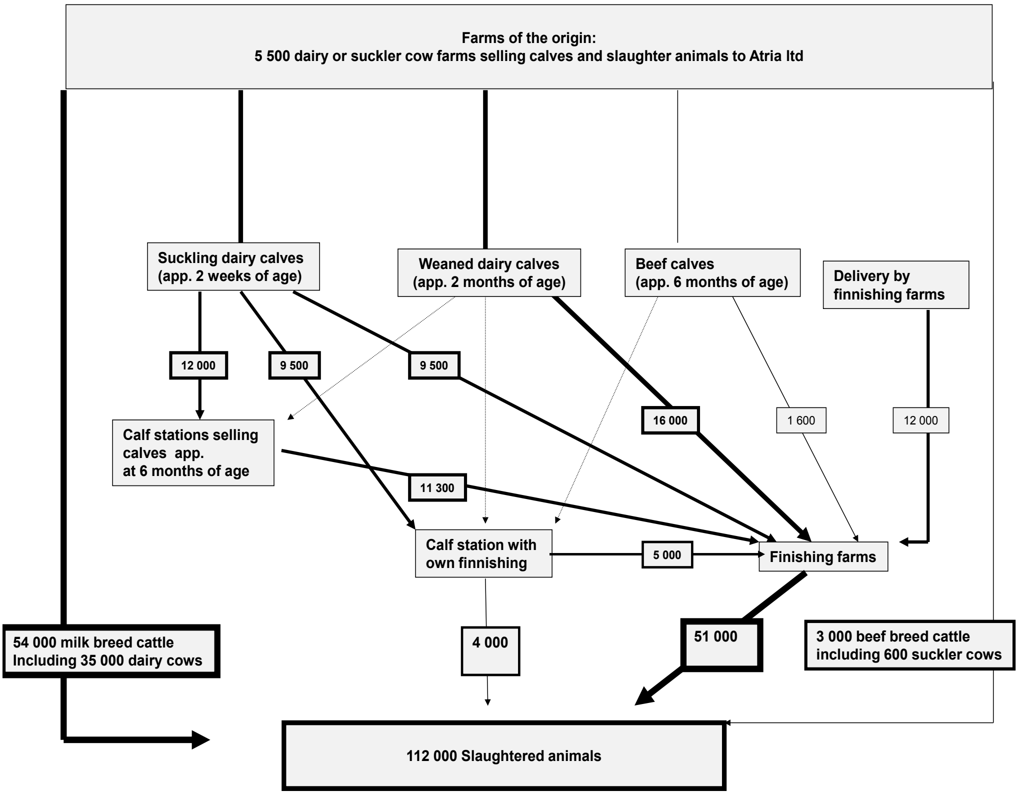
A-Index scores for each age group were evaluated using Test Theory methods (DeVellis, 2003, Nunnally and Bernstein, 1994). Difficulties for each item were calculated by dividing the mean value of the item by the maximum value and subtracting the quotient from 1. Correlations between each item and total score, as well as total score excluding the particular item (Item rest correlation, r), were computed. Cronbach's alphas for total scores and effect of each item on the alphas were determined. Regarding internal consistency of a scale, an alpha below 0.6 is unacceptable, up to 0.65 undesirable, between 0.65 and 0.7 minimally acceptable, between 0.7 and 0.8 respectable and between 0.8 and 0.9 very good (DeVellis, 2003). If alphas are much above 0.9 one should consider shortening the scale. The ability of the A-Index to differentiate farms with good as well as bad welfare was evaluated comparing item correlations with item difficulties. Difficult (difficulty near 0) items with item rest correlation over 0.2 differentiated farms with excellent welfare from farms with good welfare. Items with moderate difficulty (near 0.5) differentiated average farms and easy items (difficulty near 1) farms with poor welfare. Items were excluded from the partial scores used as welfare score (WFS) in further analysis if the correlation with total score excluding the particular item was under 0.2. Repeatability of A-Index and WFS was evaluated using Cronbach's alpha.

Factor analysis, principal component analyses and item response analyses are regularly used methods in Test Theory, but are not suitable tools to evaluate the A-Index because this index included items with only two alternatives and scale length varied among items.

7.3. Data used in epidemiologic models

Factors affecting production results were studied using commercial data from farms co-operating with Atria in 2003 (II-IV). Individual-level data including the date of birth, breed, type of animal, delivery date, farm that sold and respectively bought the calf, weight and price of a calf were recorded for each delivery. Only part of suckling dairy calves were weighed at the delivery. Carcass weight, conformation and fat score and meat inspection findings were recorded at slaughter. The structure of the beef production in Atria is described in Figure 4.

Figure 4. Structure of the beef production in Atria in 2003 in Finland with approximate numbers of animals in the boxes. The more animals the thicker the lines.



Calves delivered in 2003 for the first time were selected for the study. Animal delivery data for the first and last delivery of the calves were individually connected with the slaughtering data. Age and daily gain of an animal were calculated for each delivery and the slaughter to reflect the quality of the delivered calves. The farm of origin, rearing and finishing were identified for each of the calves. Farm-specific variables were used to reflect differences in management and feeding between farms. Number of all delivered calves by farm was determined to describe farm size and infectious pressure in various parts of the chain. Thereafter, female calves were excluded from the data due to large differences in production results compared to bull calves. Mean daily gain at delivery and at slaughter were calculated for each farm to describe general production efficiency of the farm. Altogether, information about 38 855 bull calves delivered was available for the study (Attachment 1).

Mortality on finishing farm, estimated daily carcass gain, carcass fat and conformation scores at the slaughter were used as outcome variables. Mortality information for non-slaughtered bulls, alive at 183 days of age, and identities of sires of bulls were collected from the National Animal Identification Register for Cattle. Altogether 1089 dead bulls were recorded. The information on 823 different sires for 15 914 bulls was found.

The A-Index scores and WFS for different age groups (I-II), excluded index items (I-II) and commercial information (Attachment 1) of the delivered bulls were used as independent variables. Items were used as class variables or converted into hierarchic dummy variables. The following management factors were evaluated using the excluded items: 1) Group size for calves under 2 months and young stock; 2) Group stability for young stock; 3) Dehorned groups; 4) Human-animal relationship; 5) Number of suckling calves per one teat; 6) Feeding space per animal; 7) Roughage availability; 8) Roughage quality; 9) Concentrate availability for bulls; 10) Concentrate quality; 11) Ratio formulation; 12) Incidence of foot diseases; 13) Incidence of respiratory diseases in calves; 14) Disease recording; 15) Isolation of sick animals; 16) Handling facilities; and 17) Loading facilities. Hereditary effects were estimated using the identity of the sire in models used for carcass fat and conformation scores.

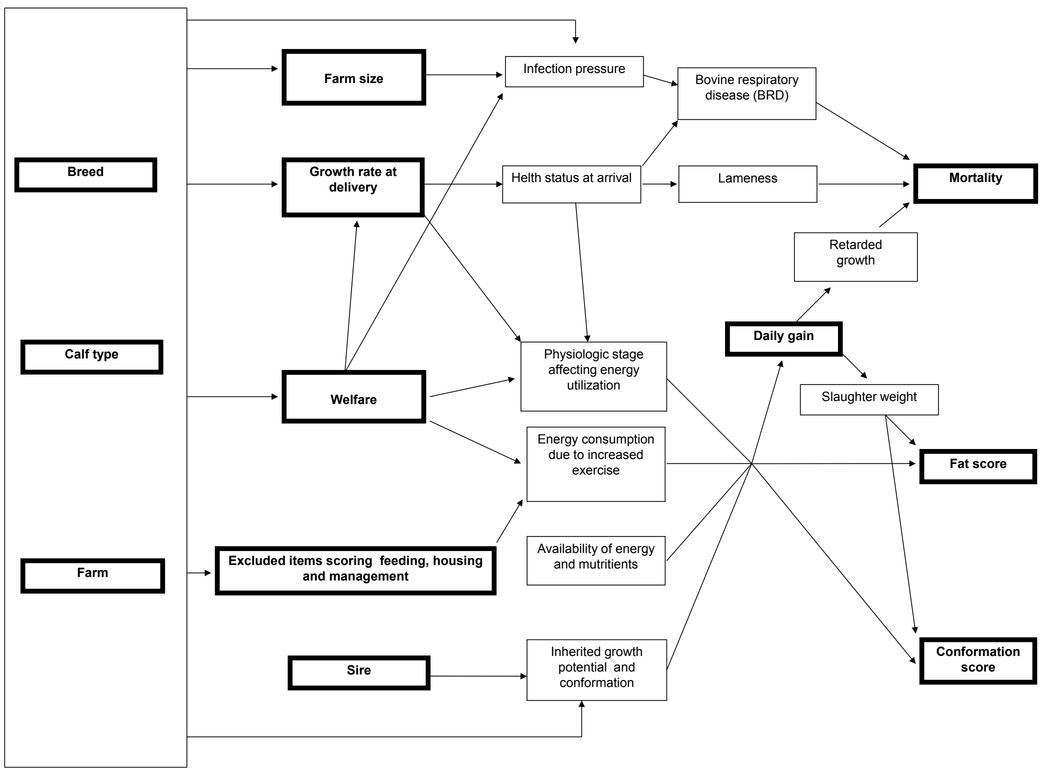
Due to incomplete data the number of included observations varied greatly between different statistical models depending on the variables used.

7.4. Epidemiologic models

Factors affecting the outcomes were studied using statistical models after preliminary evaluation of distributions and one-to-one relationships.

Statistical models were based on causal diagrams describing factors affecting daily gain, mortality, carcass fat and conformation scores to find possible confounders and intervening factors for the A-Index and AWS (Figure 5).

Figure 5. A causal diagram describing factors affecting daily gain, mortality, carcass fat and conformation score. The information available in the study is shown in boxes with bold lines.



The chosen models were based on the type and the distribution of the outcome. Due to cross classified three to four level data structure and a large data set, distribution of variation in various levels was estimated using preliminary modelling described in the original publications (II, III). Fat and conformation scores were transformed into dichotomous data to be able to include random effects in the models. The random effect models were not appropriate for the analysis of mortality due to the excess zero-count data type. In all other models slaughtering farm was used as a random variable. Models used are summarized in Table 4. More detailed descriptions can be found from the original publications (II, IV).

Table 4. Description of the models used in the study.

Outcome (original publication)	Type of outcome	Model type	Modelled associations	Number of observations	Model diagnostics
Mortality on finishing farm (IV)	Excess zero-count data	ZINB model on farm level	WFS farm size and mortality	168	Comparison of predicted and real values between ZINB, NB, Poisson and ZIP model
Estimated daily carcass gain (II)	Continuous	Linear random effect model	A-Index, commercial information and daily carcass gain	12 661	Linearity, homoscedasticity, residual diagnosis
As above	As above	As above	Individual items, commercial information and daily carcass gain	12 466	As above
Fat score (II)	Dichotomous	Generalized linear latent and mixed model	Model predicting fat scores 3–5	5 288	Residual diagnosis
As above	As above	As above	Model predicting fat scores 4–5	5 288	As above
Carcass conformation score (IV)	Dichotomous	Generalized linear latent and mixed model	Model predicting conformation scores from O+ to E+	5 120	As above

Original publication shown by Roman numerals, ZINB = Zero-inflated negative binomial model, WFS = Welfare score, a subset of A-Index, NB = negative binomial model, ZIP = zero inflated Poisson model

Results of statistical models published in the original articles (II-IV) were described visually by figures based on scenarios using practically applicable input values.

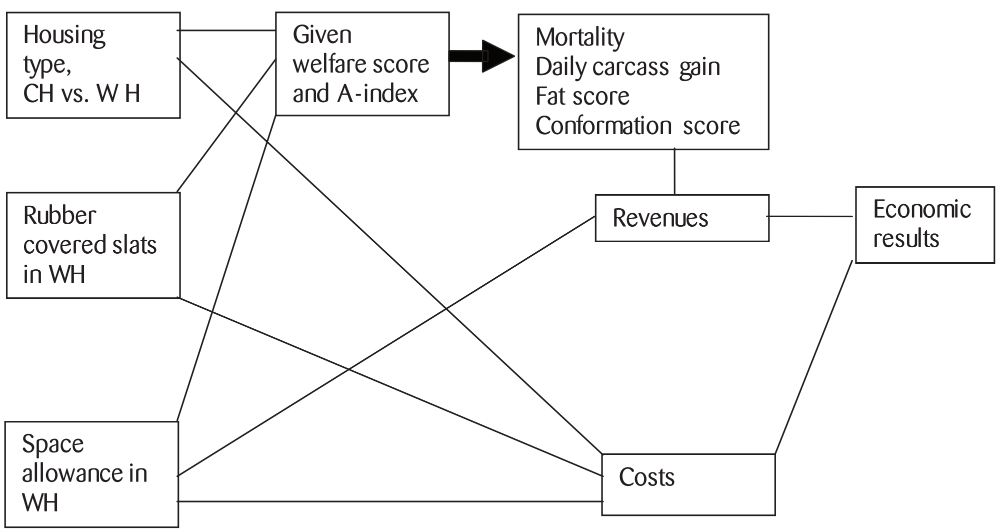
Results of statistical models were used in evaluation of responsiveness and sensitivity of the A-Index in line with the QoL assessments for human beings (Testa and Simonson, 1996). They were also exploited as input values for economic models.

7.5. Economic modelling

Economic evaluation of AW was based on comparison between cold and warm housing on a farm with 200 bulls (IV). Additional analyses were used to gauge the economic effect of space allowance and rubber covered slats in WH. A-index and WFS were determined by input values. The model consisted of a stochastic part predicting production results by given WFS and A-Index. A deterministic part was built in to calculate costs, revenues and economic results by given input values and predicted production results (Figure 6). Used costs were based on statistics published by Economy doctor (MTT Agrifood Research Finland, 2013) and a survey on the most intensive cattle farms (Rantala, 2005). The input values used were checked and updated by experts consulting in beef production in Finland.

Cost structure, net return to labour and management (NRLM), labour efficiency (€/h) and farm profit were used to describe economic performance under different situations. Support per carcass production (€/kg) and subsidy ratio (=100 * Total amount of subsidies / NRLM) were calculated to evaluate agricultural policy with respect to AW. A relationship between AW and sufficiency of domestic beef was estimated by calculating carcass production per delivered calf.

Figure 6. A bio-economic model to study housing, animal welfare (AW) and farm economics. Deterministic parts are shown by lines and stochastic parts by a bold arrow. CH= cold housing, WH = warm housing.



The bio-economic model was tested using sensitivity analysis for varying feed, calf and bedding material prices, subsidy regions and target daily gain.

8. Results

8.1. A-Index modifications and repeatability

A-Index scores are shown in detail in Tables 5 and 6. Based on high Cronbach's alphas (A-Index for calves ≤ 2 months 0.78, all others >0.8), reliability of A-Indices and WFS for all age groups was good. Comparatively good performance of calves ≤2 months of age in welfare scorings explained distribution of difficulties quite near zero. Only two items (calving and cow-calf -relationship) had difficulties over 0.5. Those items were excluded due to poor correlation with the full score. Items evaluating group size and number of teats per calf were excluded due to negative correlation with the full score. After evaluation 21 items were included in the WFS for animals under 2 months of age (Table 6).

Welfare of calves between 2 and 6 months was on an intermediate level (Table 5). Items evaluating roughage quality and the human-animal relationship were excluded due to negative correlation with full score. After evaluation 17 items were included in the WFS for calves between 2-6 months of age (Table 6). Welfare of bulls and heifers was estimated to be poorest of all age groups (Table 5). An item evaluating group size was excluded due to negative correlation with full score. After evaluation 18 items were included in the final score (Table 6).

Delivery and slaughter data of every delivered calf were connected to a particular WFS and A-Index score by the farm the calf had been in at a certain age to be used in epidemiologic models. The WFSs for different age groups were used as general welfare indicators, whereas A-Index scores were regarded as more production oriented measures. A-Index and WFS were available for 6 165 individual animals during all three age periods. Those animals were delivered for the first time to 75 different farms and slaughtered on 104 different farms.

Table 5. Description of joined A-Index data used in epidemiologic studies. The original articles describing particular indices are referred to by numbers I and II.

Variable	Level of observation	Number of observations	Median	Minimum	Maximum	Number of animals
A-index for suckling calves (≤2 months) (II)	The farm rearing calves on milk	90	79	47.5	92	12 942
WFS for suckling calves (≤2 months) (II)	The farm rearing calves on milk	90	48	16	51	12 942
A-index for fattening calves (>2 to 6 months) (II)	The farm rearing fattening calves	78	67.5	46.5	89.5	10 025
WFS for fattening calves (>2 to 6 months) (II)	The farm rearing fattening calves	78	35	17	49	10 025
A-index for bulls and heifers (>6 to 24 months) (I,II)	Finishing farm	168	62	42.5	89.5	13 738
WFS for bulls and heifers (>6 to 24 months) (I,II)	Finishing farm	168	24	13	50	13 738

WFS = Welfare score, a subset of A-Index

Table 6. Items included in the welfare scores for each age group. Original articles are referred by numbers I and II.

Age group	0-2 months (II)		>2 to 6 months (II)		>6 to 24 months (I,II)	
Item name	Mean score	Max. score	Mean score	Max. score	Mean score	Max. score
Length of the shortest side of the pen	1.50	2	1.33	2	0.87	2
Confrontations between animals	1.65	2	1.57	2	1.58	3
Space allowance	1.58	3	1.50	3	1.19	3
Possibilities to lie down and stand up in a natural manner	2.62	3	2.31	3	2.11	3
Tight floor on the walking area	1.58	2	NI	NI	1.18	2
Pen fixtures	0.84	1	NI	NI	NI	NI
Group stability	NI	NI	0.50	4	NI	NI
Group size	NI	NI	2.87	3	NI	NI
Outdoor access in winter	NI	NI	NI	NI	0.11	2
Pasture access in summer	NI	NI	NI	NI	0.21	2
Outdoor walking ground	NI	NI	NI	NI	0.25	2
Relations between calves	2.87	3	NI	NI	NI	NI
Soft lying area	1.38	2	NI	NI	1.45	6
Clean lying area	3.57	4	4.14	6	4.11	6
Tight lying area	1.82	2	1.48	2	1.37	2
Dry lying area	3.70	4	NI	NI	1.45	2
Barn ventilation	3.11	4	2.87	4	2.93	4
Effective temperature	3.28	4	1.35	2	NI	NI
Draughts on lying area	3.41	4	2.58	4	2.43	4
Water availability	1.37	2	2.52	4	2.53	4
Noise	NI	NI	1.04	2	0.98	2
Night light	0.95	1	NI	NI	NI	NI
Availability of concen-trates	3.42	4	3.98	6	NI	NI
Clean calves	2.75	3	2.40	3	NI	NI
Traumas due to pen fixtures	0.99	1	NI	NI	NI	NI
Foot health	NI	NI	NI	NI	1.45	2
Loading facilities	NI	NI	NI	NI	0.85	1

Max. = maximum, NI= not included in the WFS of the particular age group

8.2. Factors affecting beef cattle performance: criterion validity and sensitivity of A-Index

Welfare score affected mortality, fat and conformation score at slaughter (Figure 7, III-IV). Daily carcass gain was affected by the more production oriented A-Index (II). Other factors affecting the outcomes are described in Tables 7 and 8 (II-IV).

Figure 7. Predicted association between welfare score and production results on an average 200 bull farm.

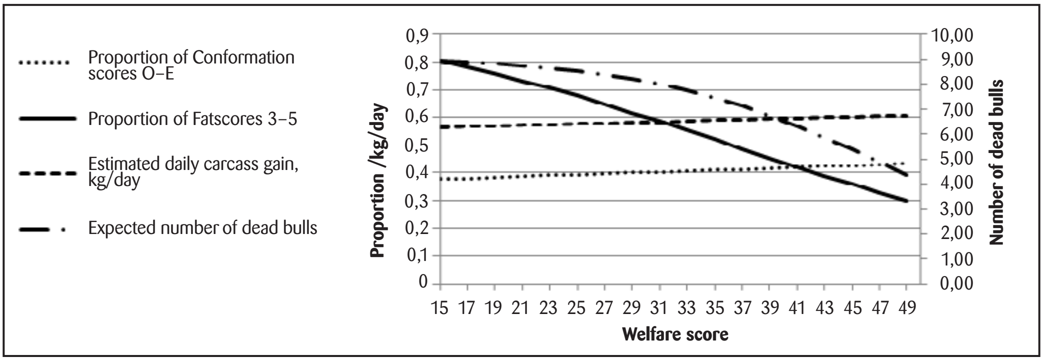


Table 7. Description of models for estimated daily carcass gain and mortality.

Model	Estimated daily carcass gain by A-Index, g/d	Estimated daily carcass gain by separate index items, g/d	Mortality, ZINB-model
Groups	180	178	168
Observations	12 661	12 466	168
ICC	0.38	0.35	N/A
Constant	479	430	N/A
A-Index g/d per one unit	1.2	N/A	N/A
WF-scale	N/A	NS	Odds ratio 1.13 per each scale unit for not any deaths
Estimated class variables:			
Number of delivered calves	S	NS	S
Calf type	S	S	NS
Breed type	S	S	NS
Space allowance	N/A	S	N/A
Dehorned groups	N/A	S	NS
Feeding regime	N/A	S	NS
Feed planning	N/A	S	NS

ZINB = zero inflated negative binomial model, N/A= not applicable, NS = non significant, S = significant effect.

Table 8. Description of models for fat scores 3-5, fat scores 4-5 and conformation scores O–E, N/A= not applicable, NS = non significant, p>0.1, p-values greater than 0.01 shown in the table.

Outcome	Fat scores 3-5	Fat scores 4-5	Conformation score O-E
Number of observations	5288	5288	5120
Number of groups	78	78	80
ICC	0.13	0.16	0.17
	Odds ratios (and their 95% confidence interval) for independent variables		
The WFS for bulls 6-24 months of age	0.55 (0.43–0.70)***	0.55 (0.39–0.78)**	0.91 (0.84–0.98)*
Carcass weight, kg	0.98 (0.95–1.00)	1.02 (1.016–1.022)***	1.02 (1.01–1.02)***
Average daily carcass gain at finishing, kg/d a	1.0*10-18 (6.02*10-26-1.66*10-11)***	0.001 (2.97*10-9 - 342)	5.91*105 (4.35*104-8.03*106)***
Interaction between carcass weight and average daily carcass gain at finishing	1.09 (1.05–1.14)***	NS	NS
Sire inheriting low fat	16.0 (5.27–194)*	0.16 (0.064–0.39)***	N/A
Sire inheriting good conformation	N/A	N/A	2.60 (1.83–3.70)***
Interaction between sire and carcass weight	0.99 (0.98–1.00)**	NS	NS
Growth at calf rearing, kg/d	1.57 (0.98–2.51)	NS	NS
Interaction between the WFS and carcass weight	0.9997 (0.9994–0.9999)**	NS	NS
Interaction between average daily carcass gain and the WFS	2.92 (1.99–4.26)***	2.41 (1.38–4.23)**	1.000326 (1.000097–1.000554)**
Free roughage availability	1.47 (1.15–1.88)**	1.85 (1.22–2.79)**	NS
Optimal roughage quality	0.73 (0.58–0.92)	NS	NS
TMR feeding	1.66 (1.31–2.10)***	NS	NS
>320 delivered calves per year	2.58 (2.05–3.23)***	1.95 (1.45–2.64)***	NS

* p<0.05, ** p<0.01, ***p<0.001, WFS = Welfare score, a subset of A-Index, TMR = Total mixed ratio

Responsiveness (criterion validity) of the A-Index and the WFS were estimated to be reasonable because estimated daily carcass gain and proportion of high conformation scores increased, and the proportion of high fat scores as well as mortality decreased in association with an increasing WFS, although the comparison criteria used did not include all aspects of welfare like fear, pain or frustration. A-Index and WFS were found to be sensitive welfare indicators reflecting small changes in outcome variables. A single unit corresponded approximately to a 1 g difference in daily carcass gain and 1% difference in proportion of fat scores.

8.3. Economic simulations

Cold housing with enhanced welfare and bedding based on own straw at a reasonable price was economically favourable. Net return to labour and management (NRLM) was €11 460, net profit €8 720 and calculated salary €4.31/h greater in CH compared with WH (Table 9). Based on the smaller difference between median and minimum estimates, production risk was also slightly smaller in CH. These benefits were nearly lost using commercial average priced peat bedding (€75 /bull). In the case of expensive bedding (€150/bull), like purchased wood chips, NRLM was €13 320 smaller in CH compared with WH (IV).

In CH there was €0.02/kg more support compared with WH, but subsidy per NRLM was 190% in CH compared with 223% in WH. Support per kilogram and meat production per delivered calf were quite stable in different scenarios, although CH favoured slightly (9kg) meat production per delivered calf (IV).

Restricted space allowance and increased number of animals were calculated to favour economic performance, although effects on production parameters were negative due to lower AW. An investment in rubber covered slats for the resting area was demonstrated to be profitable (IV).

Table 9. Simulated economic results of a 200 bull farm in warm and cold housing in Finland.

	Warm housing	Cold housing
Net return for labour and management (NRLM), (T€)	29.7	41.0
Net profit (T€)	4.7	13.4
Calculated salary (€/h)	17.2	21.5
The effect of 27% increase (€0.19 vs €0.15/11,9 MJ) in feed price on NRLM, (T€)	-21.84	-22.52
The effect of 20% change in calf price on NRLM, (T€)	-17.04	-15.84
The effect of low target daily gain (500 g/d vs. 600g/d) on NRLM, (T€)	-17.78	-12.39
The effect of 200% (€75 vs. €25/ bull place) increase in bedding price on NRLM, (T€)	N/A	- 9.88

T€= thousand euro, N/A= not applicable

9. Discussion

Animal welfare measured by validated WFS was shown to support beef production as hypothesized. It was associated with increased daily gain and carcass conformation score and decreased mortality and carcass fat score. It also favoured economic performance in CH vs. WH, if bedding price was reasonable. According to the referred literature AW science is not directly answering to the public concern about AW, which can represent a major barrier to find mutual benefit for animals, farmers, industry and society.

9.1. Welfare measurements

Based on the study, the Test theory methods used to develop QoL indices for humans seemed to be practical to use for on-farm animal welfare assessment. The WFS was an indicator of general on-farm welfare, whereas the A-Index was more appropriate as a tool to evaluate the production environment on farms.

All of WQ®-principles (Botreau, et al., 2007b) were covered at least to some extent in the A-Index. Consequently, coverage and content validity of the A-Index were considered to be good.

Most animal based parameters were excluded from WFS. Relations between suckling calves, traumas caused by pen fixtures for suckling calves and leg problems for bulls were the only animal-based measures included in the developed WFS. Other items evaluating a good human–animal relationship, absence of prolonged hunger, general fear and diseases were not included in the WFS due to a poor repeatability. Rejected and excluded items were not stringent enough (difficulty near 0) to provide any extra information for WFS or they were not consistent with other items due to low correlation with the A-Index. WFS did not cover all aspects of AW, although it was a significant predictor of mortality, carcass fat content and carcass conformation. Interestingly, the A-Index, with a better content validity, was a better predictor of estimated daily carcass gain. Reported poor repeatability of indices comprising animal-based measures is a challenge for on-farm welfare assessment.

The value of the findings concerning repeatability and internal consistency can be questioned, because the A-Index included both cause- (e.g. space allowance) and effect- (e.g. human-animal interaction) indicators of AW.Internal consistency is applicable mainly for reflective (i.e. effect) indicators, which are effects of the latent variable (Bollen, 1984). Causal or formative indicators of the latent variable are not assumed to correlate. Consequently, internal consistency or principal component analysis are not valuable tools in the evaluation of indices comprising causal indicators. Nevertheless, the methodology used helped to build WFS, which proved to be a better predictor of AW-relevant phenomena like mortality and fatness or conformation of carcasses. Whereas, the more production oriented A-Index was better indicator of daily gain. The established association between WFS, mortality, fatness and conformation of carcasses, as well as the association between the A-Index and the estimated daily carcass gain, can be considered as proof of criterion validity.

Instead of the widely used methodology described for reflective indicators, instructions for the use of causal indicators are more dispersed. Content and indicator specification, collinearity of indicators used and external validation are considered to be the main issues in index construction

(Diamantopoulos and Winklhofer, 2001). Specifications were thoroughly considered during the development of the A-Index. Collinearity of the indicators used in the A-Index remains to be tested. High collinearity between indicators can be a reason to exclude indicators that are totally explained by other indicators of the index (Diamantopoulos and Winklhofer, 2001).

The A-Index can be seen as a battery (Fayers and Machin, 2007) measuring unrelated domains of multidimensional AW. More precise evaluation of the construct validity of the A-Index would firstly need a thorough theoretical evaluation of the sub scores used for space, social contacts, resting area, technical environment, feeding, management and health. The health indicators used can be seen as effect indicators for other sub scores, although they are formative indicators for AW defined as feelings. A poor environment and feeding are predisposing factors for diseases, which in turn affect AW. The human-animal interaction score is the only effect indicator of AW included in the A-Index. All indicators included in sub scores could be studied by multiple indicators and multiple causes model (MIMIC) (Jöreskog and Goldberger, 1975). Human-animal interaction score, estimated daily carcass gain, fat content or conformation of carcasses and mortality should be considered as effect indicators for AW (Bollen, 1984, Diamantopoulos and Winklhofer, 2001). Other scores should be treated as cause indicators. Correlations between sub scores would give information concerning convergent and discriminant validity of the A-index (Fayers and Machin, 2007). Sub scores for space and resting area can be supposed to be more correlated than other sub scores due to high space allowance and soft resting area in CH. A negative correlation between social contact score and previous scores would also be expected due to large group size and unstable groups associated with CH.

There has been substantial progress in animal-based welfare indicators since 2002 (Winckler, et al., 2003) when the A-index was developed. The nature of these indicators as a cause or an effect of AW, defined as a state of mind of an animal, should be carefully estimated before construction of an overall AW indicator (Fayers and Machin, 2007).

The described methods are a way to respond to the claims presented by Rushen (2003), questioning whether welfare is a measurable property of an animal. Welfare can be determined as a concept concerning a prolonged mental state, resulting from how the animal experiences its environment over time. Development and regular use of indices based on QoL methodology can be seen as appropriate for overall animal welfare. Welfare statements based on separate behavioural, physiological and health indicators are theoretical assumptions or implicit opinions. Explicit welfare statements should be based on direct measurements of latent overall welfare. The measurements could be based on batteries, which according to QoL literature consist of both causal and effect indicators of AW, covering all aspects of the multidimensional concept. Identification of the type of relationship between AW and each indicator is an essential part of development of the battery.

9.2. Performance

Based on the results of the study it can be concluded that AW increases performance of bulls in beef production (II-IV) as hypothesized. A consistently defined welfare using WFS was shown to affect mortality, fat and conformation score at slaughter (III, IV), whereas a more widely defined welfare using the A-Index, including feeding items, was found to increase daily gain (II). It has to be emphasized that an increase in WFS is an increasing A-Index and consequently daily gain if the excluded items are kept constant.

The observed relationship between welfare, daily gain and carcass fat can be supposed to increase daily gain by reduced stress. It supports the hypothesis of Webster et al. (1972) that stress increases the proportion of energy retained as fat instead of muscle tissue. The observed interaction between welfare and average daily gain also confirms the hypothesis, showing that reduced welfare increases the risk of high fat scores even at low levels of available energy. The observed effect of welfare on carcass fat and conformation supports the hypothesis that exercise could explain differences in carcass characteristics (Aalhus and Price, 1990, Andrighetto, et al., 1999, Huuskonen, 2009). This is confirmed by the interaction between welfare and average daily gain showing that exercise combined with available energy increased carcass conformation score due to greater musculature in the proximal pelvic limb. The associations between welfare, farm size and mortality are in line with the reported factors involved in diseases explaining mortality (EFSA Panel on Animal Health and Welfare (AHAW), 2012).

The study confirms many effects of on-farm conditions found in previous experimental studies. Positive relationships between space allowance, as well as A-Index and growth rate, are in line with many other studies (Andersen 1997, Hickey 2003, Mogensen 1997, Ruis-Heutinck 2000). Ingvartsen (1993) concluded that changing space allowance from 1.5 m^2/animal up to 4 m^2/animal increases daily live weight gain approximately by 20%. In our study the effect of variation in welfare was less than half and the effect of space allowance alone only one quarter of that (Figure 7, Table7). The difference is understandable due to the large amount of unexplained variation in the on-farm study possibly hiding part of the real effect.

Many observed effects are likely to be due to differences in availability of energy. The model including separated index items was able to explain 115 g/d difference in daily gain caused by feed planning and feeding regime. In contrast, the changes in the items scoring feeding in the A-Index explained only a minor part of the variation resulting from feeding (Table 7). The model including separated index items gave previously lacking support for widely recommended feed planning to optimize the use of own feed and full-fill energy and other nutrient requirements of cattle. Availability of energy evaluated as an average on-farm daily gain was an important predictor of carcass fat and conformation. Previous effects, as well as the observed effects of farm size, on daily gain and on higher proportion of high fat scores, are likely explained by differences in availability of energy between farms of different size. Therefore, the effect of increasing farm size on mortality can be explained by the well-known increase in infectious pressure in large farms (EFSA 2012).

The observed effect of slaughter weight on carcass fat was in line with the reviewed literature (Owens, et al., 1993, Steen and Kilpatrick, 1995). The effect of slaughter weight on carcass conformation was not found to be significant in a previous study (Keane and Allen, 1998), although the animals in the heavier group had approximately 10% better conformation score on average. Our study had much more statistical power compared with Keane's and Allen's experiment with 36 animals. Inherited differences between animals, estimated by breed, calf type and sire in this study, are well known from the reviewed literature (McGee, et al., 2007).

In this study most of the animals received the best score for the item estimating the human-animal relationship. Consequently, the association between good human-animal interaction and productivity reported by Hemsworth et al. (1998, 2002) was not confirmed in the study. Also the reported association between group size and BRD (EFSA Panel on Animal Health and Welfare (AHAW), 2012) was not seen in the present design. Maybe because lameness-related problems could have been a more important cause of death than BRD among the animals studied. Also the sensitivity of individual classifications is known to be poor (Nunnally and Bernstein, 1994), which can explain that the score estimating group size was not able to reveal a possible effect.

The study design was a retrospective cohort and cohort studies as such are better for valid causal inferences due to their longitudinal nature than are other observational studies (Dohoo, et al., 2003). The relationship between the variables studied and the outcomes is supposed to be mainly indirect. Measured variables were estimates for underlying causative factors. In this respect a scale that evaluates the underlying concept is a more reliable measure than a collection of individual class variables. The WFS and A-Index were proved to be useful tools to evaluate and develop production facilities to support performance.

Sub scores for space, social contacts, resting area, technical environment, feeding, management and health were not used in the epidemiologic models because internal consistency was considered to be essential for the scores used. According to Bollen (1984), consistency of an index including causative indicators is not needed. It would be interesting to compare abilities of the sub scores versus WFS to predict performance.

9.3. Economics

Our findings that an elevated welfare favours profitability are in line with findings from previous field studies based on cattle auction databases. Koknaroglu (2005) found that profit tended to be highest in the open lot with overhead shelter compared with cattle fed in an open lot or in confinement systems. However, Pastoor et al. (2012) reported better performance and greater economic return in bedded confinement than in open lot facilities. In experimental design, tethered animals with less exercise eat approximately 4% less and have an approximately 4% lower feed conversion ratio (Ingvartsen and Andersen, 1993, Tuomisto, et al., 2009), but there has not been a clear difference in loose WH vs. CH (Ingvartsen and Andersen, 1993, Lowe, et al., 2001, Mossberg, et al., 1993). These partly controversial findings can be due to lower statistical power or better control of feed intake in experimental design compared with that in field studies. Also, variable environmental factors during experiments explain some differences between studies. For example, Mader (2003) reported that wind protection had no effect on performance in an experiment with yearling steers during a mild winter, but the protection was of clear benefit for heavier steers in a follow-up study.

During recent years rubber-covered slats have been recommended for beef cattle in intensive production systems to enhance AW (EFSA Panel on Animal Health and Welfare (AHAW), 2012). According to our simulations these recommendations are economically feasible for a resting area. Nonetheless, the benefit (€500 benefit compared with €21 000 investment) was rather small and in some farms there could be more profitable investment opportunities. For example, lowering feeding costs through installation of new technology may give higher profit for the same investment (IV).

Biological efficacy decreases by increased live weight (Huuskonen, 2009). Economic efficiency depends also on relative prices of calf, carcass and feed. In our study optimal slaughter weight was much higher (362-366 kg) compared with in a previous study (250 kg) done in Finland (Pihamaa and Pietola, 2002). This is mainly due to pricing changes favouring heavy carcasses and a shift from animal-based subsidies to animal-day-based subsidies. We also included carcass conformation scores in the simulation model, which can be expected to give more robust estimates than using mean prices by slaughter weight.

In WH low space allowance increases farm profitability but decreases animal welfare. These findings are in line with those of Lusk et al. (2011) who stated that optimal stocking rate in laying hens is three times greater when profit is maximized compared with maximized egg production per hen. This effect is a good explanation for quite frequently existing low space allowance and decreased AW in commercial farms. In contrast, simulated results conflict with our preliminary findings from eight commercial farms with available bookkeeping records and A-Index scores.

In contrast to our simulations, increased space allowance favoured economic performance in those particular farms (Rantala, 2005). There seems to be a need for a better understanding of interactions between different costs, AW and space allowance, because it is possible that inadequate input values used in economic calculations overestimate the economic value of overstocking, which can be a major barrier to boosting on-farm welfare.

According to the sensitivity analyses, concerning differences between CH and WH, our model is quite stable for fluctuation in feed and calf prices (Table 9). Nonetheless, the effect of feed price on NRLM was double compared with the housing type. Also a one fifth change in calf price affected NRLM by approximately 50% more than housing type.

Warm housing is somewhat more sensitive to changes in daily gain. Low target daily gain increased marginal NRLM by six and half thousand euros in CH vs. WH. The overall effect of low target daily gain in CH is on the same level compared with the effect of housing type. In WH the effect is clearly stronger, which is equal to €0.22/d greater gross margin with target daily gain 600g/d compared with 500g/d (Table 9).

Increasing bedding costs heavily reduced NRLM. Cold housing with a reasonable bedding price was very compatible with WH. The advantage was only small in the average price of peat bedding (€75/bull place). Individual farms with the highest actual bedding costs (€150/bull place) were simulated to lose approximately as much as they would have gained with reasonably priced bedding. Bedding price was found to be a major factor against CH, favouring AW. Developing better availability of bedding material would enhance AW.

Subsidies are vital for farm profitability in Finland; production would not be economically sustainable without subsidies. The existing production environment in WH favours high stocking rates at the cost of animal welfare. The benefit from increased stocking rate could be prevented by an animal welfare subsidy, which is to be based on sufficient space allowance. The effect of AW was quite steady in different subsidy regions, although the profitability was much better in C region compared with AB region, when production costs were kept the same between regions.

Our findings can boost business-minded farmers to favour AW. Modification of subsidies in a way that would prevent the benefits gained by overstocking would also be an effective fillip for AW.

9.4. Barriers and opportunities for enhanced animal welfare

Although there was a clear positive effect between AW and performance, economics related to AW are more complicated. Cold housing with reasonable bedding price favours AW and profitability together, but CH is very vulnerable to fluctuations in bedding price. The recommended rubber-covered slatted flooring seems to be a profitable investment, but there is no experience of how they work in practice in Finland, and thus representing a barrier to rapid progress. It is also quite likely that on most farms there would be more profitable investments to be made if financing were not a problem. Overstocking endangers AW, but according to present knowledge, it can be calculated to favour profitability. Further information on interactions between AW and costs at the farm level is urgently needed.

Among other objectives, subsidies aim to support animal welfare, but currently a bigger proportion of profitability is covered by subsidies on farms with low space allowance and consequently lower AW compared with farms with better AW. Subsidies should be reformed in order that their aims are realized.

Animal welfare supports domestic production by slightly increasing the amount of meat per delivered calf, but industry is not likely to be willing to endanger the profitability of farms by allocating more space to the delivered calves.

Conflicts between AW, performance and profitability can be solved by developing production systems and reforming subsidies. The reviewed inconsistency of determinations and perceptions of AW (Kupsala, 2011) can represent an even greater barrier to enhancing AW. Kuismin and Autio (2014) argued that consumers see farm animal welfare through three frames. From the first perspective animal origin or AW is secondary compared with sensory quality and domestic production. The second frame emphasizes the natural environment as a proof of AW. A good life, where an animal has dignity, is central to the third perspective. Kuismin and Autio (2014) concluded that WQ®-measurements are only of limited added value for consumers in all three perspectives. Although A-Index and WFS are covering some aspects of natural environment and good life of cattle, added value of the A-Index and WFS as a welfare statement is likely to be limited. There is also a great uncertainty as to whether any AW-enhancing measure in intensive commercial farms could alleviate public concern over AW in food production as long as there is an unrealistic picture of AW in traditional animal husbandry.

Although there was a positive relationship between WFS and performance, some other AW evaluation system could give very different results. A sustainable welfare scheme should give sufficient production benefits or added value to cover the extra costs of the measure. Costs and benefits of the measures should be available before risk-averse farmers can be expected to join the schemes. Possibilities for farmers to enhance AW are limited if they can't be confident that their efforts meet economic or personal goals and alleviate public concerns of AW.

10. Conclusions

1. Good animal welfare was found to favour animal performance in general in beef producing cattle farms in Finland.
2. A thorough understanding of farm economics is essential to find practicable ways to enhance on-farm AW.
    - Cold housing with enhanced welfare and reasonable bedding price was more profitable than WH.
    - Profitability of CH was very sensitive to fluctuation in bedding price.
    - Developing a reasonably priced market for bedding material would be a major way to enhance AW.
    - Rubber covered slatted floors were established to be a profitable way to enhance AW.
    - More information about interactions between AW and production costs should be sought for adequate farm budgeting calculations to resolve the conflict between space allowance, AW and profitability.
    - A reform of the subsidy system was suggested to be needed to fulfil the aims of the subsidy regime to support AW.
3. Lack of an AW definition accepted by all stakeholders was concluded to be a major barrier to farms enhancing AW.
4. Test Theory, multilevel statistical models and economic simulation models were appropriate tools to utilize the information gathered in regular trade operations to develop beef production.

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