Proceedings of the World Congress on Genetics Applied to Livestock Production, 11. 1021

The economic value of R_0 for macroparasitic diseases

K. Janssen[1], H. Saatkamp[1], P. Bijma[1], M.C.M. de Jong[1] & H. Komen[1]

[1] Wageningen University & Research, P.O. Box 338, 6700 AH, Wageningen, the Netherlands

Summary

Economic values are used to balance the emphasis on breeding goal traits, and determine whether selection for a trait is worthwhile. The basic reproduction ratio (R_0) determines transmission dynamics of a disease and, therefore, R_0 is an appropriate breeding goal trait. This study presents an easy to use framework for the derivation of the economic value of R_0 for macroparasitic diseases. An example for sea lice in salmon is provided, resulting in an estimate of R_0 of 2.9 with an economic value of -0.072 €/unit R_0/kg production.

Keywords: Economic value, R_0, epidemiology, disease

Introduction

Macroparasitic diseases affect many livestock species: e.g. ticks in cattle, worms in sheep, and sea lice in salmon. Conventional treatment based on drugs relieves the negative effects on livestock, but loses its effectiveness when parasites develop drug resistance (Kaplan, 2004). Genetic improvement of livestock provides a long term effect that can complement existing control strategies. Breeding companies, therefore, desire to improve resistance to macroparasitic diseases (Janssen et al., 2017a). Moderate improvement of disease resistance might result in anything between a minor change in disease prevalence to complete eradication of the disease (Bishop et al., 2010) depending on the value of the basic reproduction ratio, R_0. R_0 determines transmission dynamics of a disease and accounts for such non-linear responses in prevalence, hence R_0 is an appropriate breeding goal trait. An animal's breeding value for R_0 is determined by its own genotypes for susceptibility and infectivity, and population average genotypes for susceptibility and infectivity (Anche et al., 2014). Economic values are used to balance the emphasis on breeding goal traits, and determine whether selection for a trait is worthwhile. Economic values of production traits have been derived for many species (e.g. Groen, 1989; Janssen et al., 2017b), but economic values of disease traits have only been derived in a few cases (Amer et al., 1999; Gicheha et al., 2005; Lobo et al., 2011). This study presents a framework for the derivation of the economic value of R_0 for macroparasitic diseases.

Costs of livestock diseases

Costs of livestock diseases are the sum of production losses (L) and expenditures for treatment (E) (Mcinerney et al., 1992). The loss-expenditure frontier gives the minimum level of L for any level of E (Figure 1). L decreases when E increases. Treatment frequency is at its economic optimum when $\delta L/\delta E=-1$. Genetic improvement of R_0 lowers the loss-expenditure frontier, hence improvement of R_0 results in:

1. Reduction of L at a constant level of E for below optimum treatment frequency.
2. Reduction of E at a constant level of L for above optimum treatment frequency.

3. Reduction of E and L at optimum treatment frequency.

Epidemiology

For macroparasitic diseases, R_0 is defined as "the average number of offspring (female offspring in a dioecious species) produced throughout the reproductive lifespan of a mature parasite that themselves survive to reproductive maturity in the absence of density-dependent constraints on population growth" (Anderson and May, 1992). Macroparasites are assumed to be endemic. The number of parasites (I) per animal increases over time as:

, (1)

where I_{min} is the minimum infection level and t is the number of generations of the parasite. Treatment is applied when the maximum tolerable number of parasites per host is reached, i.e. when . Extremes of I are assumed to be within such a narrow range in livestock production systems that R_0 is density independent. The mean number of parasites ($\bar{I}$) over period τ is:

, (2)

where τ is the number of parasite generations between treatments. We assume that the transition from one production cycle to the next has no effect on the number of parasites per host.

Economic values

The economic value is the partial derivative of a profit function with respect to trait level. Profit is a function of L and E, which in turn are functions of R_0. L is assumed to be linearly related to the number of parasites per animal (Anderson and May, 1978), hence variation in parasite numbers between animals and over time is ignored. Thereby L is a linear function of the mean number of parasites per animal:

, (3)

where $L_{par.}$ are production losses due to a single parasite. E is linearly related to the number of treatments per production cycle of length T (in parasite generations):

, (4)

where are expenditures for a single treatment.

At below optimum treatment frequency, genetic improvement of R_0 reduces L at a constant level of E, hence the economic value of R_0 is:

, where: (5)

. (6)

The relation between R_0 and its relative economic value is given in Fig. 2 for different values of τ. The relative economic value decreases when R_0 decreases, τ is larger than about 2 and $R_0>1$. The actual economic value is negative.

At above optimum treatment frequency, genetic improvement of R_0 reduces E at a constant level of L, hence the economic value of R_0 is:

, where: (7)

. (8)

The relation between R_0 and its relative economic value is given in Fig. 3. The relative economic value increases when R_0 decreases and $R_0>1$, and it decreases when increases. The actual economic value is negative.

When treatment frequency is optimized before genetic improvement, Eq. 5 and 7 yield equivalent results (Wilton and Goddard, 1996). Treatment frequency is optimized by equating the partial derivative of profit with respect to τ to zero. The relation between R_0 and its relative economic value is given in Fig. 4. The relative economic value increases when R_0 decreases when $R_0>1$.

Example: sea lice in Norwegian salmon aquaculture

Sea lice are one of the major challenges in Norwegian salmon aquaculture. Treatment is obligatory when juvenile or adult female lice numbers exceed a threshold. For simplicity, we focus on adult female lice only. Treatment frequency is above the economic optimum, hence improvement of R_0 reduces E. Treatment efficacy is 95% (Revie et al., 2005), hence is 20. Salmon is treated about 2.5 times during a production cycle (Iversen and Hermansen, 2017) of about 500 days. The generation interval of sea lice is about 70 days (Revie et al., 2005), hence generations, , and (Eq. 1). is €0.087/treatment/kg production (Iversen and Hermansen, 2017). The economic value of R_0 is:

€/unit R_0/kg production.

Note that when R_0 would be nearer to 1 in the future, either by genetic improvement or novel control measures, the economic value will be lower (Fig. 3).

Conclusion

This study presents an easy to use framework for the derivation of the economic value of R_0 for macroparasitic diseases. The actual economic value is negative, because the desired direction of improvement is a reduction in R_0. At below optimum treatment frequency, the economic value increases when R_0 decreases for $R_0>1$. At optimum or above optimum treatment frequency, the economic value decreases when R_0 decreases for $R_0>1$. For above optimum treatment frequencies, reducing R_0 by a constant proportion over generations generates increasing economic returns every generation up to the point where $R_0 \leq 1$.

List of References

Amer, P., Woolaston, R.R., Eady, S.J., McEwan, J.C., 1999. Economic values for sheep internal parasite resistance traits in New Zealand and Australia, Proc. Assoc. Advmt. Anim. Breed. Genet. .

Anche, M.T., de Jong, M.C.M., Bijma, P., 2014. On the definition and utilization of heritable variation among hosts in reproduction ratio R0 for infectious diseases. 113, 364-374.

Anderson, R.M., May, R.M., 1978. Regulation and Stability of Host-Parasite Population Interactions: I. Regulatory Processes. J Anim Ecol. 47, 219-247.

Anderson, R.M., May, R.M., 1992. Infectious Diseases of Humans. Dynamics and Control. Oxford University Press,, Oxford, UK.

Bishop, S.C., Axford, R.F.E., Nicholas, F.W., Owen, J.M., 2010. Breeding for disease resistance in farm animals, 3rd ed. CABI, Wallingford, Oxfordshire Cambridge, MA.

Gicheha, M.G., Kosgey, I.S., Bebe, B.O., Kahi, A.K., 2005. Economic values for resistance to gastrointestinal helminths in meat sheep in Kenya. J Anim Breed Genet. 122, 165-171.

Groen, A.F., 1989. Economic Values in Cattle-Breeding 2. Influences of Production Circumstances in Situations with Output Limitations. Livestock Production Science. 22, 17-30.

Iversen, A., Hermansen, Ø., 2017. Cost development in farming of Norwegian Salmon. Nofima, 46 pp.

Janssen, K., Chavanne, H., Berentsen, P., Komen, H., 2017a. Impact of selective breeding on European aquaculture. Aquaculture. 472, 8-16.

Janssen, K., Berentsen, P., Besson, M., Komen, H., 2017b. Derivation of economic values for production traits in aquaculture species. Genet Sel Evol. 49, 5.

Kaplan, R.M., 2004. Drug resistance in nematodes of veterinary importance: a status report. Trends in Parasitology. 20, 477-481.

Lobo, R.N.B., Pereira, I.D.C., Faco, O., McManus, C.M., 2011. Economic values for production traits of Morada Nova meat sheep in a pasture based production system in semi-arid Brazil. Small Ruminant Res. 96, 93-100.

Mcinerney, J.P., Howe, K.S., Schepers, J.A., 1992. A Framework for the Economic-Analysis of Disease in Farm Livestock. Prev Vet Med. 13, 137-154.

Revie, C.W., Robbins, C., Gettinby, G., Kelly, L., Treasurer, J.W., 2005. A mathematical model of the growth of sea lice, Lepeophtheirus salmonis, populations on farmed Atlantic salmon, Salmo salar L., in Scotland and its use in the assessment of treatment strategies. J Fish Dis. 28, 603-613.

Wilton, J.W., Goddard, M.E., 1996. Selection for carcass and feedlot traits considering alternative slaughter end points and optimized management. Journal of animal science. 74, 37-45.

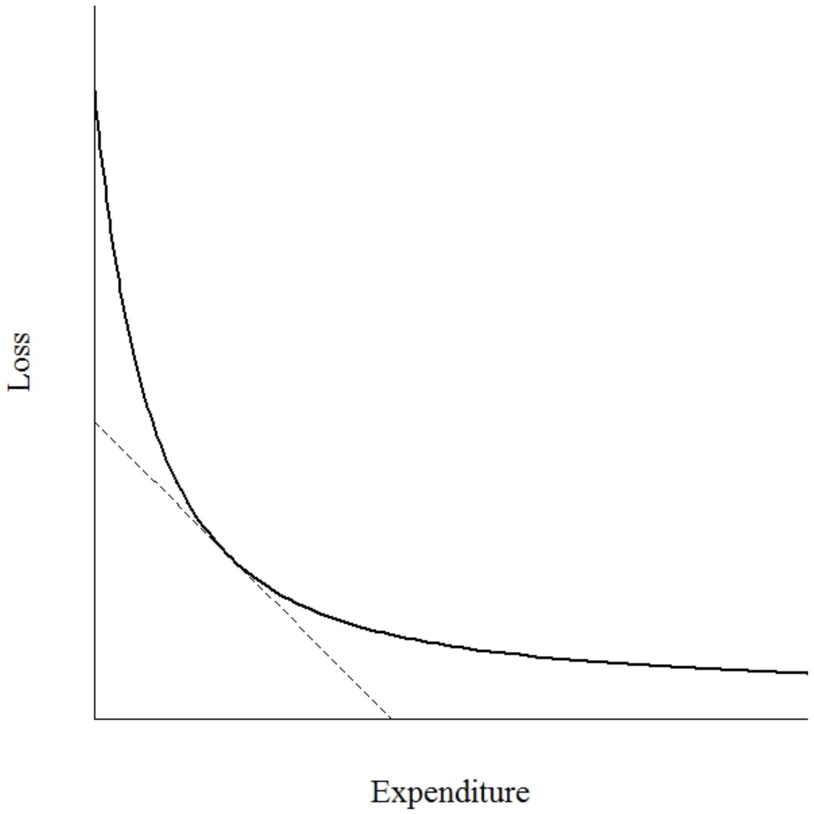

Figure 1. Loss-expenditure frontier. The grey dotted line ($\delta L/\delta E=-1$) crosses the loss-expenditure frontier at the economic optimum.

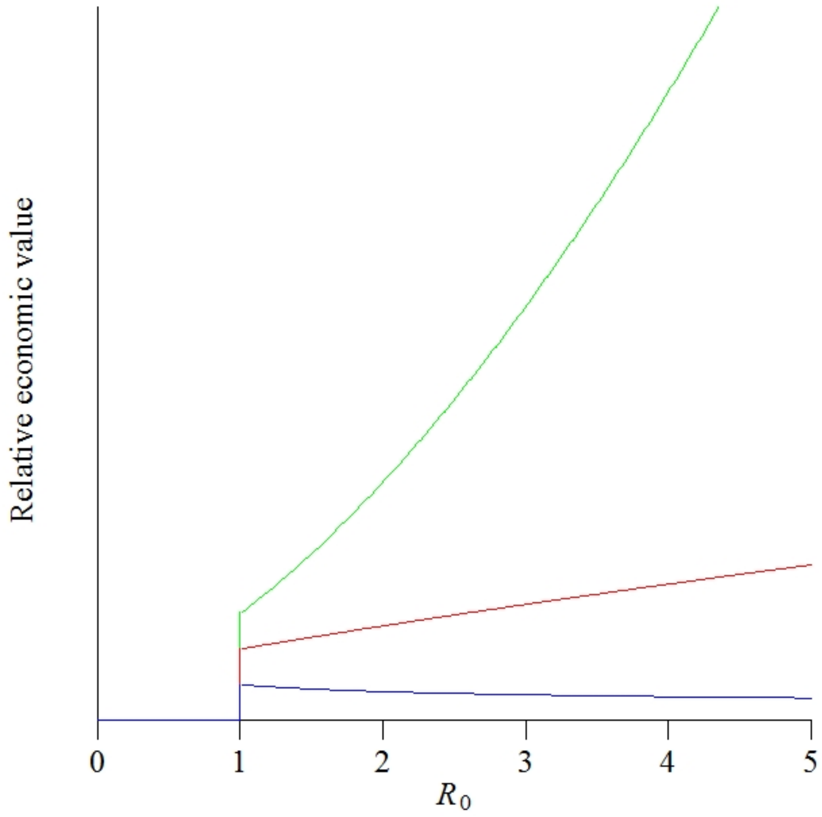

Figure 2. The relative economic value of R_0 *when the level of expenditures is below its optimum for* $\tau=1$ *(blue line),* $\tau=2$ *(red line), and* $\tau=3$ *(green line).*

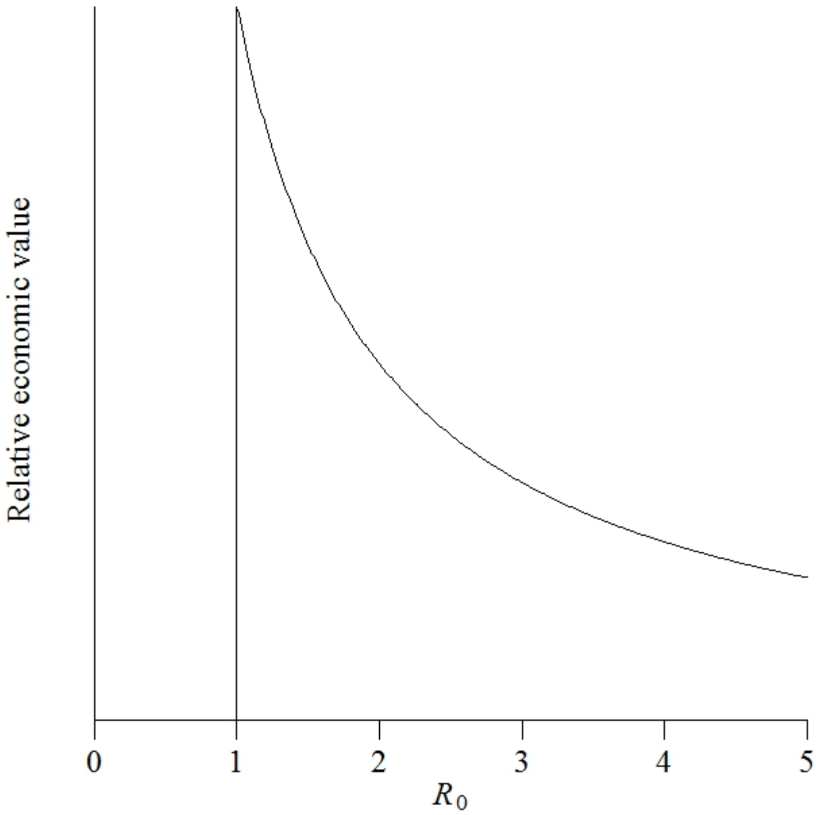

Figure 3. The relative economic value of R_0 *when the level of expenditures is above its optimum.*

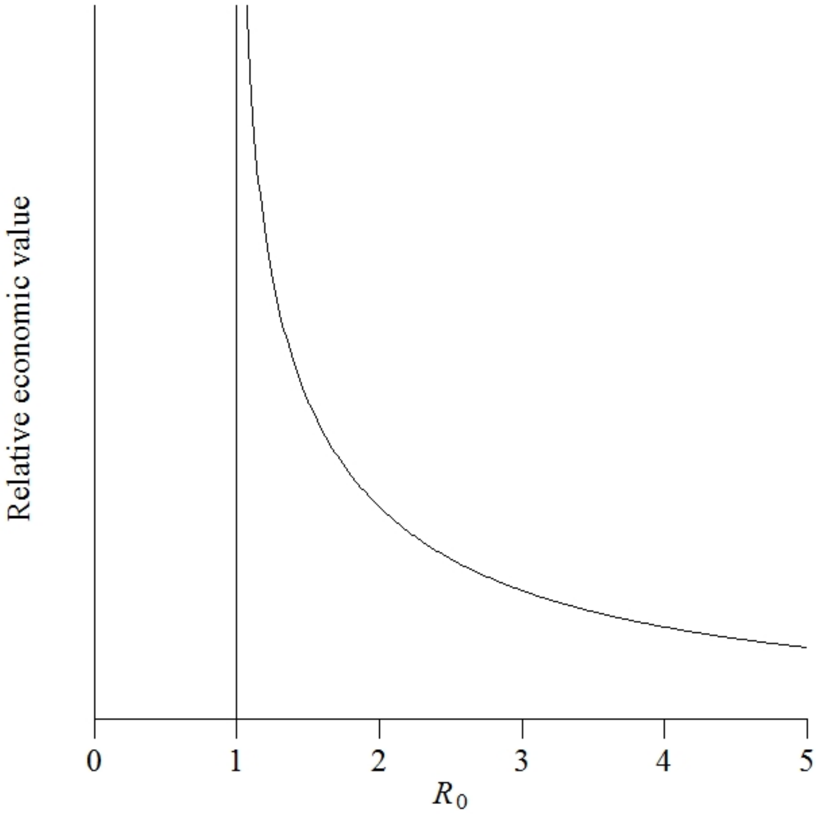

Figure 5. The relative economic value of R_0 when the level of expenditures is at its optimum.