
A law that approximate fatigue of animals (that race to survive)

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Résumé

In 1906, Arthur E. Kennelly, an electrical engineer and mathematician published a pioneering article in the Proceedings of the American Academy of Arts and Sciences entitled "An approximate law of fatigue in the speeds of racing animals" (Kennelly 1906). A mathematical law was proposed for the first time to describe the relationship between locomotion speed and the distance or duration of effort. Half a century later, this relationship between the intensity of an effort and the duration over which it can be sustained made a major breakthrough in understanding human exercise. Initially developed in the field of work ergonomics, these models aimed to describe "the amount of work a muscle can do before being exhausted" and "the conditions of a fatiguesless task" (Monod & Scherrer 1965) with a view to optimising man power and working conditions in post-Second World War.

More recently, the study of the intensity-duration relationship (i.e. critical power model) has flourished in the context of exercise physiology (Poole et al. 2016). This framework offers a robust approach for examining and comprehending the physiological and pathophysiological mechanisms of fatigue and endurance throughout the lifespan of both healthy individuals and patient groups. The critical intensity concept offers considerable potential for refining athletic training strategies and enhancing performance as well as for improving the quality of life of individuals with chronic diseases.

The critical intensity model can now offer a conceptual framework for opening new and broader horizons in the field of ecology. Striated muscles appeared hundreds of millions of years ago. Shared across the animal kingdom, it has emerged as a key evolutionary solution, allowing for movement. Because of their conserved anatomical structure and biochemistry, animals share fundamental muscle properties, such as fatiguability (as was foreseen by A.E. Kennelly). If movement ecology has remained hermetic in this field, this is probably (partly) due to the difficulty of evaluating animals. Indeed, historically confined to laboratory settings, assessing critical intensity is a particularly difficult challenge for most species. However, the last decade has seen the emergence of the "record profile method", an in-field method to characterise the critical intensity of human athletes (Smyth and Muniz-Pumares, 2020). Many species are regularly equipped with instrumented collars (for example, GNSS, accelerometer), it is possible to implement the methods initially developed for Homo sapiens to better understand the fatigue of non-human animals.

Our team proposed a proof of concept to evaluate the critical intensity in free-ranging animals using the GNSS measure (hunting dogs; Rozier-Delgado et al. 2025) or fine-scale

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accelerometers (wild wolfs) in natura. Furthermore, the model proposed by Bowen et al. (2024) offers the opportunity to characterise the endurance and fatigue of free-living animals within the context of their ecology and behaviour. In particular, it allows us to investigate when, where, and for how long an animal is performing at a fatiguing intensity, integrating energetic trade-offs and fatigue into the broader framework of ecology, behaviour, and physiology. Biomechanical and physiological models of locomotion that have been widely developed for athletic performance are now being applied to ecology to understand the exhaustion of animals due to human activities (leisure activities, hunting), climate change (effects of environmental stress), and prey-predator interactions that are evolving in line with public policy (reintroduction of the wolf). This work provides key information on today's crucial issues in biodiversity preservation.

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