Field weed population models: a review of approaches and application domains

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Introduction

Mathematics is widely accepted as one of the purest forms of science. While the mathematical models of physics are accepted as laws of nature, mathematical models of living systems are approximations to nature, simplifications of systems much too complex to grasp fully and in detail. Ecological modelling has been seen as 'the construction of elaborate diagrams and mystico-mathematical representations of assumed relationships' (Hedgpeth 1977). Although mathematics can be used as the common language of natural science, wherein thoughts can be expressed objectively and unambiguously, 'Was sich überhaupt sagen lässt, lässt sich klar sagen' (Wittgenstein 1918), to the uninitiated mathematical models can be incomprehensible and an obstruction, rather than a pathway, to communication and insight. How can we as scientists put models to best use?

'Models help us formulate notions ... about the dynamics of the different species that an ecosystem comprises. These models are most useful when they help us to formulate and to test theory ..., and to manage ecosystems in an environmentally friendly manner' (Gutierrez 1996). Thus we must use models both as thinking tools, helping scientists to form a consistent conception of ecological systems and providing a frame for their research, and as practical tools ultimately causing farmers to take better decisions. From the outset of model development, it is important to realise which aim has priority.

We evaluated models of weed population dynamics based on an analysis of their assumptions, biological rationale, flexibility, documentation, accessibility, demand for parameter estimation and documented validity. We arrived at general recommendations regarding which modelling approach should be applied in order to address different application domains.

Materials and methods

The development of weed population dynamics models has not been excessively prolific, maybe due to the problem of validating such long-term processes. Thus we aim at reviewing all models of this kind, expecting to find 50 models in total, only 10-15 of these being very complex. We will identify which questions the models address, the structure of model, what kind of life cycle aspects are accounted for, which factors are assumed to have an influence on population dynamics (intrinsic species characteristics, weather and climatic factors, management), and whether any validation has been attempted.

Results and discussion

Natural populations are regulated via factors operating in a density-dependent manner (Gutierrez 1996). For weed populations these factors are competition for common resources within and between species, but also weed control actions if these are applied by the farmer in response to weed density. Density-dependent relations are thus at the heart of any model of weed population dynamics. Positive feedback, readily seen in the explosive proliferation of weeds in badly managed fields, is the force underlying the necessity for weed control. When positive feedback mechanisms are coupled with density-dependence in models, chaotic behaviour may arise (Berryman and Millstein 1989) and indeed weed population dynamics have been claimed inherently chaotic and thus in principle unpredictable (Firbank 1989; Gonzalez-Andujar and Hughes 2000). In the field, however, environmental variation caused by weather and agricultural practice are the main causes for the variability of weed population dynamics, rather than chaos (Berryman and Millstein 1989; Freckleton and Watkinson 2002). Thus weed population dynamics *are* predictable – within bounds.

General recommendations for developing ecological models:

(1) The questions that the model should address must be clearly formulated, before an appropriate modelling approach can be chosen and modelling itself begun. Beware of the temptation to just get the modelling going as a starting point.

(2) For a model to have scientific merit, its mathematics and rationale should be published, and its implementation made publicly available on Internet or by request. The model coding itself should be open for scientific review. Demanding code secrecy, in style of commercial software, is incompatible with scientific ethics and progress.

(3) Turning the model into a black box, either through sloppy implementation or documentation, should be avoided. The modeller is likely to lose track of the model's inner workings, and the scientific community is likely to lose interest all together.

(4) The model should be based on well-established biological relationships and sound rationale, rather than inventing all model components and equations anew.

Specific recommendations for developing weed population dynamics models:

(5) 'Agronomists look for differences, biologists for relationships' (G. Nachman, pers. cit.). To aid model synthesis of experimental results, weed scientist should give more emphasis to uncover general biological relationships than tabulate effects of agronomical treatments specific to site and year.

References

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