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Cultivating resilience by empirically revealing response diversity

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ABSTRACT

Intensified climate and market turbulence requires resilience to a multitude of changes. Diversity reduces the sensitivity to disturbance and fosters the capacity to adapt to various future scenarios. What really matters is diversity of responses. Despite appeals to manage resilience, conceptual developments have not yet yielded a break-through in empirical applications. Here, we present an approach to empirically reveal the 'response diversity': the factors of change that are critical to a system are identified, and the response diversity is determined based on the documented component responses to these factors. We illustrate this approach and its added value using an example of securing food supply in the face of climate variability and change. This example demonstrates that quantifying response diversity allows for a new perspective: despite continued increase in cultivar diversity of barley, the diversity in responses to weather declined during the last decade in the regions where most of the barley is grown in Finland. This was due to greater homogeneity in responses among new cultivars than among older ones. Such a decline in the response diversity indicates increased vulnerability and reduced resilience. The assessment serves adaptive management in the face of both ecological and socio-economic drivers. Supplier diversity in the food retail industry in order to secure affordable food in spite of global price volatility could represent another application. The approach is, indeed, applicable to any system for which it is possible to adopt empirical information regarding the response by its components to the critical factors of variability and change. Targeting diversification in response to critical change brings efficiency into diversity. We propose the generic procedure that is demonstrated in this study as a means to efficiently enhance resilience at multiple levels of agrifood systems and beyond.

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1. Introduction

Intensified climate and market turbulence has brought considerable uncertainty to human activities (Coumou and Rahmstorf, 2012; Dessai et al., 2007). The volatility of the food and financial markets has reintroduced food security on to the world agenda. Resilience and adaptive capacity, robustness and multi-stability are required to complement the 'predict and adapt' approach of preparing for projected long-term changes (Dessai et al., 2007; Scheffer et al., 2001). Diversification is the strategy with highest expectations, with response diversity being the key (Folke et al., 2004; Elmqvist et al., 2003). Response diversity, if empirically assessed, could lay the groundwork for adaptive management and facilitate, at the interfaces of science, policy and private actors, adaptive governance for a resilient society.

To recognise resilience, we must move beyond species, cultivar and genetic diversity. Diversity in functional properties rather than diversity of types per se (Page, 2010) is crucial for the provision of ecosystem services (Diaz et al., 2007). Response diversity refers to the diversity of responses within a functional group (e.g. within a species, or group of species providing the same function) (Elmqvist et al., 2003; Nyström, 2006). While providing diversity of responses to disturbances, response diversity within a functional group ensures that at least some members of the group maintain their function when facing such disturbances. Consequently, response diversity enables the continuous provision of the same function in turbulent and changing environments also (Folke et al., 2004; Nyström, 2006). In addition, response diversity, by providing material for selection in new conditions or for new targets, builds

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the capacity for successful transformations (Chapin et al., 1997). Therefore, theoretically, diversity does not per se enhance resilience, whereas diversity in responses to critical variability and change produces such enhancement.

Despite appeals to manage for resilience (Folke et al., 2004; Chapin et al., 1997; Scheffer et al., 2001), the conceptual and theoretical development of this approach has generated few empirical applications to date (Laliberte et al., 2010). A limited number of field studies have observed that response diversity serves to sustain system functions following disturbances in coral reefs (Nyström, 2006), lakes (Schindler, 1990), bee communities (Winfree and Kremen, 2009), rice fields (Zhu et al., 2000) and grasslands (Walker et al., 1999). Indirect assessments of the impact of management on response diversity, which depend on the generic and hypothetical division of plant function and response traits, have also been reported (Laliberte et al., 2010). However, the adequate classification of responses should be based on the function of interest (Aubin et al., 2009) and reflect differential responses to roughly specified critical disturbances (Naeem and Wright, 2003). In an agrifood system, the response traits of fodder and food supply may be different for shifts in, for example, climate and pests, demand and price, even at the cultivar level. Therefore, the response diversity must be identified and quantified directly (Aubin et al., 2009) for each given question and case (Petchey and Gaston, 2006). Multivariate statistical methods, including clustering and ordination methods that are applied to assess genetic or species diversity (Laliberte et al., 2010; Petchey and Gaston, 2006; Mohammadi and Prasanna, 2003), provide examples of methodological solutions for the direct empirical quantification of response diversity.

Here, we introduce an empirical approach for directly revealing response diversity and apply this approach to a case of food security when facing climate change, i.e. to barley cultivar responses to weather in Finland. Barley cultivars vary in response to weather parameters (Hakala et al., 2012). For example, particular cultivars are drought susceptible, whereas others do not tolerate flooding or heat stress. We hypothesised that the assessment of the response diversity would yield a different estimate of the regional cultivar diversity than that obtained from mere type diversity. If so, then the approach based on response diversity would allow a more valid assessment of diversity in terms of the response to climate variability and change. In the case of added value by response diversity, this approach could provide a generic procedure as a practical tool to manage resilience.

2. Materials and methods

Our analysis involved two stages that were composed of five steps (Fig. 1).

2.1. Stage I: Identification of the responses to change factors

Stage I determines the factors of change that are critical to the system performance and the component responses to variations in these factors. In our example, we considered the agro-climatic parameters most critical to barley grain yield (Hakala et al., 2012; Rötter et al., 2013; Trnka et al., 2011) and the grain yield response of barley cultivars to variations in these parameters in multi-location trials (Hakala et al., 2012), which spanned three decades, in Finland. The generality of the results can be tested by validating the critical change factors and responses using other data. We determined the correlation in cultivar responses between the trial data and data from farms to test, whether the cultivars respond to the agro-climatic parameters under farm conditions similarly as in the trials, i.e. whether the response diversity model that was created using the trial data is valid in practical farming conditions, and thus applicable to guide the adaptive management of farmers and decision-making in, for example, breeding or agricultural policy.

2.1.1. Step 1: selecting the critical factors of change and variation

Data from the MTT Agrifood Research Finland Official Variety Trials (Hakala et al., 2012) from 14 locations from Mietoinen in the south (60°23′ N, 22°33′ E) to Ruukki in the north (64°40′ N, 25°06′ E) and to Tohmajärvi in the east (62°14′ N, 30°21′ E) were used. Consequently, the cultivar trials represented all of Finland except for the northernmost part of Lapland, i.e. of region I, and the south-western peninsula of Ahvenanmaa, i.e. region XVI (Table 2, Fig. 2). Six trials were in regions II to VIII and eight trials were in regions IX to XV (Fig. 2). The trials were of a randomised complete block design or an incomplete block design. The number of replicates was 3 or 4. Cultivars in the experiments differed in the long term; however, standard reference cultivars were used across the trials. Fertilizer use depended on the cropping history, soil type and soil fertility and was consistent with the farmer practices (Hakala et al., 2012). Cultivars for which there were more than 25 observations were included in the analysis. Estimates were substituted for a few missing values for the phenological development dates (Hakala et al., 2012). The data consisted of a set of 112 modern cultivars of both Finnish and foreign origin from the early 1980s to the present (8.430 records) (Table 1).

The agro-climatic data of the Finnish Meteorological Institute for the trial locations were used. Ten agro-climatic parameters that most affected barley grain yield in the trials were identified using a regression analysis for parameters, which were selected based on previous literature and observations (for details, see Hakala et al., 2012). The correlating parameters were excluded to avoid multicollinearity. Two additional parameters (parameters 9 and 10 below) were selected based on the recent European study by Trnka et al. (2011). Consequently, the following twelve phenology-related agro-climatic parameters, which are the most critical for barley performance in Finland, were selected.

1. Precipitation during one month before sowing (mm).
2. Deviation from a fixed early sowing date (d).
3. Drought 3–7 weeks after sowing indicated by accumulated precipitation (mm).
4. Heat stress days of ≥ 25 °C one week before through two weeks after heading (d).

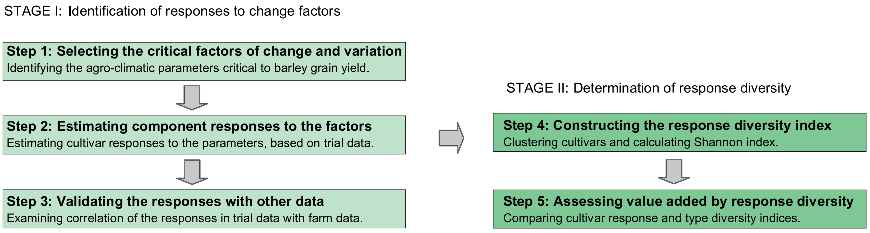

Fig. 1. The proposed approach to response diversity assessment. The steps of the generic procedure are presented in bold. The procedure that is applied to the case is specified for each step.

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