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Invited Commentary

Ecological Recovery and Resilience in Environmental Risk Assessments at the European Food Safety Authority

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ABSTRACT

A conceptual framework was developed by a working group of the Scientific Committee of the European Food Safety Authority (EFSA) to guide risk assessors and risk managers on when and how to integrate ecological recovery and resilience assessments into environmental risk assessments (ERA). In this commentary we advocate that a systems approach is required to integrate the diversity of ecosystem services (ES) providing units, environmental factors, scales, and stressor-related responses necessary to address the context dependency of recovery and resilience in agricultural landscapes. A future challenge in the resilience assessment remains to identify the relevant bundles of ecosystem services provided by different types of agroecosystem that need to be assessed in concert. *Integr Environ Assess Manag* 2018;14:586–591. © 2018 The Authors. *Integrated Environmental Assessment and Management* published by Wiley Periodicals, Inc. on behalf of Society of Environmental Toxicology & Chemistry (SETAC)

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INTRODUCTION

The European Food Safety Authority (EFSA) performs environmental risk assessments (ERAs) for regulated products connected to the production of food and feed, such as pesticides, genetically modified organisms (GMOs), and feed additives, and also for invasive alien species that are harmful for plant health. Different protection goal options can be selected in prospective ERAs. For example, the "threshold option" permits zero to negligible (regulatory and biologically relevant) population-level effects on nontarget organisms and ecosystem services (ES) delivery. In Europe, this option is, for example, selected for feed additives that enter agricultural soils via manure, or for pesticide exposures in off-field areas. The "recovery option" in the ERA for pesticides, however, permits some population-level effects on nontarget organisms if ecological recovery occurs within a specified, acceptable time period and essential ES are not at stake. For example, after pesticide use, the effect period for in-field nontarget organisms in soil should be shorter than a single growing season, and soil fertility should not be impacted. In the impact assessment for invasive alien species, a longer time horizon (e.g., 5 to 30 y after invasion) is considered, and the focus is on the assessment of the long-term resilience in ES delivery of impacted agroecosystems. In 2015 and 2016, a working group of the Scientific Committee of EFSA developed a conceptual framework, based on a systems approach, to incorporate ecological recovery and resilience in ERA conducted at EFSA (EFSA SC 2016a). The present article summarizes the conceptual framework, focusing on links between ecological recovery and resilience.

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CONCEPTS RELATING TO ECOLOGICAL RECOVERY AND RESILIENCE

Above certain thresholds of exposure, environmental stressors disrupt the normal operating range (NOR) of ecological entities. The NOR is defined as the range of values of a given ecological measurement or assessment endpoint that is normally observed during a predefined period for a reference (i.e., nonexposed) population, community, ecosystem, or process. In broad terms, ecological recovery can be thought of as the return of an attribute of an ecological entity to its NOR, having been perturbed outside of that range by a stressor or multiple stressors. Consequently, an important challenge in ERA is to define and collect information on the NOR, bearing in mind that this may vary in time and between different ecosystems.

Populations of species and functional groups, and their diversity, are important drivers of ES. Furthermore, ES delivery is a relevant endpoint for assessing the resilience of an ecosystem to a given regulated stressor. Consequently, ecosystem resilience is intrinsically linked to the structural and functional recovery of populations of species and functional groups that deliver key ES. Population dynamics after a disturbance may be governed by internal and external recovery processes (Barnthouse 2004; Liess and Von der Ohe 2005; Caquet et al. 2007; Frampton et al. 2007; Solomon et al. 2008; Kattwinkel et al. 2012; Topping et al. 2014; Gergs et al. 2016). "Internal" population recovery depends upon surviving individuals in the stressed ecosystem or upon a reservoir of resting propagules not affected by the stressor. "External" population recovery depends on the immigration of individuals from neighboring areas to the impacted area by active or passive dispersal, and this redistribution may lead to "action at a distance," that is, the impact of a stressor on population densities outside the area of direct exposure (Spromberg et al. 1998; Brock et al. 2010; EFSA PPR 2015).

Population recovery is influenced by species' demographic traits (e.g., life span, voltinism, number of offspring) and recolonization traits (e.g., dispersal capacity, distribution patchiness, territorial behavior) (Liess and Von der Ohe 2005; Rubach et al. 2011). Species traits, community and landscape properties, and exposure patterns together may determine the potential for ecological entities (e.g., populations responsible for ES delivery) to escape or cope with a stress event (panel C of Figure 1), illustrating that the potential for recovery of ecological entities from an effect of a potential stressor is multifactorial.

The NOR and ecological recovery of ES providing units within an ecosystem are closely linked to the concepts of resistance (also termed "robustness")—the ability of a system to maintain itself within the NOR—and resilience—the capacity of a system to return to the NOR after a perturbation outside this range (e.g., Holling 1973; Pimm 1984). A related concept is ecological regime shift (incomplete ecological resilience)—the ability of ecosystems to operate and organize in multiple alternative stable states, each characterized by a specific NOR (e.g., Gunderson 2000; Scheffer and Carpenter 2003; Elliot et al. 2007; Bundschuh et al. 2017). Because EFSA uses the ES concept to derive specific protection goals for ERA, it is logical to also express resilience in terms of ES delivery in relation to the intensity of the stressor (see panels A, B, D, and E of Figure 1). Ecosystem services delivery, and the portfolio of ES valued by society, will vary among different ecosystems and in space and time. To make the assessment of ES delivery operational in ERA requires the definition of ecological production functions (Munns et al. 2015; Bruins et al. 2016; Maltby et al. 2018). Ecological production functions enable quantitative linking (e.g., by means of models) of key ES provision by specific ecosystems and associated ES providing units based on a description of how this ES output varies as the underlying structure and function of ecosystems change.

When ES delivery returns to its original NOR after disturbance, ecological resilience is complete and the loss in ES provision is transient (panels A and B of Figure 1). Even in the case of complete ecological resilience, the trajectory of the negative impact of the disturbance on ES delivery may be different from the trajectory of recovery (recovery hysteresis in panel A of Figure 1). Complete ecological resilience may be expected in ecosystems when 1) redundancy within functional groups of organisms is sufficient, 2) the diversity in traits of ES providing units is not or only briefly perturbed, and/or 3) populations of keystone species and essential ecological functions (e.g., nutrient cycling, decomposition rates of organic matter, pollination) are only temporarily, and not severely, impacted (see the link of panel C to panels A and B in Figure 1). In some instances, incomplete ecological resilience (ecological regime shift) might lead to an alternative stable state, characterized by a more permanent loss in ES delivery (the link of panel C to panels D and E in Figure 1). "ES-hysteresis" (type II hysteresis in Elliot et al. 2007) refers to the difference in the provision of key ES between the NOR of the original ecosystem and that of the alternative stable state. Clearly, these are considerations underlining the need for a systems approach to ERA, supported by a conceptual framework.

CONCEPTUAL FRAMEWORK AND SYSTEMS APPROACH

Due to the complexity of ecological systems and the need to evaluate effects in spatial and temporal dimensions and at different levels of biological organization (e.g., population, community, ecosystem), a conceptual framework was developed to guide risk assessors and risk managers on how to integrate ecological recovery and resilience assessments into ERA (Figure 2). The conceptual framework links together the supporting information (I), key parameters (II), ERA tools to assess the magnitude and duration (rate of recovery) of ecological effects of exposure to a specific environmental stressor (III), and verification of ecological resilience potential (IV). A summary of this conceptual framework is described below in this section and more details are given in EFSA SC (2016a).

Environmental risk assessments for regulated products require well-defined specific protection goals (SPGs) that

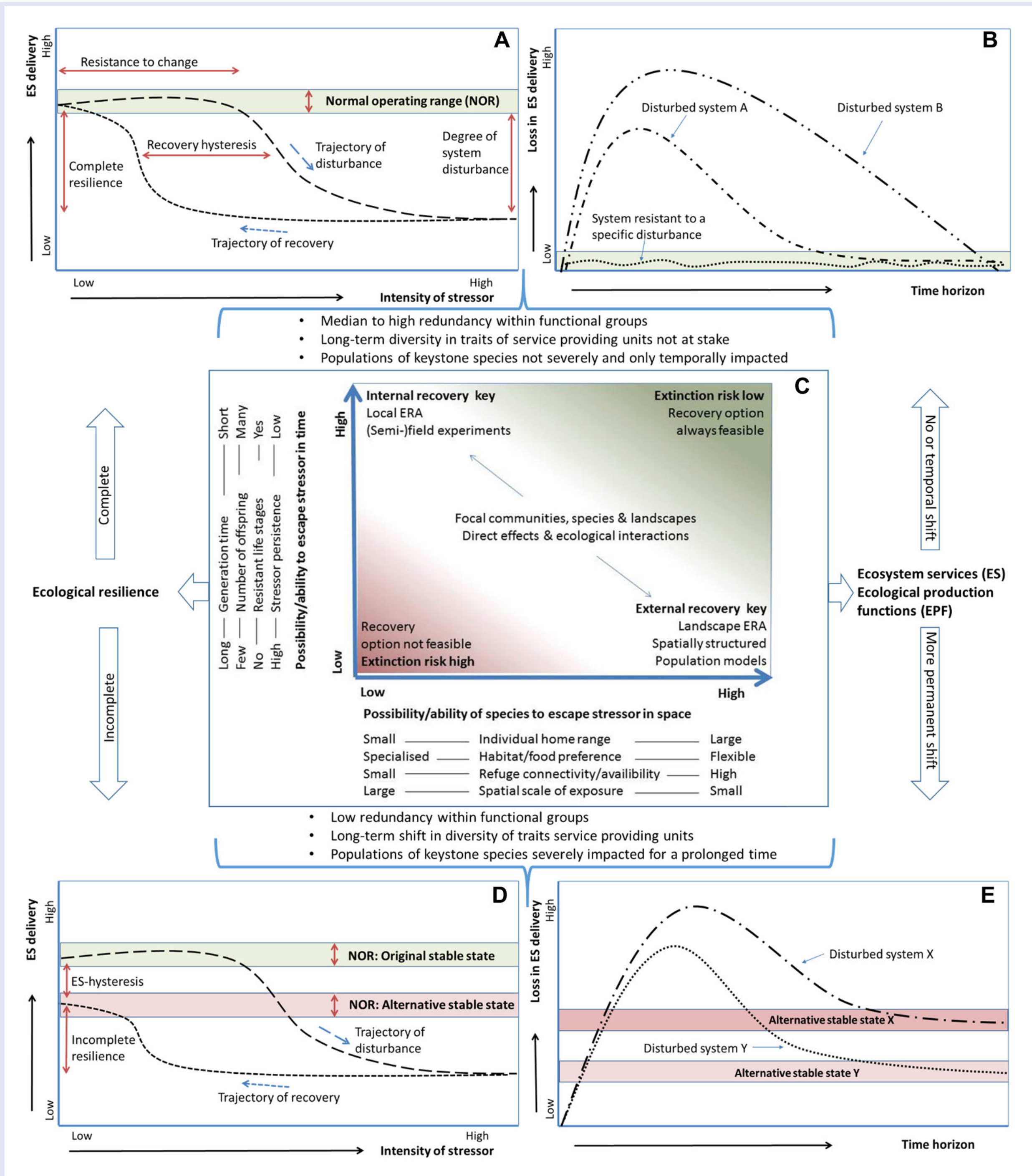

Figure 1. Schematic illustration of the recovery of ES providing units (Panel C) in relation to factors that govern their internal and external recovery and complete (Panels A and B) or incomplete ecological resilience (Panels D and E), expressed in terms of ES delivery in agroecosystems (adapted and revised from EFSA SC 2016a). ERA = environmental risk assessment; ES = ecosystem services.

operationalize the broad policy protection goals of relevant jurisdictions by delineating the ecological entities that need to be protected, where and over what time period, and the maximum impact that can be tolerated. Information on ES delivery in agroecosystems is an important foundation for SPG definition at EFSA (EFSA PPR 2010; Nienstedt et al. 2012; Devos et al. 2015; EFSA SC 2016b).

The key parameters required in ERA include the toxicity, fate properties, and agricultural use of regulated products such as pesticides and GMOs. For an alien pest species, the important traits to assess are its ability to invade new areas and its interactions with other species in the invaded areas (e.g., EFSA PLH 2014). In ERA not all ES providing units can be assessed always and everywhere. Therefore, the selection of key ES and related focal taxa, communities, or landscapes is an important prerequisite for prospectively addressing the impact of potential stressors on resilience in ES delivery. Focal taxa are relevant for both experiments and models;

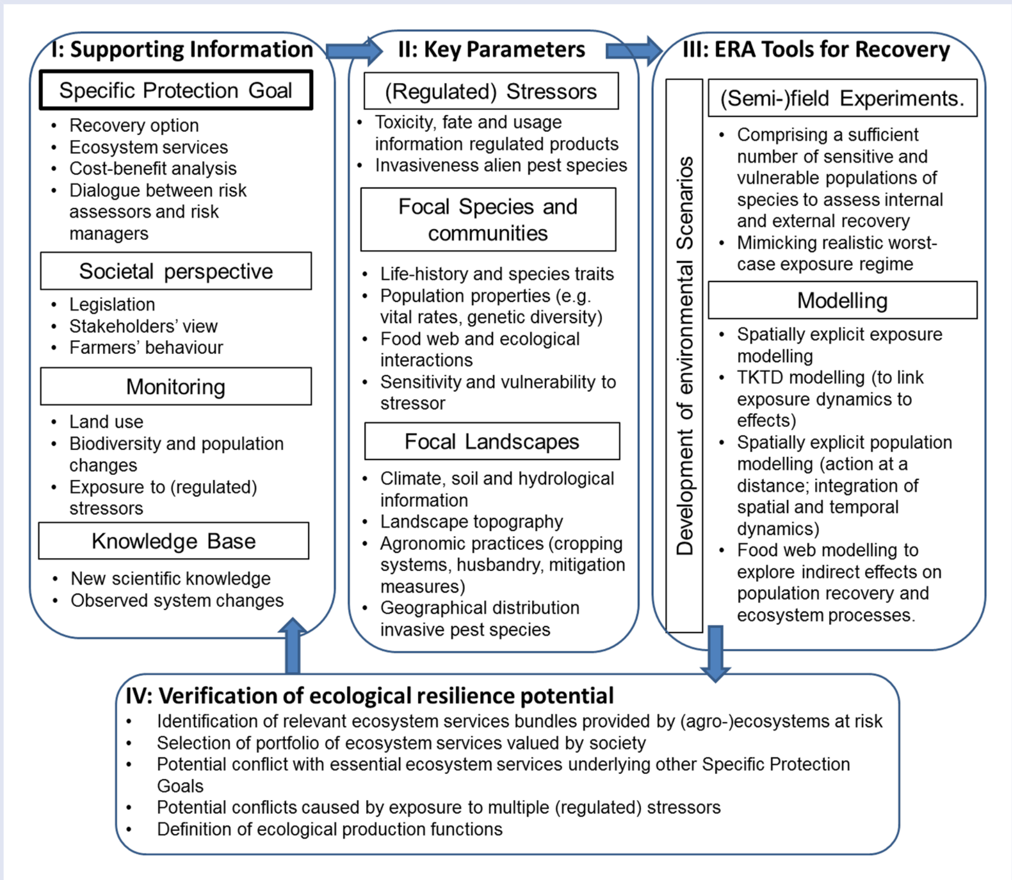

Figure 2. Conceptual framework for the assessment of ecological recovery and resilience in ERA for regulated products and invasive alien pest species at EFSA (revised from EFSA SC 2016a). EFSA = European Food Safety Authority; ERA = environmental risk assessment.

focal communities are relevant for semifield and field experiments and food-web models; focal landscapes are relevant for spatially explicit population models (e.g., Dietzen et al. 2014; De Laender et al. 2011; Focks et al. 2014; Topping et al. 2016). If essential key parameters for modeling a system cannot be obtained experimentally or from literature searches, a possible solution may be to estimate these parameters (and surrounding uncertainties) by using expert knowledge elicitation (EFSA 2014).

Environmental risk assessments based on focal taxa, communities, and their ES delivery require selection of an appropriate spatial scale to address the magnitude and duration of effects caused by exposure to one or more stressors. Significant differences exist in abiotic and biotic properties of agricultural landscapes among different areas in Europe. Consequently, for prospective ERA within the European Union, different and representative environmental scenarios (complementing current exposure scenarios with ecological information) need to be developed (EFSA PPR 2014; Rico et al. 2017) that define the basis for the ERA tools to assess effects, recovery of ES-providing units, and resilience of ES provision in ecosystems for exposure to the stressors of concern.

Small-scale semifield and field experiments may be appropriate tools to conduct local risk assessments suitable to address population dynamics and internal recovery processes of ES providing units during and after exposure to a stressor, including some possible indirect effects on ES delivery due to local shifts in species interactions. However, if external recovery processes are key, either large-scale field studies (e.g., Frampton 2001) or spatially explicit population models (e.g., Focks et al. 2014; Topping et al. 2016) may be the appropriate tools. Food-web models (e.g., De Ruiter et al. 2005; De Laender et al. 2011) are tools to explore in greater detail the possible stressor-induced effects on interactions between populations and ES providing units within ecosystems and on ecosystem processes.

Prospective ERAs that address certain SPGs are based on standardized test procedures, scenarios, and models to address the environmental risks of individual regulated products. A novel challenge is the evaluation of risks to all relevant SPGs, and consequently bundles of ES provided by (agro-)ecosystems, as potentially affected by multiple stressors. To evaluate the relationships between different SPGs potentially affected by the same regulated stressor in the agricultural landscape, or the effects of multiple stressors on bundles of ES in (agro-)ecosystems, a systems approach, including resilience of ES provision, is the way forward. Approaches are urgently required to define ecological production functions as operational steps to link ecological measurement endpoints for service providing units to the delivery of key ES valued by society. In addition, ecological modeling approaches should be promoted to predict the impact of realistic exposures of single and multiple environmental stressors on the portfolio of ES valued by society at the relevant spatial–temporal scale of agroecosystems (Holt et al. 2016).

OUTLOOK

The proposed systems approach allows the integration of the various ES providing units, environmental factors, scales, and stressor-related responses necessary to address the context dependency in ecological recovery and resilience. Although this may appear to generate a complex and data-hungry ERA, to reject a systems approach on the basis of complexity would ignore the fact that current decisions based on general approaches may not provide adequate levels of protection (either over- or underprotective). To ensure confidence in this approach, it is important that the tools (species or community trait database, environmental scenarios, models, ecological production function definitions) be developed as a common resource, ensuring transparency and reliability. The systems approach, considering both local and landscape-level ERA, is already advocated and outlined in several recent EFSA documents for regulated products such as pesticides (e.g., EFSA PPR 2015, 2018), for GMOs (e.g., EFSA GMO 2015), for invasive alien pest species (e.g., EFSA PLH 2014), and to protect endangered species (EFSA SC 2016c). A future challenge in the resilience assessment remains to identify the relevant bundles of ES provided by different types of (agro-)ecosystem that need to be assessed in concert.

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