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Meta-analysis on the responses of traits of different taxonomic groups to global and local stressors

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ABSTRACT

Climate change and pollution are considered as major drivers of biodiversity loss. Climate change is a global multi-stressor, whereas pollution predominantly acts on the local scale. Organisms traits provide mechanistic links between biotic responses and stressors. We reviewed and analyzed the literature on the responses of vertebrates, invertebrates, microorganisms and plants traits to climate change (437 studies) and pollution (121 studies), to assess whether there was uniformity (i.e. convergence) in the responses of traits to the multi-stressors. For climate change, the traits related to tolerance responded uniformly across taxonomic groups, indicating trait convergence. For pollution, the low number of studies hampered a comparison across taxonomic groups. However, aquatic invertebrates that are tolerant, or exhibit high dispersal or reproduction capacities increased in response to pollution, whereas body mass and size increased in phytoplankton and fish, respectively. We provide a set of traits that have the potential to predict ecosystem-wide effects of climate change and pollution.

Contents

1. Introduction

The Millennium Ecosystem Assessment (MEA) considers

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climate change and pollution as major stressors in ecosystems (MEA, 2005), which may lead to a global ecosystem state shift and threaten ecosystem services that are crucial for human well-being (Perrings et al., 2010; Barnosky et al., 2012). Climate change and pollution act on different spatial scales; climate change is related to large spatial scales and pollution is often a local or a regional phenomenon, though diffuse inputs may result in an ubiquitous presence of some chemicals (MacLeod et al., 2014). The alteration of ecosystems structure and functioning by these multi-stressors has promoted the search for diagnostic and predictive tools that can also be applied over large spatial scales (Lamouroux et al., 2002; Schäfer et al., 2007; Newbold et al., 2012; Díaz et al., 2013). Here, climate change and pollution are termed as 'multi-stressors' due to their association with multiple individual stressors such as changes in precipitation and temperature in the case of climate change. Traits have been advocated as a tool that may overcome the limitations of taxonomy-based approaches when diagnosing and predicting the effects of climate change and pollution (McGill et al., 2006; Statzner et al., 2007; Green et al., 2008).

Traits have a long tradition in ecology, particularly in plant ecology (Cornelissen et al., 2003), where they have shown potential to predict community composition (Shipley et al., 2006). They have also been applied to detect the effects of stressors, for example in aquatic ecosystems (e.g., Statzner et al., 2001; Mouillot et al., 2006; Mellado-Díaz et al., 2008). Trait databases on different spatial scales have been compiled for different taxonomic groups and are a crucial prerequisite to advance the establishment of trait-stressor relationships (Table S1). In comparison with taxonomy-based approaches, traits have several advantages: traits permit data aggregation at variable spatial-scales, thus allowing detection of the effects of stressors across biogeographic regions (Díaz et al., 1998; Dolédec et al., 1999; Moretti et al., 2009), which is particularly relevant for climate change due to its manifestation over large areas. On large spatial scales, taxonomy-based approaches often lack power to find the effects of stressors on biota because of strong variations in the species pools. Moreover, traits can establish explicit, and in many cases mechanistic, relationships between biotic responses and environmental gradients and stressors, which improve the interpretation and allow testing ecological hypotheses (Shipley, 2010). In this context, traits add value to taxonomic data by revealing functional structures and often portray seasonal and inter-annual stability compared to taxonomic measures (Bêche and Resh, 2007). Finally, traits can provide a sensitive tool for predicting biological responses to stress across different taxonomic groups (Aubin et al., 2013). For example, the decrease in organisms body size has been suggested as an universal response to climate change in various taxonomic groups (e.g., birds, Van Buskirk et al., 2010; fish, Daufresne et al., 2009; Baudron et al., 2014; salamanders, Caruso et al., 2014). Identification of similar trait responses within and across taxonomic groups indicates trait convergence; in other words the development of similar adaptations in response to specific environmental and habitat conditions (Grime, 2006). The idea of trait convergence is also inherent to the 'habitat templet concept' hypothesizing that spatio-temporal habitat variations provide a 'templet', which selects for life history and other species traits (Southwood, 1977). Similarly, Keddy (1992) developed a conceptual framework where environmental factors and stressors act like a 'filter', removing species lacking the required combinations of traits, such that organisms with certain traits dominate in a particular environment.

Previous reviews on traits were limited to specific taxonomic groups (e.g., lichens, Cornelissen et al., 2007; stream invertebrates, Menezes et al., 2010; birds, Luck et al., 2012), whereas a comparison of the responses of different taxonomic groups to specific multi-stressors is lacking. We reviewed the literature and conducted a meta-analysis on the responses of organisms traits to two multi-stressors acting on different spatial scales (i.e. climate change and pollution). We aimed to (i) quantify the response (and non-response) of traits of different taxonomic groups to climate change and pollution, and (ii) assess whether there is trait convergence in responses to multi-stressors across taxonomic groups.

2. Methods: literature survey and data analysis

We extracted peer reviewed studies on the effects of climate change and pollution on organisms traits by searching the *Web of Science* database (years 1972–2014). We used search terms such as '(algae OR plankton* OR diatom* OR phytoplankton OR periphyton OR macrophyte*) OR (fish*) OR (zoobentho* OR invertebrate* OR zooplankton*) OR (forb* OR grass OR sedge* OR tree* OR shrub* OR lichen* OR bryophyte* OR plant*) OR (myriapod* OR crustacean* OR chelicerate* OR arachnid* OR insect* OR arthropod*) OR (avian* OR bird*) OR (microb* OR bacteria OR virus* OR fungi OR protist* OR protozoa* OR microorganism*) AND (functional group* OR functional type* OR functional category* OR trait*) AND (climat* OR warming OR drought* OR temperature OR pollution OR contamination OR toxic*)' to find the respective papers. The papers were screened for information on the response of traits related to populations (e.g. average body size of population) or communities (e.g. abundance-weighted average body size of the community) to climate change and pollution. A total of 558 studies were included in our analysis and a brief description of the trait responses to climate change and pollution in the individual studies is provided in Table S2. Though not exhaustive, we consider that our study selection was unbiased. However, we focused on organism traits and, thus, studies on microorganisms may have been undersampled as they partly rely on functional genes. The studies were classified into field monitoring and experiments, which relied on field sampling and experiments, respectively, as well as into laboratory studies. We classified the trait information as specific traits that were often used, such as body size, mass, reproduction, functional diversity and tolerance, and into two general categories (other biological and other ecological traits) that were rarely reported. Furthermore, traits were categorized as responding and non-responding significantly to the multi-stressors under scrutiny, where the direction was coded as positive ('+') or negative ('−') for responding traits and as neutral ('0') for non-responding traits. Thus, positive and negative responses indicate a statistically significant increase and decrease in a trait (e.g. body mass), respectively, whereas a neutral response indicates no significant change. Pollutants were categorized as organic, inorganic or nutrients. To evaluate the potential convergence of the trait responses, we aggregated the direction of the trait response across studies within the same taxonomic groups as follows:

$$Response = \frac{(\sum('+') - \sum('-'))}{(\sum('+') + \sum('-'))} \quad \text{(i)}$$

We also evaluated the strength of trait responses by calculating the proportion of responding traits per taxonomic group as follows:

$$Proportion = \frac{(\sum('+') + \sum('-'))}{(\sum('+') + \sum('-') + \sum('0'))} \quad \text{(ii)}$$

The aggregated response was only calculated for taxonomic groups or traits for which more than 10 studies were available. All calculations and graphics were done in R (R Development Core Team, 2014).