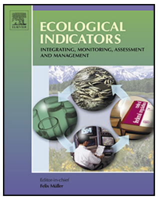
Ecological Indicators 50 (2015) 150–160

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind



A multi-trait approach for the identification and protection of European freshwater species that are potentially vulnerable to the impacts of climate change

Yaron Hershkovitz *, Veronica Dahm, Armin W. Lorenz, Daniel Hering

University of Duisburg-Essen, Faculty of Biology, Department of Aquatic Ecology, Universitätsstraße 5, 45141 Essen, Germany

A R T I C L E I N F O

Article history:
Received 2 April 2014
Received in revised form 21 October 2014
Accepted 25 October 2014

Keywords:
Climate change
Traits
Indicator species
Freshwater ecosystems
Adaptation measures
Protected Areas

A B S T R A C T

We present a multi-trait approach to identify potentially vulnerable species of *Ephemeroptera* (mayflies), *Plecoptera* (stoneflies) and *Trichoptera* (caddisflies), collectively referred to as EPT, to the impacts of climate change (CC). The "climate change vulnerability score" (CCVS) is an aggregation of six autecological traits that are known to be associated with vulnerability to CC: endemism, micro-endemism, temperature preference, altitudinal preference, stream zonation preference, and life history. We assigned a vulnerability score (0 – invulnerable to 6 – highly vulnerable to climate change) to 1940 EPT species and discussed the applicability of the index at three spatial scales: (1) continental (Europe), (2) state (the German Federal State of North Rhine-Westphalia) and (3) a river basin (the Ruhr River). We identified 157 EPT species (ca. 8%) as highly vulnerable to climate change (CCVS $\geq$ 4), including 95 species of caddisflies, 60 species of stoneflies and two species of mayflies. These are mostly found in France and Italy (52 species each), Spain and Slovenia (36 and 34, respectively), and Austria and Switzerland (30 species each), of which 95 are caddisflies, 60 stoneflies, and 2 mayflies. Using data collected in routine regional sampling we show that although no endemic EPTs were found in the German Federal State of North Rhine-Westphalia, eight species can still be identified as relatively vulnerable to CC (CCVS of 3). Almost all of these species are occurring in the 'mountainous' regions of the state (>200 m a.s.l.), the Sauerland and the Eifel. The upper reaches of the Ruhr catchment have been found to be relatively rich in vulnerable species, including several locally rare species. This index can assist conservationists to identify "hotspots" in terms of climate vulnerability and climate change refuge areas that can be considered for protection or the application of restoration measures at a local and regional scale. Nevertheless, not all species have complete autecological information, which hinders our ability to fully recognize the areas of priority. To further stabilize and enhance the applicability of this method, it is essential to fill these knowledge gaps in the future.

1. Introduction

A growing body of literature shows that human-induced climate change (CC) is already occurring and will have more dominant effects on ecosystems over the upcoming centuries (Blois et al., 2013; Loarie et al., 2009). As the climate changes, many aquatic ecosystems will be subjected to multiple increasing pressures, including the melting of mountain glaciers (Finn et al., 2010; Gobiet et al., 2014; Muhlfeld et al., 2011), flow fluctuations (Verdonschot and van den Hoorn, 2010), elevated temperature and salinity, and the deterioration of water quality (Jeppesen et al., 2010; Perkins et al., 2010; Whitehead et al., 2009; Wilby et al., 2010; Woodward et al., 2010). A major determinant of aquatic life and particularly the longitudinal distribution of species is water temperature (Illies, 1978). Thus, the increase in water temperature may become one of the main impacts of CC on stream biota, particularly on the survival of cold-water species such as salmonids (Eaton and Scheller, 1996; Imholt et al., 2013) and invertebrates (e.g., Haidekker and Hering, 2007; Isaak et al., 2011). In some areas, water temperature has already significantly increased, particularly during summer (e.g., Daufresne et al., 2004; Isaak et al., 2011; Kaushal et al., 2010). Further problems arise through altered flow regimes; for example, when there is less minimum discharge to balance summer drought situations or higher floods in shorter periods of time (Van Vliet et al., 2013). This will lead to changes in macrophyte composition (Alahuhta et al., 2011), invertebrate communities (Cordellier et al., 2012; Domisch et al.,

---

* Corresponding author. Tel.: +49 0 201 183 3046.
E-mail address: yaron.hershkovitz@uni-due.de (Y. Hershkovitz).

http://dx.doi.org/10.1016/j.ecolind.2014.10.023
1470-160X/© 2014 Elsevier Ltd. All rights reserved.

2011, 2013; Ott, 2010) and fish assemblages (Comte et al., 2013; Daufresne and Boët, 2007; Logez and Pont, 2012). As many freshwater ecosystems are already severely modified, the impacts of CC will further exacerbate existing pressures (Dudgeon et al., 2006; Hering et al., 2010; Palmer et al., 2009; Perkins et al., 2010; Woodward et al., 2010).

Minimizing the projected impacts of CC on biodiversity (adaptation, IPCC, 2007) is therefore a challenge to scientists, conservationists and practitioners. Adaptation measures involve a range of actions that aim to increase the ability of the biota to adapt to changes, primarily focusing on vulnerable systems or species (Adger, 2006; Füssel, 2007). One of the possibilities for applying adaptation measures is through the allocation of 'Protected Areas' (PAs, Hannah et al., 2007; Le Saout et al., 2013; Pittock et al., 2008), which are a "clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long term conservation of nature with associated ecosystem services and cultural values" (Dudley, 2008).

A vital step in the creation of adaptation schemes based on PAs is the prioritizing of locations that will be protected and suggesting particular measures that should be performed to achieve the protection objectives (Groves et al., 2012). In Europe, the 'Habitats Directive' (92/43/EEC) is one of the main legislation tools for selecting and protecting habitats and the species within them. Nevertheless, some argue that the criteria for including taxa in the Habitats Directive are often too subjective, with no objective assessment of threat, vulnerability, rarity or endemism (Cardoso, 2012). For example, although freshwater ecosystems support approx. 10% of all described species, including more than 12,000 species of fish and >75,000 freshwater insects (Balian et al., 2007), they have been far less represented in designated PAs (Abell et al., 2008; Heino et al., 2009; Lovejoy, 2006; Strayer and Dudgeon, 2010).

The 'biodiversity hotspot analysis' for example, is one of the methods to identify potential conservation regions, which is based on the presence of biological communities that maintain a large concentration of endemic species facing considerable threats (Lovejoy, 2006). The definition of such 'key biodiversity areas' can be based for example on the presence of Red List species (Eken et al., 2004), although this approach has rarely been applied to freshwater ecosystems (Holland et al., 2012). Furthermore, within aquatic systems, climate change adaptation measures often focus primarily on the protection of relatively large and commercially important species such as fish (e.g., Bowler et al., 2012; Jonsson and Jonsson, 2009), whereas the smaller, seemingly less "attractive" organisms, such as aquatic invertebrates have been given far less attention (Cardoso, 2012; Strayer and Dudgeon, 2010). Invertebrates are one of the central biotic elements in aquatic systems, supporting a variety of functions such as the processing of organic matter, nutrient cycles, secondary productivity, decomposition, and translocation of materials (Wallace and Webster, 1996). Macroinvertebrates are also widely used for ecological monitoring and the assessment of water bodies worldwide (Birk et al., 2012; Kenney et al., 2009). Nevertheless, almost all the monitoring programs were developed primarily for reflecting the impact of the more prevalent stressors, such as eutrophication, organic pollution, acidification and the occurrence of toxic substances, and were not designed for assessing the impacts of climate change (Hering et al., 2010).

One possible way to assess climate change effects is by using existing biotic metrics (e.g., changes in the composition of sensitive species; Lawrence et al., 2010) or by adjusting the current assessment methodologies by adding 'climate specific components' to these assessment systems (Conti et al., 2014; Hering et al., 2010; Stamp et al., 2010). For example, the use of specific autecological characteristics or species traits has been found to be useful for linking trait groups to environmental conditions (Díaz et al., 2008; Dolédec and Statzner, 2008; Poff et al., 2010; Townsend et al., 1997). Several EU-funded projects (e.g., 'AQEM' and 'STAR', Schmidt-Kloiber et al., 2006; 'Eurolimpacs', Battarbee et al., 2008; 'WISER', Schmidt-Kloiber et al., 2013) have resulted in the production of a large collection of autecological traits (e.g., life history, morphology, behavior, physiology), which is now available as an online database (www.freshwaterecology.info; Schmidt-Kloiber and Hering, 2012). This information allows an in-depth analysis of aquatic ecosystems across Europe, including the use of specific traits for assessing species vulnerable to climate change (Domisch et al., 2013; Hering et al., 2009; Rosset and Oertli, 2011; Sandin et al., 2014).

Here we present the development and application of a new biotic index – the Climate Change Vulnerability Score (CCVS), which aims for the operationalization of ecological traits that are potentially vulnerable to CC. The index can be used for identifying water bodies harboring species that are possibly vulnerable to climate change, which could then be prioritized for applying mitigation measures. For this purpose we applied a trait-based approach on a species level using three groups of well-studied aquatic insects: *Ephemeroptera* (mayflies), *Plecoptera* (stoneflies) and *Trichoptera* (caddisflies), collectively treated as EPTs. Many species of EPTs are highly sensitive to temperature changes and other forms of CC impacts (Haidekker and Hering, 2007; Maiolini et al., 2011; Sandin et al., 2014; Sauer et al., 2011), and are therefore, more vulnerable to extinction under most future climate scenarios (Conti et al., 2014; Domisch et al., 2011, 2013; Hamilton et al., 2010; Hering et al., 2009; Tierno de Figueroa et al., 2009; Sauer et al., 2011). The suitability of the index is exemplified by analyzing the EPT spatial distribution at three scales: continental (Europe), a federal state (North Rhine-Westphalia, Germany) and a river basin (the Ruhr).

2. Methods

The construction of the CCVS is based on a collection of biological traits currently available for most European EPT species (Buffagni et al., 2009; Graf et al., 2008, 2009). The data were obtained from the online database www.freshwaterecology.info (Schmidt-Kloiber and Hering, 2012), which currently holds information on the distribution patterns and ecological preferences of approximately 18,000 European freshwater taxa, including 344 mayfly species, 510 stonefly species and 1185 caddisfly species.

Following previous studies (Conti et al., 2014; Domisch et al., 2011, 2013; Hering et al., 2009; Tierno de Figueroa et al., 2009), we selected seven parameters that represent the potential vulnerability of aquatic insects to climate change:

- Endemism: species that are only found in one of the 25 European ecoregions (Illies, 1978).
- Micro-endemism: endemic species that are found only in a specific geographical area within an ecoregion.
- Headwater preference: species restricted to upper reaches (the crenal and epirhithral zones).
- High altitude preference: species preferring streams at elevations of >800 m above sea level (a.s.l.).
- Cold-water preference: species that only exist in low water temperatures (<10 °C).
- Long-lived species: species with a life span of >1 year.
- Uni-voltine and semi-voltine species: species that only reproduce every year and every 2 years, respectively.

Endemic species may face extinction when conditions rapidly deteriorate, either from human activities, climate related changes, or both. This assumption is particularly applicable for micro-endemic species that are confined to a relatively small area within a specific ecoregion (e.g., the caddisfly *Ernodes kakofonix*, found