ARTICLE IN PRESS

Forest Ecology and Management xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Long-term impacts of three forest management strategies on herpetofauna abundance in the Missouri Ozarks

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A R T I C L E   I N F O

Article history:
Received 2 March 2016
Received in revised form 20 July 2016
Accepted 21 July 2016
Available online xxxx

Keywords:
Amphibians
Reptiles
Even-aged management
Uneven-aged management
Hierarchical models
MOFEP

A B S T R A C T

Herpetofauna play a critical role in forest ecosystems as key components of biodiversity. Although there have been many studies of forest management impacts on herpetofauna, the majority investigate a small number of species or are limited in spatio-temporal scale. We examined the response of 28 species of herpetofauna to forest management through the Missouri Ozark Forest Ecosystem Project (MOFEP), a long-term, landscape-scale experiment comparing even-age, uneven-age, and no-harvest management strategies. We assessed counts of each species at the local (stand-level) and landscape (compartment-level) scales before and up to 18 years after forest management activities. Four species showed a response at the compartment level; we captured fewer of two species in even-age compartments, more of one species in uneven-age compartments, and fewer of one species in uneven-age compartments. At the stand-level, we documented variable responses to regeneration methods across species and through time. For example, we captured more of all lizard species and some snake species in stands with greater disturbance, such as clearcuts or group openings. For other snakes, salamanders, and toads, we captured more individuals in stands of intermediate disturbance such as intermediate thin and single-tree selection. All lizards exhibited immediate reactions to regeneration methods, but captures subsequently declined through time. Other species, particularly amphibians, took more than a decade to return to pre-treatment capture rates. Overall, it appears that uneven-age and even-age management may enhance herpetofauna diversity at the landscape scale, despite lower counts of some species, when regeneration activities such as clearcutting and single-tree selection occur on a limited and spatially disjunct proportion of each compartment during each management entry. After 23 years of study, even-age, uneven-age, and no-harvest forest management strategies appear sustainable with regard to herpetofauna diversity in the Central Hardwoods region of the United States.

1. Introduction

Herpetofauna play a critical, although often overlooked, role in temperate forests. This diverse suite of species serves as a key connection in trophic networks in many ways: they link invertebrates to larger vertebrates, move energy and nutrients both between and among above- and below-ground communities, and connect aquatic and terrestrial habitats (Regester et al., 2006; Whiles et al., 2006; Semlitsch et al., 2014). In terms of vertebrate biomass within a given portion of a temperate forest, herpetofauna can exceed that of birds and match that of small mammals (Burton and Likens, 1975; Semlitsch et al., 2014; Milanovich and Peterman, 2016). Herpetofauna generally exhibit high levels of species richness in forests, and are often used as indicator species for ecosystem health (Welsh and Droege, 2001; Davic and Welsh, 2004; Gibbons et al., 2006; Peterman et al., 2007; Welsh and Hodgson, 2013). Although

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http://dx.doi.org/10.1016/j.foreco.2016.07.032
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Please cite this article in press as: Rota, C.T., et al. Long-term impacts of three forest management strategies on herpetofauna abundance in the Missouri Ozarks. Forest Ecol. Manage. (2016), http://dx.doi.org/10.1016/j.foreco.2016.07.032

herpetofauna are essential to intact, functioning forest ecosystems, populations of these diverse species are generally in decline across the globe, including in temperate forests (Gibbons et al., 2000; Stuart, 2004; Adams et al., 2013; Alroy, 2015). Anthropogenic habitat alterations can drastically affect local herpetofauna populations because the home ranges and movement capability of these species are small relative to the scale of land management (Semlitsch et al., 2009).

Effects of forest management on herpetofauna can vary depending on the management activity, species, and spatio-temporal scales of disturbance. Timber harvests, particularly clearcuts, are well known to negatively affect salamanders, frogs, and toads at the local (i.e. forest stand) scale (deMaynadier and Hunter, 1995; Harpole and Haas, 1999; Herbeck and Larsen, 1999; Homyack and Haas, 2009; Semlitsch et al., 2009; Popescu et al., 2012; Maigret et al., 2014). Reduction in canopy cover and leaf litter leads to higher maximum temperature and lower moisture, leading to lower survival and abundance of amphibians due to their sensitivity to desiccation (Chen et al., 1997; Rittenhouse et al., 2008; Todd and Andrews, 2008). Reptiles have not received the same scientific attention as amphibians regarding forest management effects (Gardner et al., 2007), and the research that has been conducted produced mixed results. Reptiles are more resistant to desiccation than amphibians, and tend to have greater movement capabilities and larger home ranges than salamanders in particular. Generally, forest management activities appear to increase reptile species richness at the landscape scale (i.e., forest compartment or watershed) (Greenberg et al., 1994; Renken et al., 2004; Greenberg, 2001; Loehle et al., 2005). However, at the species level, reptile responses are varied, with lizards and some snakes often increasing after forest management activities (Greenberg et al., 1994; Renken et al., 2004) and other species of snakes, especially small-bodied snakes, declining following regeneration cuts (Todd and Andrews, 2008).

Although the effects of timber harvests and other forest management techniques have been reasonably well-studied at the stand-level and in the short term, there is a need for more information on the landscape-level effects of broad-scale forest management strategies on herpetofauna diversity (Renken et al., 2004; Gardner et al., 2007). Most studies of forest management effects on herpetofauna focus on stand-level responses that are short-term relative to the time-scale of forest regrowth (e.g. Greenberg et al., 1994; Greenberg, 2001; Todd and Andrews, 2008; Semlitsch et al., 2009; Homyack and Haas, 2009; Popescu et al., 2012; Connette and Semlitsch, 2013), yet we know that populations of plethodontid salamanders can take decades to recover after clear-cutting (deMaynadier and Hunter, 1995; Homyack and Haas, 2009; Connette and Semlitsch, 2013). Given the important role of herpetofauna in temperate forest ecosystems, it is critical to have a comprehensive and holistic understanding of how forest management activities affect the herpetofauna community. With an improved understanding of these dynamics managers can balance objectives and adjust forest management practices to promote healthy, sustainable forests. To better elucidate herpetofauna response to forest management over time, it is vital to have replicated, landscape-scale, longitudinal studies (Sheriff and He, 1997; Renken et al., 2004; Gardner et al., 2007; Popescu et al., 2012).

The Missouri Ozark Forest Ecosystem Project (MOFEP) is a long-term forest experiment comparing three landscape-scale forest management strategies (Brookshire et al., 1997; Knapp et al., 2014). Starting in 1991, researchers began monitoring how even-aged management (EA), uneven-aged management (UA), and no-harvest management (NH) treatments affects all aspects of forest ecology including soils, overstory trees, ground flora, birds, small mammals, and herpetofauna (Knapp et al., 2014). This project is designed as a ⩾100-year forest management experiment and is meant to elucidate long-term management effects.

For this study, we experimentally evaluated how the number of individual herpetofauna species captured varied in response to EA and UA forest management for up to 18-years post-treatment. We evaluated responses of 4 species groups that we expected would respond similarly to management activities: anurans (frogs and toads); salamanders; lizards; and snakes. We tested 4 specific hypotheses: (1) given the scale of experimental forest treatments relative to the home ranges of most herpetofauna we examined (Semlitsch et al., 2009), most species would respond more strongly to local-level (i.e., forest stand) regeneration methods (clearcut, and intermediate thin on EA compartments, single-tree selection and group opening on UA compartments) relative to landscape-level (i.e., EA, UA) treatments; (2) given that clearcuts are known to negatively impact amphibian populations (deMaynadier and Hunter, 1995; Semlitsch et al., 2009; Popescu et al., 2012), the number of amphibians captured should decline the sharpest immediately following clearcut regeneration methods relative to intermediate thinning, group opening, or single-tree selection regeneration methods; (3) given that plethodontid salamanders can take decades to recover following clearcuts (deMaynadier and Hunter, 1995; Herbeck and Larsen, 1999; Homyack and Haas, 2009; Semlitsch et al., 2009; Connette and Semlitsch, 2013), salamander captures, particularly plethodontids, should remain depressed for a decade or more following regeneration cuts; (4) given their resistance to desiccation, the number of lizards and larger-bodied snakes captured should increase for a short period (<1 decade) following high intensity regeneration methods that result in more arid conditions, such as clearcuts (Greenberg et al., 1994; Greenberg, 2001), whereas the number of smaller-bodied snakes captured should immediately decrease following intermediate intensity regeneration methods such as single-tree selection and intermediate thinning (Todd and Andrews, 2008). We anticipate that this long-term experiment will better illuminate the holistic, community-level effects of these treatments on the Ozark herpetofauna across the landscape.

2. Methods

2.1. Study area and design

This study was located in Carter, Shannon, and Reynolds Counties in south-central Missouri (91°01′–91°13′W, 37°00′–37°12′N), within the Current River Hills subsection of the Ozark Highlands (Meinert et al., 1997). The area was typified by narrow ridges and hollows with many ephemeral streams, and was 84% forested at the beginning of the study in 1990 (Xu et al., 1997), with most dominant trees 50–70-years old at that time (Brookshire and Dey, 2000). The forests were predominantly upland oak-hickory and oak-pine forest, with dominant species including white oak (*Quercus alba*), black oak (*Quercus velutina*), post oak (*Quercus stellata*), scarlet oak (*Quercus coccinea*), blackjack oak (*Quercus marilandica*), shortleaf pine (*Pinus echinata*), and hickory (*Carya* spp.) (Xu et al., 1997). Mean annual temperature was 13.3 °C and mean annual precipitation was 1120 mm (Xu et al., 1997).

The MOFEP study employs a complete randomized block experimental design to compare even-aged (EA) and uneven-aged (UA) management to each other and to no-harvest management (NH, the control in this experiment). Within each of 3 experimental blocks, one of the 3 treatments (EA, UA, or NH) was randomly assigned to one forest compartment averaging 421 ha (range: 312–514 ha). Compartments were further divided into forest stands along practical boundaries such as roads, streams, and topography. Although foresters holistically manage compartments,

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