Biological Conservation 204 (2016) 276–283

Contents lists available at ScienceDirect

Biological Conservation

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

Bombs, fire and biodiversity: Vertebrate fauna occurrence in areas subject to military training

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ARTICLE INFO

Article history:
Received 31 July 2016
Received in revised form 19 October 2016
Accepted 23 October 2016
Available online 6 November 2016

Keywords:
Mammals
Birds
Reptiles
Fire
Military training effects on biodiversity
South-Eastern Australia

ABSTRACT

Military training areas (MTAs) cover 6% of the earth's land surface, but the impact on biodiversity of weapons use in MTAs remains largely unknown. We quantified the effects of military training on vertebrates in a 5-year study at Beecroft Weapons Range in south-eastern Australia by contrasting the occurrence of birds, mammals and reptiles between 24 sites within an area subject to repeated weapons use and a matched set of non-impacted sites. Species richness of mammals and reptiles was similar within versus outside the impact area, although many individual species responded to fire, which occurred more frequently in impacted sites. Bird species richness, the occurrence of larger-bodied and migratory bird species, and the occurrence of most individual bird species, was reduced within the impact area. Many bird species that displayed low prevalence in impacted sites also declined over time across the whole study area. Differences in biota between the impact and non-impact areas were detectable after controlling for the effects of recent fire, suggesting that weapons use impacted vertebrates through mechanisms additional to altered fire regimes.

Overall, our data indicated that Beecroft Weapons Range maintained considerable biodiversity value despite prolonged military use. Hence, MTAs have the potential to make a substantial contribution to conservation outside the formal protected area network. However, managers of MTAs need to explicitly state their environmental objectives. This is because management practices may be different if the aim is to maximize species richness rather than to secure populations of particular species.

1. Introduction

An estimated 2.5% of the world's GDP is allocated to defence spending (SIPRI 2014). Training of an estimated 28 million defence personnel worldwide often takes place on specifically designated areas, hereafter termed Military Training Areas (MTAs). Zentelis and Lindenmayer (2015) estimated that MTAs cover at least 1% of the earth's terrestrial land surface and possibly as much as 5–6%. In Australia, MTAs cover an area of approximately 18 million ha, which is approximately 2.3% of the continent (Zentelis and Lindenmayer 2015). MTAs often encompass a wide range of ecosystem types because of requirements to train defence personnel under different environmental conditions (Aycrigg et al. 2015). MTAs therefore have the potential to make a significant contribution to biodiversity conservation if they are managed in environmentally-appropriate ways (Hills 1991; Zentelis and Lindenmayer 2015; see also Stein et al. 2008). However, empirical investigations of the conservation value of MTAs are rare (Jentsch et al. 2009; Fiott 2015). Moreover, few studies have quantified the impacts of military training on biodiversity. This is despite the fact that the maintenance of biodiversity and environmental integrity are among the primary objectives for the management of MTAs in many jurisdictions globally (e.g., Gazenbeek 2005; Department of Defence 2014). In the study reported here, we sought to address knowledge gaps associated with the impacts of military training on biodiversity using a 5-year empirical study of birds, mammals and reptiles at Beecroft Weapons Range in south-eastern Australia. This area has been subject to military training for >150 years, much of it repeated bombing from naval ships.

Our overarching question was: **What are the impacts of military training on vertebrate fauna?** Answering this apparently simple question is more complex than initially appears (Fig. 1) because, conceptually, the impacts of military training may manifest in several ways. First, there may be direct impacts on animals such as being struck by ordinance or they may be stimulated to flee through noise and nearby physical disturbance. Second, there may be indirect effects on animals such

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http://dx.doi.org/10.1016/j.biocon.2016.10.030
0006-3207/

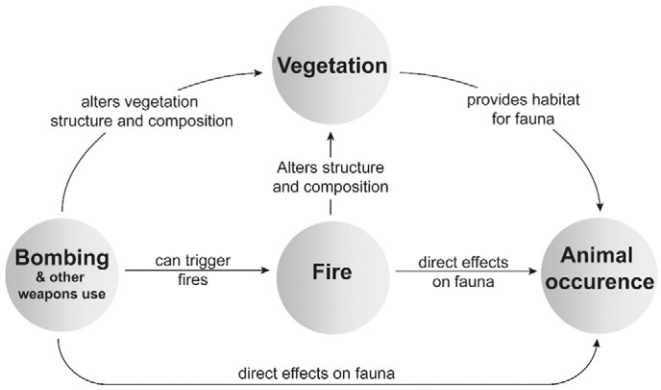

Fig. 1. Conceptual model of the potential inter-relationships between military training, fire, vegetation structure, and vertebrate fauna. The strength of both direct and indirect effects may be mediated by life-history attributes of impacted fauna.

as the occurrence of fires that are triggered by bombing and the use of other weapons. Fires can directly kill animals (Bell et al. 2001; Thonicke et al. 2001; Keith et al. 2002) or indirectly affect their occurrence by altering vegetation structure and habitat suitability (Whelan 1995; Swan et al. 2015). Third, weapons use can physically modify vegetation structure (without fire occurring) and this also can effect habitat suitability for fauna (Fig. 1).

To answer our overarching question about the effects of military training on birds, mammals and reptiles, we developed three postulates to compare the species richness and the occurrence of individual species in these vertebrate groups within versus outside areas subject to weapons use.

- **Postulate #1.** The vertebrate fauna inhabiting sites within the "impact area" subject to repeated weapons use would be depauperate relative to that on sites located outside the impact area. The effects of military training would be reflected by marked differences in standard measures of biodiversity such as species richness and the occurrence of individual species (Fig. 1). This postulate was based on elements of various disturbance theories which suggest that species other than early successional specialists may be eliminated from, or be rare in, places subject to disturbances that are recurrent, frequent and of high-intensity and/or high severity (reviewed by Pulsford et al. 2016). We also might expect to observe differences in population trajectories between the impact and non-impact areas as reflected by an interaction between impact area and year. This was because of differences in the type and prevalence of recurrent disturbances between the impact and non-impact areas, consistent with succession theory (Pulsford et al., 2016).
- **Postulate #2.** Differences in vertebrate fauna within and outside the impact area can be explained, in part, by differences in the prevalence of fire between the two areas (as reflected by fire regime variables such as time since fire and number of past fires) (Fig. 1). This postulate was based on past work in similar vegetation types in the broader region which has indicated that fire regime variables can have significant impacts on groups such as birds (Lindenmayer et al. 2008b; Lindenmayer et al. 2016b) and mammals (Lindenmayer et al. 2016a).
- **Postulate #3.** Differences in vertebrate fauna within and outside the impact area can be explained by the performance filtering hypothesis (Mouillot et al. 2012). This hypothesis predicts the gain or loss of species with particular functional traits from areas subject to environmental change (Newbold et al. 2013; Lindenmayer et al. 2015; Tilman 2001; Schleuter et al. 2010; Hidasi-Neto et al. 2012). We tested this postulate only for birds as it was the sole taxonomic group we studied with sufficient species richness and functional diversity to test trait-based hypotheses. We explored relationships between disturbance by military training and key life history attributes such as movement patterns given that migratory taxa are known to be sensitive to perturbations (Runge et al. 2014). We also quantified relationships between disturbance and body size, diet and the substrates used for foraging given well known links between some of these traits and extinction proneness (Lindenmayer and Fischer 2006) and/or links with environmental change (Luck et al. 2012).

Understanding the factors which influence biodiversity within MTAs is important for the development of best practice management of these globally extensive, and likely environmentally important, areas of land (Lawrence et al. 2015; Zentelis and Lindenmayer 2015). This study therefore makes a significant contribution toward the objectives of better quantifying the impacts of military training within MTAs and assisting better management of environments subject to this kind of land use.

2. Methods

2.1. Study area

We conducted this study at the Beecroft Weapons Range (35°03′ S, 150°49′ E) which is a ~4200 ha area of Beecroft Peninsula located ~135 km south of Sydney on the south coast of New South Wales, south-eastern Australia (Fig. 2). Beecroft Weapons Range has a temperate maritime climate with an average monthly rainfall of 103 mm (SD = 21 mm), and average minimum and maximum air temperatures for January (summer) and July (winter) of 18–24 °C and 9–15 °C, respectively (Bureau of Meteorology 2016).

Beecroft Weapons Range is managed by the Department of Defence and it contains a ~2000 ha area (see Fig. 2), hereafter termed the "impact area", that has been used regularly for weapons training since the 1800s (Welbourne et al. 2015). This area is often closed to public access for periods of several days to several weeks during which there is testing of a wide range of ordnance including ship-based naval gun fire, air to ground missiles, and small weapons (e.g. rifles, grenades and other kinds of hand-held armaments). The impact area is also used for demolition training.

The Beecroft Weapons Range has been subject to repeated fires over the past 38 years (Fig. 2). These fires are either triggered by bombing or are prescribed fires intentionally used as a means of reducing the risk of wildfire escaping the training area. Sites (as defined below) have been subject to up seven fires in the past four decades (see Fig. 2). There is a significant difference in the average number of fires per site over the past 38 years within versus outside the impact area ($F_{1,38} = 11.12$, $P = 0.002$) (0.81 in non-impact area sites, 2.38 in impact area sites, standard error of difference = 0.47). In addition, the average time since fire was 16 years inside the impact area and 28 years outside it ($F_{1,38} = 12.02$, $P = 0.001$).

2.2. Study design

Our study comprised 40 sites, with a site defined as a 100 m long transect. A total of 24 sites was located within the impact area (subject to military training) with the remaining 16 sites outside the impact area (Fig. 2). All sites were dominated by heathland comprising shrubs such as heath banksia *Banksia ericifolia*, scrub she-oak *Allocasuarina distyla*, dagger hakea *Hakea teretifolia*, and tea tree *Leptospermum* spp. (Skelton and Adam 1994).

We identified the appropriate location for each of our 40 sites by careful inspection of maps, on-the-ground field reconnaissance, and consultation with staff from Beecroft Weapons Range. The site locations were approved by the Officer in Charge at Beecroft Weapons Range and the Defence Environment team. Each of the 24 sites within the impact area was cleared of unexploded ordinances in January 2010 (see Fig. A1).