Mitigating the impacts of agriculture on biodiversity: bats and their potential role as bioindicators

Kirsty Park

Biological and Environmental Sciences
University of Stirling
Stirling,
Scotland, UK
FK9 4LA
Email: k.j.park@stir.ac.uk
Tel. + 44 (0) 1786 821811

1 **ABSTRACT**

2 Agriculture is a dominant land use worldwide with approximately 40% of the land's surface used for

3 farming. In many countries, particularly parts of Europe, this figure is substantially higher and most

4 agricultural land is under intensive practices aimed at maximising the production of food. The

5 intensification and expansion of modern agricultural practices led to the biological simplification of

6 the farmed environment, which has resulted in declines in farmland biodiversity during the last

7 century. As with other taxa, many bat species have suffered severe population declines during the

8 20th century, with agriculture believed to be one of the main drivers reducing roost availability and

9 foraging habitat. Lower intensity farming methods, and the creation or management of habitat features

10 on farmland could potentially mitigate some of these negative impacts but the effects of this on bats,

11 in comparison to other taxa, have received relatively little attention. Here, I review evidence on the

12 impacts of efforts to increase biodiversity in agricultural landscapes on bat populations, and explore

13 whether responses of bats to agricultural activities are similar to those of other taxa, a necessary

14 requirement if they are to be used as bioindicator species.

15 The review revealed that there are relatively few studies with which to assess the effects of

16 management interventions on bats in agricultural landscapes, and these are restricted to only a few

17 countries. Nevertheless, there is evidence that bats benefit from lower intensity agricultural systems,

18 specifically organic farming and shaded agroforestry: these systems tend to be associated with higher

19 bat abundance, species richness and diversity, and are more heavily utilised by foraging bats. Whilst

20 very few studies have explicitly tested the utility of bats as bioindicators in agricultural landscapes,

21 overall, the response of bats to lower intensity agricultural systems also reflect responses by other

22 taxa. These studies have been largely restricted to temperate regions, however. The review highlights

23 several major gaps in our knowledge of bats in agricultural landscapes and where future research

24 could be usefully directed including: 1) a broader geographical range of studies examining both the

25 efficacy, and the underlying mechanisms through which lower intensity agricultural systems may

26 benefit bats; 2) the potential for lower intensity systems in key crops such as oil-palm; 3) studies of

27 the demographic effects of conservation management on bats; 4) in order to assess the potential of

28 bats as bioindicators, studies quantifying the response of both bats and other taxa to environmental

29 change in a wider range of biomes and regions are needed.

30

31

32 **Keywords:** Chiroptera, agriculture, conservation, bioindicator species

33

INTRODUCTION

In the past ten thousand years, as *Homo sapiens* switched from a largely nomadic subsistence way of life to settlements and farming, the demands of the rapidly growing population have driven the expansion of world's terrestrial surface used for agricultural production to 40 % (Ramankutty et al. 2008). However, it wasn't until the end of the Second World War in 1945 that the "industrialisation" of agriculture started to gain in acceleration, with increasing mechanisation, the development of a wide range of chemical applications to control weeds and insect pests, and a far higher degree of specialisation on individual farms. Such trends were exported to many developing countries where agriculture had shifted from wholly susbsistence production to land used for the export market following European colonialism in the 17th and 18th centuries (Perfecto and Vandermeer 2008).

The practical effects of such changes from diverse low-intensity agriculture to intensive monocultures greatly improved yields from crops and livestock, but drastically reduced native habitat cover, leading to an impoverished agricultural matrix, and exposure of many wildlife species to toxic levels of pesticides. The implications of such changes for wildlife started to be recognised in the 1960s and was brought to the public's attention with publications such as Rachel Carson's Silent Spring (1962). In the last few decades compelling evidence of the disastrous effects of an increasingly intensive agricultural industry on biodiversity worldwide has accumulated (e.g. Pain and Pienkowski 1996; Krebs et al. 1999; Tilman 1999). The mechanism by which agricultural activities impinge on wildlife are varied and differ according to taxa, but are primarily related to the loss of resources required for food and shelter, and the effects, both direct and indirect, of chemical applications. The overall reduction in suitable habitat also means that the remnants are fragmented and increasing isolated, reducing landscape connectivity and making populations vulnerable to local extinctions.

The recognition of the biodiversity impacts arising from agricultural activities has led, in many countries, to an increased interest in more sustainable farming methods, such as organic farming, agri-environment schemes and agroforestry. The amount of land farmed organically, a low intensity system using crop rotation, compost, and biological pest control, has expanded greatly, increasing by 135% in the decade 2001-2011 (Paull 2011), and in 2012 stood at 37.5 million hectares, although this is still only 1% of total agricultural land worldwide (FiBL-IFOAM Survey 2014). Agri-environment schemes (AES) have been introduced in Europe, North America and Australia, with similar programmes in other countries as an attempt to reverse biodiversity declines by the adoption of less intensive, environmentally-sensitive agricultural practices (e.g. extensive grazing, reductions in chemical inputs and maintenance of landscape features; EEA, 2005). Whilst schemes in Europe and the United States (Conservation Reserve Programme) include financial incentives to encourage farmer uptake, the Australian Landcare Programme is a largely unsubsidised, community-based approach (Abensperg-Traun et al. 2004). Approximately 25% of all agriculture land in the 15 longest-standing

69 EU countries is under some form of AES management (EU 2005), and in some countries this figure is

70 considerably higher (e.g. 45% in the UK: DEFRA, 2008). Agroforestry, the inclusion of woody

71 perennials within farming systems (e.g. for coffee and cacao) is a traditional land use for subsistence

72 farmers throughout much of the world and, depending on the system, has a high potential for

73 biodiversity conservation (Perfecto and Vandermeer 2008). Global estimates are difficult to calculate

74 as the percentage tree cover varies greatly; however Zomer et al. (2009) estimated 17% of worldwide

75 agricultural land involves agroforesty with > 30% tree cover, rising to 46% with > 10% tree cover.

76 Nevertheless, with the expansion of crops such as oil palm that employ intensive management and,

77 based on current consumption patterns, forecasts of a 100-110% increase in global crop demands by

78 2050 (Tilman et al. 2011), large areas of land continue to be converted for intensive agriculture.

79 Quantifying biodiversity responses to different management regimes is crucial if we are to examine

80 the effects of current agricultural systems and for providing an evidence-base with which to improve

81 future agricultural policy for nature conservation.

82

83 *Bats and agriculture*

84 It has been estimated that 16% of the world's 1150 bat species are under threat from extinction with

85 the main driving forces being the loss of roosting and foraging habitats (IUCN Mammal Red List

86 2008; Mickleburgh et al. 2002), primarily from agricultural intensification and urbanisation. At the

87 same time there is increasing evidence of the economic value of bats for agricultural production, at

88 least in some systems. Across species, bats have a diverse array of diets; whilst approximately 70% of

89 all bats are predominately insectivorous, nectivorous and frugivorous species are known to be

90 important pollinators and seed dispersers for a large number of wild and cultivated plants (e.g.

91 Fleming et al. 1994; Kunz et al. 2011). The potential role of bats in controlling insect pests in

92 agricultural systems has long been suggested but it is only in the last few years that the necessary

93 experiments to quantify this have been conducted, with marked effects of bats on insect herbivores

94 (Williams-Guillén et al. 2008; Boyles et al. 2011), culminating in substantially increased crop yields

95 due to bat predation (Maas et al. 2013).

96 Intensification of agricultural practices can potentially impact upon bats through reductions in prey

97 availability, reduced survival through loss of suitable roost sites, loss or degradation of foraging areas

98 and exposure to toxic compounds used in agrochemicals (Stebbings 1988; Defra 2005). In Europe,

99 North America and Australia where habitat selection studies are commonly conducted using

100 radiotracking or acoustic detectors, research has consistently indicated avoidance of intensive

101 agricultural habitats (e.g. improved grassland, arable crops) and selection of native woodland or

102 remnants of semi-natural habitat within agricultural landscapes (e.g. Walsh et al. 1996; Vaughan et al.

1997; Henderson and Broders 2008; Fischer et al. 2010a,b; Fuentes-Montemayor et al. 2013; Womack et al. 2013). Similarly, trapping studies in the tropics have shown reductions in abundance and species richness as previously forested land is converted to pasture and crop monocultures (e.g. Estrada et al. 1993; Harvey and González Villalobos 2007; Castro-Luna and Galindo- González 2012). It has been suggested that the perception that bats may be at lower risk of extinction due to their ability to fly has led to their being overlooked in tropical biodiversity assessments and fragmentation research (Struebig et al. 2008). However, as Struebig et al. 2008 argue, there are many aspects of bat ecology, including strong site fidelity and slow rate of reproduction, that are likely to make them very susceptible to habitat loss and fragmentation, particularly for tree and foliage roosting species.

Responses to changes in the extent and configuration of native vegetation varies considerably between bat species, corresponding to their foraging guilds (based on echolocation calls and wing morphology) and roosting behaviour which influence habitat selection (Jung et al. 2012; Fuentes-Montemayor et al. 2013), and I refer to the differential response of bats according to guild characterstics throughout this review. For example, some bats are highly manoeuvrable and are able to forage in dense cluttered environments; others predominately forage along woodland edges, whilst fast flyers with high aspect ratio wings and wing loading typically fly in open habitats or above vegetation (Altringham 2011).

Bats as bioindicators?

Concern over the loss of ecosystem services, such as pollination and insect pest control, has heighted awareness of how reliant humans are upon high quality, functioning ecosystems and the use of bioindicators (biological processes, species, or communities) has been suggested as one way of assessing changes in environmental quality over time as a result of anthropogenic impacts (e.g. Carignan and Villard 2002; Holt and Miller 2010). The potential role for bats as bioindicator species has been highlighted by Jones et al. (2009) and this special edition of *Mammalian Biology* is the result of an exploration of these ideas. Jones et al. (2009) outline a range of characteristics that may make bats suitable bioindicator species, including their position at high trophic levels, widespread distribution and relative taxonomic stability. In order to be suitable as a bioindicator however, it is also critical that their responses to anthropogenic disturbance, such as habitat loss, and attempts at mitigating against habitat loss, reflects those of other species.

Aims of the review

The aims of this review are to evaluate the impacts of efforts to increase biodiversity in agricultural landscapes on bat populations, and explore whether responses of bats to agricultural activities correlate with those of other taxa (i.e. their potential as bioindicator species). Specifically I shall address the following questions:

137   1. What evidence is there that lower intensity agricultural systems (e.g. organic farming,
138   agroforestry) are beneficial for bats relative to high intensity systems?
139   2. What habitat features in agricultural landscapes, and at what scale, can be used to mitigate
140   negative effects of agriculture on bat populations?
141   3. Is there evidence from these studies that bats are useful indicator species for other taxa?

142 A recent synopsis on conservation interventions for bats, including those on farmland, provides a
143 useful summary of studies relating to questions 1 and 2 above (Berthinussen et al. 2014). Here, my
144 intention is to explore the various approaches to these questions in different geographical regions, and
145 look to highlight gaps in our knowledge, and where future research efforts would be usefully directed.
146 In assessing the suitability of bats as bioindicator species, I shall focus specifically on the association,
147 or lack of, between the responses of bats to agricultural activities and those of other species.

148 **METHODS**

149 *Criteria for inclusion*

150 Agriculture can be defined as the practice of cultivation by humans for food, fibre, fuels and raw
151 materials, and on this basis would also include forestry plantations (Spedding 1988). Since there has
152 been a recent review on the effects of silviculture on bats (Lacki et al. in press), I have excluded
153 forestry for timber production from studies reviewed here. In order to evaluate the value of lower
154 intensity agricultural systems for bats, I restricted my focus to studies where metrics for bat responses
155 (e.g. species richness, diversity metrics, abundance, activity) have been quantified for at least two
156 different levels/types of agricultural system (e.g. organic farming versus its conventional equivalent).
157 Chemical applications are a fundamental aspect of modern agriculture and some are known to impact
158 on bat populations (e.g. Jeffries 1972). However, other than indirectly through agricultural systems
159 that reduce or prohibit certain fertilisers or pesticides, this is outside the scope of the current review
160 and is dealt with by another paper in this special edition (Korine in review).

161 *Literature reviewing*

162 In order to source publications (up to May 2014) that assessed responses of bats in relation to levels of
163 agricultural intensity (question 1), the following combinations of keywords were used as a Web of
164 Science search: bat OR bats and any one of the following: agricultur*, farm*, organic, agri-
165 environment, agroforestry, conservation reserve programme, landcare scheme (the U.S. and
166 Australian programmes respectively). To ensure that I had not missed studies that omitted these terms
167 I also included specific names of some agricultural systems or crops including biofuel*, cotton, oil
168 palm, sugar, soy. In addition, I included grey literature where there was sufficient information to
169 allow evaluation. In this review all but one study is published as a peer reviewed paper with one UK

170   government report, available online, also sourced. Many of these studies also measured the responses

171   of other taxa as part of the same study; these were used to evaluate the extent to which the response of

172   bats to variation in agricultural intensity compares with those of other taxa (question 3).

173   In addition to recognised agricultural systems (e.g. organic farming) that may benefit biodiversity,

174   efforts to improve the quality of agricultural landscapes may also involve the creation or maintenance

175   of natural or created habitat features; therefore studies evaluating bat utilisation of such habitat

176   features were incorporated into the literature search in order to address question 2. These studies were

177   were identified as part of the reviewing for questions 1 and 3 and references cited therein.

178   **RESULTS AND DISCUSSION**

179   *1. What evidence is there that lower intensity agricultural systems are beneficial for bats*
180   *relative to high intensity systems?*

181   A total of 14 studies were found that quantified bat responses within agricultural landscapes that

182   differed in their level of management intensity (Table 1): five European studies provided an

183   assessment for organic methods of farming; three European studies (including one which also

184   assessed organic farming so is double counted here), evaluated the effects of agri-environment

185   schemes (AES); and seven studies in the Neotropics have examined the response of bats to different

186   agroforestry regimes, primarily coffee, but two incorporating other crops such as banana, cacao,

187   plantain, citrus and allspice (Table 1). Across these studies, seven also assessed the responses of other

188   taxa including, invertebrates (n=6), plants (n=3) and birds (n=2) which were used for comparing with

189   bat-management associations. All the European studies exclusively used acoustic detectors and

190   therefore the response metrics for these studies are primarily levels of foraging activity using number

191   of bat passes. Whilst some of these studies make a distinction between bat activity and foraging

192   activity (i.e. bat passes containing distinctive feeding buzzes), here I use total bat passes as a proxy for

193   foraging activity. Numerous studies have found a strong correlation between the two measures (e.g.

194   Park and Cristinacce 2006), and there are often too few feeding buzzes recorded to allow statistical

195   analysis. Since many bats can be identified by their echolocation calls, information was provided on

196   species presence/absence and also activity measures for particular species, species richness and other

197   diversity indices (e.g. Shannon's H index, evenness, dominance). Some bat calls, however, are very

198   similar making it hard to distinguish between species so authors either grouped together bats with

199   similar calls (e.g. the genus *Myotis*), or used discriminant analyses with call libraries of known species

200   to assign a level of probability to passes (e.g. Davy et al. 2007).

201   Overall, lower intensity agricultural systems had higher levels of bat activity, higher species richness

202   and diversity scores (Table 1). Four studies on organic farming, focussing on arable, pastural or mixed

203   farming were from the U.K; three of these showed a higher number of bat species on organic farms

204 than their conventional counterparts and higher levels of activity by at least some species
205 (Wickramsinghe et al. 2003; Fuller et al. 2005; Macdonald et al. 2012a). Fuller et al. 2005 also found
206 lower dominance scores indicating higher diversity on organic farms. The fourth, Pocock and
207 Jennings (2008) was primarily designed to uncover the mechanism(s) through which organic arable
208 farming may benefit bats which precludes a simple comparison between farming types. Interestingly,
209 this study showed no effects of agrochemical inputs, or from the use of hay rather than silage, but
210 suggested that most bats were highly sensitive to boundary loss (e.g. hedgerows, field margins) and
211 that these features may be more important than other management practices such as use of
212 agrochemicals. In one study in Greece, foraging activity of bats (all species) was approximately 25%
213 greater in organic vs non-organic olive groves (Davy et al. 2007), although the non-organic orchards
214 in this study were relatively low intensity (one chemical application per year), which may explain
215 why the differences were relatively modest (and not statistically significant).

216 The effect of agri-environment schemes on bats has been addressed by only three studies, all in the
217 U.K. In a replicated paired study, activity of *Pipistrellus pygmaeus* and *P. pipistrellus* was 38% and
218 50% lower (respectively) on AES farms than their conventional counterparts (Fuentes-Montemayor et
219 al. 2011a). When examined at habitat level (four habitats within each farm type were examined), bat
220 activity of both species was lower at AES managed hedgerows, water margins and species-rich
221 grasslands, but higher at AES field margins. However at this scale the differences were not significant
222 which the authors attribute to over-dispersion in the data and a consequent loss of statistical power.
223 None of the six bat species surveyed under AES management by MacDonald et al. (2012a)
224 demonstrated any differences in activity when compared to conventional farms, other than those that
225 were also under organic management (see above). In a study to assess whether there were any
226 additional biodiversity benefits through AES designed for cirl buntings *Emberiza cirlus*, MacDonald
227 et al. (2012b), found bat activity on AES farms was 2.6x higher than on conventional farms, although
228 this difference was not significant.

229 In contrast to the European studies above, all but one of the studies on agroforestry in the tropics
230 included native forest as one of their comparator habitats. Agricultural landscapes have been a
231 dominant feature in some parts of Europe for over 2000 years (Williamson 1986) so choosing control
232 habitats with which to compare agricultural practices in such areas would not be feasible.
233 Nevertheless, having a "original" habitat control, where possible, provides a measure of the relative
234 benefits of any particular agricultural system. There are a wide diversity of agroforestry practices for
235 the production of different crops which involve varying levels of management, vegetation types and
236 structural complexity; most of the studies reviewed here were for coffee production and were based in
237 Mexico and Colombia. In Mexico five main production systems have been described for coffee
238 increasing in management intensity (Moguel and Toledo 1999), and similar features are also
239 commonly found in other coffee producing countries: rustic and traditional polyculture, which use a

diversity of native trees for shading (Table 1: low intensity); commercial polyculture which has fewer strata in the vegetation and may involve the use of chemicals (Table 1: medium intensity); shaded monocultures, using a single canopy species and unshaded monocultures with no canopy and high levels of chemical applications (Table 1: high intensity). Where possible I have modified the term used by authors to fit within this system, as a way of easing comparisons between studies.

All the studies comparing the effect of agroforestry intensity on bats used trapping to estimate abundance and species diversity and one additionally used acoustic surveys (Table 1). Overall, species richness and Shannon's diversity index decreased from natural forest to coffee produced using increasingly intensive management (Table 1). In several studies bat abundance was actually higher in the low-input traditional polyculture than forest fragments but then declined with intensive methods such as shade monoculture (Williams-Guillen and Perfecto 2010) or unshaded production (Estrada and Coates-Estrada 2001). Focussing specfically on insectivorous bats, Williams-Guillen and Perfecto (2011) found contrasting patterns between open-space foragers and forest-bats. Whilst abundance and activity of forest bats were similar in the forest and low-medium intensity coffee plantations, it dropped sharply in high intensity plantations. The activity of open-space foragers, however, was highest in the high intensity plantations. Unusually, Estrada et al. 2006 found that bat abundance was higher in coffee systems across a range of production intensities, in comparison to forest fragments with the exception of shade monoculture; however, the sample size for this study was only one site per treatment. Species richness and abundance were considerably higher in traditional (low intensity) than commercial polyculture (medium intensity), which was similar to pasture, a common alternative land use in Mexico (Castro-Luna and Galindo-Gonzalez 2012). Numa et al. (2005) highlight the importance of the surrounding landscape for making such comparisons; they found little difference in phyllostomid species richness between forest, shaded coffee and high intensity unshaded coffee in landscapes with high levels of forest cover. In contrast, in landscapes with low forest cover species richness was highest in forest fragments, followed by shaded coffee with fewest species in unshaded coffee areas. This landscape effect is further supported by comparisons of shade agroforestry to forest fragments in Brazil; in areas with a large proportion of forest remaining, bat and bird diversity was higher in shade plantations compared to nearby forest. However, in areas dominated by shade plantations, diversity was considerably higher in forest fragments than plantations (Faria et al. 2006).

2. What habitat features in agricultural landscapes, and at what scale, can be used to mitigate negative effects of agriculture on bat populations?

Whilst there are relatively few studies that have explicitly tested the effects of different agricultural management intensities on bats, there are many more that provide valuable information regarding the types of mitigation that may improve the habitat quality for bats (see also Berthinussen et al. 2014).

274   These can be broadly grouped into i) connective elements; ii) scattered trees and woodland patches;

275   iii) water features, and are discussed in turn below.

276   *i) Connective elements*

277 Studies have repeatedly noted a close affinity of many bats to landscape elements, usually, but not

278 exclusively, consisting of vegetation or water which likely relates to their use for foraging, as

279 shelterbelts and/or protection from predation (e.g. Limpens and Kapteyn 1991; Verboom and Huitema

280 1997; Lentini et al. 2012). It has also been suggested that they are used as navigation aids (Verboom

281 and Huitema 1997), and as such bats with shorter-range echolocation calls might be expected to be

282 more susceptible to habitat fragmentation than those with long-range calls. Frey-Ehrenbold et al.

283 (2013) examined the influence of landscape connectivity across the Swiss Central Plateau between

284 bats with short (e.g. *Plecotus spp.*), medium (e.g. *Pipistrellus* spp.) and long-range (e.g. *Nyctalus* spp.)

285 echolocation calls. Activity was between 1.4 - 2.8 x higher around landscape elements versus open

286 areas for all bats but the difference was most marked for those with short-range echolocation calls.

287 They also found that the shape of elements (i.e. whether it was linear or patchy) was less important

288 than percentage cover in the landscape and how well connected these were. Connective elements,

289 such as hedgerows are a traditional feature of many agricultural landscapes but the expansion and

290 intensification of agriculture in Europe over the past 50 years has led to a substantial decline in their

291 extent and condition (e.g. between 1984-1990, hedgerow loss was estimated at 23% across the UK;

292 Barr and Gillespie 2000). There is a strong association between bat activity levels and the presence of

293 hedgerows and treelines indicating the high potential of these features to improve the quality of the

294 agricultural matrix (Downs and Racey, 2006; Linton et al. in press; Boughey et al. 2011a). This

295 association varies between species, however, with a strong response from *Pipistrellus* spp. but little

296 effect on *Eptesicus serotinus* and *Nyctalus noctula* (Boughey et al. 2011a). There is also evidence that

297 the presence of trees within hedgerows is associated with higher activity levels for some species

298 (Linton et al. in press; Boughey et al. 2011a). A positive correlation between feeding buzzes and

299 hedgerow height, which were taller on organic farms, was proposed as one reason for higher bat

300 activity on organic farms in England, UK (Wickramsinghe et al. 2003). Hedgerow width, however,

301 has not been shown to have an effect of levels of foraging activity (Boughey et al. 2011a).

302

303 "Live fences" are a common feature across large parts of South and Central America, used to

304 delineate boundaries and enclose livestock or crops; these consist of fences established using large

305 cuttings from trees to which strings of wire are attached (Estrada and Coates-Estrada 2001; Harvey et

306 al. 2005). Estrada and Coates-Estrada (2001) compared the bat community at one live fence with three

307 replicates of linear forest fragments in Mexico. Whilst bats were commonly trapped adjacent to the

308 live fence, there was lower species richness and abundance than at forest fragments, and the authors

309 suggested that live fences lack sufficient cover and tree species diversity (although it should be noted

310 that there were potential confounding issues with the live fence also being more isolated from large
311 areas of natural forest than two of three of the forest fragments). Harvey et al. (2005) surveyed bats,
312 dung beetles, butterflies and birds at live fences in Costa Rica and Nicaragua; species richness of all
313 taxa increased with the density of live fences in the landscape, and the capture rate of bats compared
314 favourably to those in forested habitats. In a follow up study, comparing live fences to a range of
315 other habitats, bat abundance at live fences was second only to that of riparian corridors, and
316 considerably higher than secondary forest or pasture habitats; species richness was also marginally
317 higher (Harvey et al. 2006). In agricultural regions of Australia "stock routes", roadside corridors of
318 remnant vegetation, are a common example of connective elements. In one study bat activity was
319 double that of adjacent open fields although there was no difference in species richness or the number
320 of feeding buzzes (Lentini et al. 2012). The authors suggested that bats would benefit from agri-
321 environment schemes that incorporated the use of connective elements, scattered trees, and lower
322 intensity land uses such as unimproved pasture (Lentini et al. 2012).
323
324 *ii) Scattered trees and woodland patches*

325 Scattered trees and small woodland patches are a feature of agricultural landscapes around the world,
326 and numerous studies have indicated their value for biodiversity, including bats (e.g. Henderson and
327 Broders 2008; Fischer et al. 2010a,b; Fuentes-Montemayor et al. 2011a). Declines of farmland trees
328 have been reported in North America, Central America, and parts of southern Europe, partly due to
329 clearance for cropland and also because of ecological and anthropogenic processes leading to heighted
330 mortality and low recruitment (Fischer et al. 2010a). The effect of such losses in Australia has been
331 predicted to lead to declines in birds and bats of up to 50% by 2100 (Fischer et al. 2010a).
332
333 Several countries have introduced financial aid for woodland creation and management in agricultural
334 areas (e.g. woodland grant schemes in EU; revegetation programmes in Australia). The resultant
335 woodland patches are often very small (Fuentes-Montemayor et al. unpublished data) but could
336 potentially help in enlarging existing patches, improve connectivity and increase the permeability of
337 the agricultural matrix. Even fairly low tree densities can result in marked biodiversity benefits, but
338 the relationship between tree density and metrics related to bat abundance differs between studies.
339 Lumsden and Bennett (2005) found that relative abundance, as assessed by trapping, showed a linear
340 increase with increasing tree density, whilst the highest activity of bats was at intermediate tree
341 densities. Fischer et al. (2010b), however, found that the marginal value of trees was highest for both
342 birds and bats when tree cover was at its lowest: compared to treeless sites the presence of 3-5 trees
343 within a 2 ha site was associated with a tripling of bat species richness, and an 100-fold increase in
344 activity. After this point, the marginal effect of additional trees on birds and bats diminished rapidly
345 (Fischer et al. 2010b). A comparison of roosts and random non-roost locations in the U.K. showed

346   that *P. pipistrellus, P. pygmaeus, Rhinolophus hipposideros, E. serotinus* and *Myotis nattereri* were

347   more likely to be found in landscapes with higher proportions of woodland, and that the greatest effect

348   was seen as woodland cover rose from 0 to 20% (Boughey et al. 2011b). Roosts were found closer to

349   broadleaved woodland than expected by chance but importantly, the size of the woodland was not

350   important indicating that even small woodland patches can contribute to improvements in agricultural

351   landscapes (Boughey et al. 2011b).

352   The benefits of woodland creation schemes for bats are likely to take a long time to be realised, but

353   there has been little work on the effect of the age of woodlands on their utilisation by bats. On-going

354   research in the UK suggests that even sites planted with deciduous trees 30-40 years ago have much

355   lower bat activity than older sites (Fuentes-Montemayor et al. unpublished data). Similarly, eucalypts

356   are routinely used in Australia as part of revegetation programmes to stem land degradation and

357   biodiversity loss (Law and Chidel 2006; Australian State of the Environment Committee 2001). An

358   assessment of the benefits of these schemes for bats found that, with the exception of larger (> 10 ha),

359   older (> 10 years) plantings, bat species richness and activity was similar to treeless paddocks and

360   considerably lower than that in native remnants. Similar results, also from Australia, were found by

361   Hobbs et al. 2003 but here the plantations were all very young (4-6 years old). Both studies stress the

362   importance of retaining old native remnants given the low use of young plantations, although there is

363   the potential for realising greater biodiversity benefits from plantations once they have matured

364   which, for eucalypts as fast growing trees, will be earlier than many European deciduous species.

365   There is considerable variation in the responses of different bat species to the extent and character of

366   woodland within agricultural landscapes that reflects their foraging guild; for example, Australian

367   farmland sites with low tree cover were dominated by large, fast flyers, and sites with dense tree cover

368   by smaller, highly manoeuvrable species (Hanspach et al. 2012). They also respond differently to

369   characteristics such as tree density and understorey cover indicating that management of woodland

370   should take into account the needs of the bats present and encourage habitat heterogeneity to fulfil the

371   requirements of different species (Law and Chidel 2006; Medina et al. 2007; Murphy et al. 2012;

372   Fuentes-Montemayor et al. 2013).

373   *iii) Water features*

374   Wetlands are an essential element in the landscape for a wide range of ecosystem services, as well as

375   supporting wildlife populations. High densities of invertebrates associated with water bodies attract

376   large numbers of bats and numerous studies have noted the importance of riparian habitat for foraging

377   and, in more arid environments, for drinking (e.g. Adams and Hayes 2008; Salsamendi et al. 2012).

378   Worldwide, it is estimated that 50% of wetlands have been lost for conversion to agricultural land or

379   industrial and urban areas (Verhoeven and Setter 2010). Some effort is now being made to create and

380   manage wetland areas through agri-environment schemes although few studies have examined the

381 effects of these on bats (but see Fuentes-Montemayor et al. 2011a). However, several studies have

382 examined the use of artificial wetlands by bats, created for a variety of purposes including irrigation

383 and to reduce erosion and which may also mitigate against some of the effects of agricultural

384 intensification on bats. Comparisons of water infrastructures with other habitats indicate that foraging

385 activity is highest over and adjacent to water bodies (Lison and Calvo 2011; Stahlschmidt et al. 2012;

386 Sirami et al. 2013), although it is not possible from these studies to assess how these compare with bat

387 activity at natural wetland features. The characteristics of newly created water bodies are important;

388 Sirami et al. (2013) found activity increased with wetland size in South Africa, whilst Lison and

389 Calvo (2011) suggested that the lack of rarer species detected at irrigation ponds in Spain was

390 probably due to the absence of suitable riparian vegetation.

391 **3. *Is there evidence from studies on the effects of lower intensity agricultural systems that bats***

392 ***are useful indicator species for other taxa?***

393 Other than studies on bats in Neotropical forests (see conclusions) there has been little formal

394 quantitative assessment of whether the response of bats to environmental change co-incides with those

395 of other taxa. Nevertheless, numerous studies have measured the responses of other taxa, in addition

396 to bats, to comparisons between high and low intensity agriculture so are included here (Table 2). The

397 bulk of these were conducted in Europe and consist of invertebrate responses conducted as part of the

398 same study as bats, with the remainder small numbers of responses from birds, other mammals and

399 plants.

400 Whilst Table 2 provides only a crude assessment of how bat responses compare to those of other taxa

401 it does indicate that overall, bats responded in a similar way to other taxa where lower intensity

402 farming consisted of organic farming and agroforestry. The main exception to this was the

403 comparison with carabid beetles (Fuller et al. 2005); in this study bat abundance, species richness and

404 diversity (dominance score) all showed favourable responses to organic farming whilst carabid beetle

405 responses varied according to the metric being used as well as spatial and temporal factors. The

406 picture for agri-environment schemes was more equivocal. There were more instances where bats and

407 other taxa differed in their response to agri-environment measures, but the strength of the sign for

408 association was usually lower than for organic and agroforestry systems. This arises as the response

409 measures for both groups were, in the few studies that compared multiple taxa, similar between agri-

410 environment and conventional farms. The main exception to this pattern was a study where moth

411 abundance was substantially higher at agri-environment scheme farms, but bat activity was

412 considerably higher at conventional farms (Fuentes-Montemayor et al. 2011a,b).

413 A key study missing from Table 2 is that of Pocock and Jennings (2008); this study examined

414 responses of 30 species or other taxonomic groupings, including four species/groups of bat, to three

415 key features of agricultural intensification (use of agrochemicals, the switch from hay to silage, and

loss of boundaries both in cereal crops and grass fields). Rather than include the very high number of comparisons that inclusion in Table 2 would necessitate, a summary of responses for broader taxonomic groupings is provided in the text. Whilst this study was primarily designed to test the sensitivity of taxa to agricultural intensification, it also allows an assessment of how bat responses compare to those of shrews and three orders of insect (Coleoptera, Diptera and Lepidoptera). None of the bats (*P. pygmaeus*, *P. pipistrellus*, *Nyctalus/Eptesicus* spp., *Myotis* spp.) responded to the use of agrochemicals in common with 17 of the 22 other species/groups for which there were sufficient data. Similarly, none of the bats responded to the switch from hay to silage, in common with 15 of the 22 other species/groups for which there were sufficient data. In contrast, all bat groups with the exception of *Nyctalus/Eptesicus* spp. responded negatively to boundary loss as did just over 50% (13/24) of the other species/groups in cereal crops, and over 60% (13/21) in grass fields. So, whilst the conclusions of the study highlight caution in the choice of indicator species regarding their sensitivity to intensification measures, there is at least some evidence that many bats respond in similar ways to quite different taxa. The lack of response from *Nyctalus* and *Eptesicus* species is not unexpected as they are fast flyers who are most active over open habitats and water bodies so may be less dependent on boundaries and other linear features in comparison to other species (Vaughan et al. 1997; Boughey et al. 2011a). The authors conclude that the sensitivity of the taxa examined to changes in agricultural practices was highly variable, and that none could be used alone as indicators of agricultural intensification.

CONCLUSIONS

It is widely acknowledged that conservation initiatives to improve biodiversity on agricultural land have had mixed success, with widely varying responses between taxa and regions (e.g. Hole et al. 2005; Kleijn et al. 2011). A conceptual model developed by Tscharntke et al. (2005) predicts maximum gains from conservation initiatives in relatively simple agricultural landscapes (low diversity, 1–20% non-crop habitat), although these will diminish in completely cleared habitats (< 1% non-crop habitat), and this is broadly in-line with some of the findings reviewed here (e.g. marginal effects of scattered trees, Fischer et al. 2010b; infuence of woodcover cover on location of bat roosts, Boughey et al. 2011b). However, Kleijn et al. (2011) argue that where the aim of management is to maximise biodiversity conservation, the focus should be on land which is already extensively managed and complex as it will be easier to protect degradation of this than to restore areas where biodiversity has already been diminished. Either approach would require a more specific targeting of resources than is currently employed in many countries.

Overall, the paucity of studies and their geographical restriction have limited the ability of this review both to assess the effects of management interventions on bats in agricultural landscapes, and their utility as bioindicators. Nevertheless, there is evidence that bats benefit from lower intensity

451 agricultural systems, specifically organic farming and shaded agroforestry: these systems tend to be
452 associated with higher bat abundance, species richness and diversity, and are more heavily utilised by
453 foraging bats. The picture for the efficacy of agri-environment schemes is equivocal however, with
454 only one study from the four sourced showing any trend, albeit non-significant, towards higher bat
455 activity at farms employing with these schemes (Macdonald et al. 2012b), and one study finding
456 significantly higher activity at conventional farms (Fuentes-Montemayor et al. 2011a). It is not
457 currently clear why these agri-environment schemes do not appear to be benefitting foraging bats but
458 it is possible in some cases the implementation of management and the relatively small scale over
459 which it operates are not sufficient to exert a positive response (Whittingham 2007). In addition,
460 studies designed to assess such effects need to consider whether there may be other differences in
461 management which have not been examined (e.g. some AES involve grazing restrictions which may
462 reduce amounts of organic matter and consequently invertebrate populations), or whether their sample
463 of non-AES farmers, who may be more likely to refuse access, is representative.

464 There was a surprising lack of studies investigating the value of lower intensity or alternative
465 agricultural systems outside of Europe, Central and South America, and the majority of studies came
466 from the UK and Mexico. The top three countries with the most organic agricultural land are Australia
467 (12 m ha), Argentina (3.6 m ha) and the United States (2.2 m ha) but I was unable to find any
468 published studies on the influence of organic farming on bats from these areas. Similarly, there are
469 large knowledge gaps for the several key systems including food crops such as oil palm, soybean, rice
470 and materials, for example, cotton and biofuels. Oil-palm production is currently the greatest threat to
471 biodiversity in Southeast Asia with 1.7-3.0 million hectares of forest cleared in Indonesia between
472 1990-2005 (Wilcove and Koh 2010; FAO 2010). An initiative to develop a more sustainable
473 agricultural system for palm oil (Roundtable on Sustainable Palm Oil 2013) has been launched
474 involving reduced use of pesticides and fires, and a focus on conserving "high conservation value"
475 habitats, but currently this represents a very small fraction of total production. In a landscape being
476 converted to oil palm production, Struebig et al. (2008) assessed the conservation value of forest
477 fragments to Palaeotropic bats. Whilst showing that there was a strong association between fragment
478 size and the abundance and various diversity metrics for bats, they suggested that small fragments
479 could nevertheless contribute substantially to landscape-level bat diversity, and facilitate the
480 movements of some species across landscapes managed for oil palms. Further research on the
481 efficacy, or otherwise of efforts towards sustainability for crops such as these is urgently needed.

482 No studies were sourced on possible effects of aquaculture on bats. Effluent from fish farms can
483 damage the ecosystem nearby and unconsumed feed and faecal matter can result in large
484 accumulations of organic matter in the sediment (Kırkağaç et al. 2009). This could potentially impact
485 upon bats through changes in the prey community or through drinking water.

486   The mechanism through which organic farming benefits wildlife, for the majority of species is not

487   known and potentially could be driven by one of several factors e.g. reduced use of agrochemicals,

488   greater use of rotational practices, taller hedgerows etc (Wickramsinghe et al. 2003). Whilst these are

489   all important features they are not exclusive to organic farming (Hole et al. 2005) and, given the very

490   low percentage of land currently under organic management, our lack of understanding over key

491   drivers which could improve farmland biodiversity is likely hampering efforts to scale-up such

492   benefits. It has been suggested that most of the benefits of organic farming in temperate regions are

493   delivered through overall higher habitat heterogeneity on organic farms rather than any specific

494   prescriptions (Krebs et al. 1999; Benton et al. 2003). Consequently, policy frameworks and farmland

495   management that focus on increasing heterogeneity at multiple spatial scales are likely to be of most

496   benefit for nature conservation in agricultural landscapes. Unfortunately, in many parts of the world

497   the required policy frameworks still do relatively little to stem biodiversity loss; the recently

498   announced EU Common Agricultural Policy reforms, for example, are largely perceived by

499   conservationists as a wasted opportunity and likely to lead to further habitat loss (e.g. RSPB 2013).

500   In line with research on other taxa, the vast majority of studies in this review focussed on metrics of

501   bat abundance and diversity, although in some cases there was also an assessment of rare species or

502   those particularly sensitive to changes in land use. Using differences in species richness or abundance

503   to infer effects of conservation action, however can be problematic due to a range of ecological

504   phenomena including source-sink dynamics, spill over effects and extinction debts (Klein et al. 2011).

505   Information on demographic variables such as sex ratio, breeding productivity and survival would

506   enable much greater insight into the effects of anthropogenic disturbance, and the effectiveness of

507   attempts to mitigate this. Collection of demographic data on wild bat populations is extremely

508   difficult but information on the age and sex of bats captured as part of trapping programmes would

509   enable an assessment of whether only males were using particular areas or if breeding females were

510   present as well. Males may be able to utilise a wider range of conditions as they have lower energy

511   demands than reproductive females and studies on habitat selection have uncovered marked

512   differences between sexes (e.g. Barclay 1991; Altringham and Senior 2005; Saldaña-Vázquez et al.

513   2013; Lintott et al. in review). Equally, information on population structure and diversity from genetic

514   material have revealed that considerably larger areas of undisturbed habitat are needed for conserving

515   genetic diversity than for species diversity (Struebig et al. 2011), but this information is generally

516   lacking.

517   There are several characteristics required for species to be useful bioindicators (McGeogh 1998). This

518   review has examined just one of these; whether responses of bats to lower intensity agricultural

519   systems reflect responses by other taxa. The studies reviewed here indicate that overall, bats

520   responded in a similar way to other taxa and this may be because organic farming and agroforestry

appear to deliver broad beneficial effects for a wide range of species, whilst the studies assessing bat responses to agri-environment schemes found relatively modest, if any, positive effects.

Research in Neotropical forests, primarily on species in the family Phyllostomidae, has previously suggested that the response of bat assemblages to habitat disturbance is not shared by other taxa, which typically are more heavily affected (Pineda et al. 2005; Barlow et al. 2007). Subsequent work in both the Neotropics and Palaeotropics has suggested that partitioning analyses based on foraging or roosting strategies, rather than at the assemblage level, may result in an improved ability to detect responses to land-use changes (Castro-Luna 2007; Struebig et al. 2008). Studies in a wider range of biomes and regions are now needed to assess whether bat responses mirror those of other species (see also Struebig et al. 2008).

In summary, the relatively limited number of studies reviewed here indicates that bats can benefit from some lower intensity agricultural systems and by the inclusion of features, particularly those consisting of woody and aquatic elements to improve habitat quality and connectivity. In relation to the utility of bats as bioindicators, a qualitative assessment suggests that the responses of bats to agricultural change is largely mirrored by those of other taxa. However, the review has revealed large knowledge gaps where future research would be usefully directed:

1. A broader geographical range of studies is needed: evidence on the efficacy of organic systems and agri-environment schemes for bats is limited to Europe, and agroforestry studies have taken place exclusively in Central and South America.
2. As has been previously noted for other taxa (Hole et al. 2005), the underlying mechanism(s) through which bats benefit from organic farming is not clear, and studies to elucidate key drivers are required.
3. Research on the efficacy, or otherwise, of efforts to improve the sustainability of intensively managed crops such as oil palms in areas of high biodiversity is lacking and urgently needed.
4. Studies of the demographic effects of conservation management on bats in agricultural landscapes are urgently needed to aid our interpretation of their impact at the population level.
5. Currently, it is not clear to what extent bats in general, and which species/groups of bats in particular, are useful as bioindicators. Studies quantifying the response of bats and other taxa to environmental change in a wider range of biomes and regions are needed.

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