Amphibians in agricultural landscapes: the habitat value of crop areas, linear plantings and remnant woodland patches

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ABSTRACT

Mitigating the negative impacts of agriculture on amphibians requires knowledge of how different land uses affect species distribution and community composition. In the case of frogs, there is currently insufficient information on their use of terrestrial habitats in cropping landscapes to inform conservation planning. We examined how four different farmland types (linear plantings, cereal crops, grazing paddocks, and woody mulch) and crop harvesting influenced amphibian abundance, richness, body condition and movement. We found the abundance of frogs was significantly higher in linear plantings compared to grazing paddocks and adjacent patches of remnant woodland vegetation. However, species richness and abundance of three individual species did not vary significantly between farmland types. For the most common frog *Uperoleia laeveigata,* body condition was higher at the edges of the woody debris treatment (coupled with higher abundance) and lower in farmland with debris and linear plantings. The body condition of *Limnodynastes tasmaniensis* and *Limnodynastes interioris* was not influenced by farmland type. Frog abundance and condition was largely unaffected by crop harvesting. However, frogs were less common after harvesting at the edges of farmland and within remnant patches. Movement patterns did not suggest mass movement out of crops after harvest, where almost half of all individuals recaptured remained within the farmland. These results suggest that some generalist frog species may have an affinity for habitats within agricultural paddocks, particularly when key habitat features like plantings are present. However, we found overall frog richness was low and did not differ between remnant patches, edges and farmland which may be an indication of habitat degradation within terrestrial habitats across the landscape. Although protection of remnant native vegetation is important, conservation strategies for the protection of amphibians will be ineffective if they do not consider the variety of land uses and the relationships of different species and their microhabitats within and outside of patches.

Keywords: *body condition index, restoration, conservation, matrix, habitat quality, land-use*

1 INTRODUCTION

Demand for agricultural products is driving intensification and expansion of agriculture, reducing and fragmenting habitats and contributing to global biodiversity decline (Thompson *et al.*, 2015, Tilman *et al.*, 2011). In some cases, agricultural landscapes can support moderate to high levels of biodiversity (Mendenhall *et al.*, 2014, Thompson *et al.*, 2015), suggesting there are opportunities for biodiversity conservation in agroecosystems (Benton *et al.*, 2003, Donald and Evans, 2006, Hazell *et al.*, 2004, Pita *et al.*, 2009). Despite well documented sensitivities of many species to modified landscapes (Brotons *et al.*, 2005, Gastón *et al.*, 2016, Knox *et al.*, 2012), the circumstances under which mixed farmland can provide habitat is context and species-specific (Driscoll *et al.*, 2013, Eycott *et al.*, 2010, Prevedello and Vieira, 2010).

In fragmented agricultural landscapes, population viability depends on functional connectivity between suitable habitat patches, with successful dispersal depending on the condition and quality of the intervening land cover types (Driscoll *et al.*, 2013, Youngquist *et al.*, 2017), ecophysiological traits of a species (preferred body temperature, skin permeability and susceptibility to evaporative water loss; Cruz-Piedrahita *et al.*, 2018, Yuan *et al.*, 2018) and species-specific behaviour (Blaum and Wichmann, 2007, Richter *et al.*, 2001). However, quantifying species preferences for particular land cover types remains a fundamental challenge in modified landscapes as some species may disperse through and utilise habitat types that are different to preferred habitat (e.g. remnant vegetation; Cline and Hunter, 2014, Cooney *et al.*, 2015, Driscoll *et al.*, 2013). Further, human-modified land cover can change over time (e.g. simplification of cover by harvesting crops) reducing species dispersal between habitat patches (Kay *et al.*, 2016), mortality risk (Anderson and Burgin, 2008, Ewers and Didham, 2008) and the likelihood of emigrating from patches (Driscoll *et al.*, 2013, Prevedello and Vieira, 2010).

Amphibians are one of the most at-risk groups of taxa in agricultural areas (Arntzen *et al.*, 2017, Cushman, 2006) due to their complex life-history and narrow habitat tolerances, which can make them susceptible to rapid changes in habitat and microclimate (Barrett and Guyer, 2008, Cogger, 2014, Cushman, 2006). Consequently, many amphibians are threatened with extinction worldwide, more so, than any other vertebrata (Thompson *et al.*, 2015, Wake and Vredenburg, 2008). Despite the rapid decline of many species of amphibians (Mendelson *et al.*, 2006), and the significant vulnerability of frogs to habitat modification, data on amphibian responses to land management and revegetation is lacking for many regions and species, particularly in Australia (Hazell, 2003, Nowakowski *et al.*, 2017a, Nowakowski *et al.*, 2017b, Thompson *et al.*, 2015)."

Frog use of, and movement within, agricultural landscapes appears to be influenced by changes within the terrestrial environment (Lamoureux and Madison, 1999, Vos and Stumpel, 1996). While breeding habitat availability can limit frog populations (e.g. breeding habitat; Cushman, 2006), suitable terrestrial habitat is also required for population persistence, and can influence movement between water sources, juvenile dispersal, foraging, over-wintering and aestivation (Cushman, 2006, Feder and Burggren, 1992, Hazell *et al.*, 2001, Mac Nally *et al.*, 2009, Miaud and Sanuy, 2005)

Thus, we should expect changes within the farmland matrix (e.g. simplification of vegetation cover) to regulate amphibian movements and potentially reduce connectivity, limit dispersal, and reduce local and regional population persistence (Cushman, 2006, Mac Nally *et al.*, 2009, Vos *et al.*, 2007).

Here, we examine frog responses to three farmland management elements that provide contrasting resources and conditions likely to influence frog body condition, abundance, richness and movement patterns in cropping landscapes. Our research questions were: (1) *Do* *different farmland types influence amphibian abundance, richness, body condition and movement patterns, in contrast to remnant patches and the edges between farmland and remnant patches*? and, *(2) Does crop harvesting reduce amphibian abundance, richness, body condition and movement between farmland types*?

Habitat use and the effects of landscape change on frogs in agricultural areas have received little attention in less studied regions such as Australia. Knowledge of how frogs use such mixed farming landscapes is limited to frog habitat use in relation to farm dams or constructed aquatic habitat (Hazell *et al.*, 2001, Hazell *et al.*, 2004). In particular, there is little research examining the use of differing modified terrestrial habitats for Australian frogs and how this has been affected by agricultural land use. This information is required to guide appropriate conservation actions based on quantified frog responses to land use change.

2 (Arntzen *et al.*, 2017, Thompson *et al.*, 2015).MATERIALS AND METHODS

2.1 Study area

Our study area was located in central New South Wales, Australia between the following towns: Young: 34° 26' 18.723" S; 148° 10' 54.975" E, Grenfell: 33° 55' 58.249" S; 147° 53' 48.729" E, Ardlethan: 34° 10' 34.776" S; 146° 50' 7.522" E; Fig. 1). Clearing for agriculture has resulted in extensive loss of native eucalypt woodland vegetation and replacement with intensive cereal cropping (wheat, canola, lupin and barley) and livestock grazing (sheep *Ovis aries* and cattle *Bos taurus*. The dominant native vegetation types within remnant patches of woodland in the western part of our study area include mallee woodland and shrubland, with some white cypress pine (*Callitris glaucophylla*). The eastern part of our study area is dominated by patches of box gum and white cypress pine woodland, including the threatened white box (*Eucalyptus albens*), yellow box (*E. melliodora*), blakely's red gum (*E. blakelyi*) woodland and derived grasslands.

2.2 Study design

We selected ten study sites, each incorporating a single block design comprising a remnant patch of native vegetation surrounded by four contrasting farmland types (Fig. 1):

1) *Cropping* paddock: Wheat crops and some barley. All paddocks were subject to harvesting.
2) *Rested* paddock: Open paddocks with a mix of native and exotic grasses. Mostly cleared of canopy and mid-story vegetation with occasional, scattered paddock trees (Fig. 1). All paddocks were grazed by livestock either sheep or cattle.
3) *Linear planting*: Linear strip of vegetation between 15 - 30 m wide comprising primarily *Acacia* mid-storey with occasional eucalypts and a mix of exotic and native grassy groundcover. All plantings were subject to occasional grazing by sheep.
4) *Woody debris*: An experimental treatment where a linear strip of native woody mulch was patchily applied to a cereal cropping paddock at each site immediately after harvesting. Woody mulch comprised processed blue mallee (*E. polybractea*) (hereafter "woody debris"). We patchily applied between 20 and 25 tonnes of woody debris (per site) to a harvested crop paddock to examine if we could increase ground layer complexity and temporarily increase frog movement in crop paddocks (Fig. 1). Mulch material was used due to the practical limitations of larger material (e.g. logs and branches) obstructing cropping machinery.

2.3 Sampling amphibians

At each study site, seven trap arrays were spaced along 400 m transects centred on, and running perpendicularly to the edge of the remnant patch, with arrays placed at the edge (0 m) and 20 m, 75 m and 200 m in both the remnant patch and the adjacent farmland type and woody mulch treatment (Fig. 1C). Each array consisted of four traps, with two pitfall traps and two funnel traps on both sides of a 15 m long and 0.35 m high drift fence (five metre spacing between traps).

Traps were opened for six days and five nights for two periods during spring (‘pre-harvest’; before the harvesting of crops) and two periods during summer (after the harvesting of crops; Fig. 1D). Pre-harvest surveys were completed between late September and early December 2014 and coincided with mid and high growth phases of crops. Post-harvest surveys were completed between January and March 2015. A total of 1,120 trap days was completed across all sites per survey, equating to 672 trap days per site across the entire survey period.

All animals were individually marked using Visible Implant Elastomer (Smith *et al.*, 2012) to examine movement patterns, and then measured and released ten metres from the trap array on the opposite side of where the individual was captured to reduce barriers the drift fence may represent to normal animal movement.

2.4 Analysis

We examined the effects of farmland type, habitat type and harvesting on the relative abundance and richness of frogs by fitting generalized linear mixed models (GLMM) with a Poisson distribution and a log link (McCullagh, 1984, Nicholls, 1989). Our response variables were total amphibian species abundance and richness. The main effects and the two and three-way interactions between treatment (four farmland types; crop, planting, pasture, and woody debris), habitat type (remnant, edge, and paddock) and harvesting period (before and after harvesting) were fitted as fixed effects. Given the spatial clustering of the sites, wide distances between clusters, and to account for broad climatic differences (e.g. climate and geographic variation), three regions (“region”) were fitted as an additive fixed effect in all models. Site number, a unique transect number, and a unique trap number were fitted as random effects to account for site variation and repeated sampling of traps.

To investigate if body condition was influenced by differences in habitat quality, we calculated a residual body condition index (hereafter BCI) following the methodology of Băncilă *et al.* (2010) and Scheele *et al.* (2014). Body weight (grams) of each species was regressed against snout-urostyle length (SUL), and where this relationship was curvilinear both were $\log_{10}$ transformed. We plotted the residuals to verify the data were normally distributed, and inspected the residual vs. fitted plots to verify the residuals were randomly distributed compared to the fitted values. We applied linear modelling after outliers were removed from the dataset (i.e. cases where body weight and SUL where clearly not credible and likely explained by a sick individual or measurement error) to individual log-scaled BCI as the response variable and the interaction between treatment, habitat and harvesting as explanatory variables. Remnant patch size (mean 5240.89 ± SE 3003.3 ha) and rainfall was found previously not to have an effect on frog species richness and abundance and thus was not considered further in this study (N. A. Hansen unpublished).

For all analyses, we calculated *P*-values using the 'Anova' function in the 'car' package to reveal significant components and interactions of the model (Bates *et al.*, 2013). Post-hoc analysis of significant interactions was calculated using the 'lsmeans' function (Lenth, 2016) and the results of this test are shown on all plots. All analyses were completed using R 3.3.2 (R team 2016) .

3 RESULTS

We captured 410 individuals from seven species, of which six were from the Myobatrachidae family, and one species from Hylidae family (Table 1) (Fig. S1). Three species accounted for 89% of all observations: smooth toadlet, *Uperoleia laevigata*; spotted grass frog, *Limnodynastes tasmaniensis,* and giant banjo frog, *L. interioris* (Table 1). Species richness per site ranged from one to five species (mean total frog richness = 4 ± 0.4SE), and total capture rate ranged from four to 123 (mean total frogs = 41 ± 13.9SE) individuals per site.

Total frog abundance and richness was higher in the eastern region of Young compared to the other regions ($P < 0.03$) (Table S1; Fig. S2). Three frog species were captured in sufficient numbers for body condition analysis: *L. tasmaniensis, L. interioris* and *U. laevigata,* (see Table 1).

3.1 Frog responses to farmland type and crop harvesting

We found frogs within farmland were more abundant in linear plantings compared to adjacent remnant patches, rested paddocks and the edges of rested paddocks ($P < 0.01$) (Tables S1 and S3; Fig. 2A), although most species were recorded infrequently across all habitat types (Table 1 and Fig. S1). We found no association between species richness and farmland type ($P = 0.42$) (Table S1). While we found frogs were generally less common after harvesting ($P < 0.02$) (Table S1), there was no interaction between harvesting and treatment, or habitat ($P > 0.31$) (Table S1).

Of the three most common amphibian species, *U. laevigata* was not significantly associated with one farmland type over another, but was more common in linear plantings compared to adjacent remnant patches ($P < 0.01$) (Table S1 and Fig. 2B). Greater numbers of *U. laevigata,* in higher body condition, also were found at the edge of woody debris transects compared to remnant patches or within the debris and plantings ($P<0.01$) (Tables S2 and S4; Fig. 2B and 3B). *Uperoleia laevigata* had higher values for body condition after harvest of crops, along crop transects ($P < 0.01$) (Table S2 and Figure 3A) and a tendency to be in poorer condition in remnant patches before harvesting (Fig.4A).

For *L. tasmaniensis,* there was a three-way interaction of body condition between treatment, habitat and harvesting but only for one pairwise comparison, where body condition was variable across remnant patches particularly prior to harvesting (Fig. 4B) with no clear ecological interpretation.

3.2 Movement responses to farmland type and crop harvesting

Of the seven species captured (Table 1), two species were recaptured (Table S5). Twenty-five individuals from the species: *U. laevigata* (n = 19) and *L. tasmaniensis* (n = 6) were recaptured. For all individuals recaptured, *U. laevigata* moved on average 149.5 m (± 37.8SE), while *L. tasmanensis* moved on average 39.2 m (± 29.6SE). Of these recaptures, 48% (n = 12; *L. tasmaniensis* (3), *U. laevigata* (9)) remained in the farmland type in which they were first captured, 16% (n=4; all *U. laevigata*) moved from one farmland type to another, 20% (n = 5; all *U. laviegata*) moved from the farmland into the patch and 16% (n = 4; all *U. laevigata*) moved from the remnant patch into the farmland (Table S5).

4 DISCUSSION

Few empirical studies have examined the relative importance of differing land uses and adjacent remnant patches for frogs in agricultural landscapes. Contrary to results from previous comparable studies (Bowen *et al.*, 2007, Collins and Fahrig, 2017, Rothermel and Semlitsch, 2002), we found that while frog abundance was positively associated with linear plantings, species were generally ubiquitous throughout farmland, edge habitats and remnant patches. There also was no evidence of a significant effect of habitat or farmland type on overall frog species richness. These results reflect the dominance of the overall amphibian assemblage by a few common species, notably *L. tasmaniensis, L. interioris* and *U. laevigata* (Table 1), all of which are widespread habitat generalists or able to persist in disturbed environments (Cogger, 2014, Ocock and Wassens, in press).

By examining both remnant patches and farmland, our results suggest that highly modified agricultural paddocks probably provide habitat for generalist frog species and that some frogs can move through a range of different farmland types. The common frog species, *U. laevigata* also showed a range of responses, including higher abundance in linear plantings. Our results indicate that it may be simplistic to assume highly modified farmland types are complete barriers to dispersal for frogs (Arntzen *et al.*, 2017) with some species using a range of habitats to persist in agricultural landscapes.

4.1 Impacts of farmland type and crop harvesting on frogs

Overall, we found most frogs exhibited limited response to farmland type and crop harvesting. This was an unexpected result given the high contrast of farmland compared to native vegetation and lack of extensive cover (Hazell *et al.*, 2001, Urbina-Cardona *et al.*, 2006), but likely because many of the frog species were generalist, disturbance-associated species and able to persist in a variety of habitats (Cogger, 2014, Hazell *et al.*, 2004). Agricultural practices create a dynamic environment which favour amphibian assemblages with a wider range of environmental tolerances, than specialist species with narrower habitat tolerances (Rittenhouse and Semlitsch, 2006, Semlitsch *et al.*, 2009, Youngquist and Boone, 2014), which could result in reduced sensitivity to differing habitats. Moreover, similar patterns have been recorded of the spatial distribution of habitat generalist frog species in anthropogenically modified habitats overseas (D'Amore *et al.*, 2010, Nowakowski *et al.*, 2018, Youngquist and Boone, 2014), however examples within Australia are scarce.

We found that overall frog abundance was significantly greater in linear plantings, relative to rested-pasture paddocks. Overall frog abundance (all species), and the abundance of at least one species, *U. laevigata,* also was higher in plantings compared to remnant patches. Globally, linear plantings have been shown to positively benefit other groups of native biota including reptiles (Jellinek *et al.*, 2014, Mendenhall *et al.*, 2014, Michael *et al.*, 2011, Pulsford *et al.*, 2017, Thompson *et al.*, 2015), birds (Lindenmayer *et al.*, 2010, Lindenmayer *et al.*, 2016) and small mammals (Bennett, 1990, Šálek *et al.*, 2009). Woodland cover is considered to provide important habitat for amphibians in modified environments (Hazell *et al.*, 2004, Laan and Verboom, 1990). The permanent structures and microhabitat within linear plantings probably act as important habitats for foraging (Hazell *et al.*, 2001, Hecnar and M'Closkey, 1996), overwintering (Lamoureux and Madison, 1999) and refugia during drier conditions. Plantings may be providing useful shelter for non-burrowing species, such as *L. tasmaniensis* and *Uperoleia* spp., and may even facilitate their persistence in adjacent cropping areas.

Pastures have been considered as highly quality habitat for some amphibians in production landscapes because of the presence of artificial waterbodies (e.g. dams) which support reproduction and movement (Hazell *et al.*, 2004, Mendenhall *et al.*, 2014). However, these habitats had the lowest frog abundance, similar to the findings of Urbina-Cardona *et al.*

(2006), and suggest pastures are not ideal habitat for the maintenance of amphibians in mixed cropping areas.

Previous studies of small-bodied amphibian species, similar to *U. laevigata* and which have terrestrial development and affinities for water, have found similar woodland and forest affiliations (Becker *et al.*, 2007, Dixo and Metzger, 2010, Mendenhall *et al.*, 2014). Desiccation risk from high temperatures and the low canopy cover typical in cleared agricultural landscapes, may be a biological filter for these species. Larger bodies species like, *L. tasmaniensis, L. interioris,* may have a greater ability to reduce their desiccation rate and can therefore frequent multiple modified habitats. Further work is required to understand what specific characteristics pertain to a survival advantage for individuals persisting in human modified landscapes.

Contrary to our expectations (Davis *et al.*, 2010, Manning *et al.*, 2013), the application of fine woody mulch did not result in more frogs within paddocks. Low capture rates within woody mulch may be due to the short time frame between application of mulch and field surveys, or the high mobility of the frogs across the farmland reducing capture rate. Previous studies have found the length of time that debris is in place, and the size and shape of the debris, can influence amphibian responses to debris application (LeGros *et al.*, 2014, Ober and Minogue, 2007, Rittenhouse, 2007). We found higher body condition of *U. laevigata* at the edges of the woody debris treatment in contrast to remnant patches or within the mulch but this cannot be interpreted beyond highlighting the potential importance of preferred microhabitat which may encourage frogs into farmland (Cogger, 2014, Hazell *et al.*, 2001, Manning *et al.*, 2013). Tracking experiments (e.g. radio-tracking) would be required to determine when areas of mulch are utilised, identify any important microhabitat that it may provide, and to determine any threats frogs may be exposed to in this edge environment and within mulch (e.g. predation).

We expected that the presence of crops should provide an influx of invertebrate prey resources for frogs, which should result in higher abundance and richness in farmlands with crops (Collins and Fahrig, 2017), and the converse response when resources are rapidly removed such as after cropping (Blomquist and Hunter Jr, 2010, Rittenhouse *et al.*, 2009). Our results did not suggest frogs were affected by the short-term impacts of crop harvesting and some individuals persisted in crop paddocks after harvesting (Table S5). This may be because the species recorded are known to be highly mobile, with the ability to utilise disturbed habitat including agricultural paddocks (Cogger, 2014, Hazell *et al.*, 2001, Ocock and Wassens, in press). We speculate that some species also may be able to persist in farmland by intermittently using nearby permanent habitat (remnant patches and plantings; Blomquist and Hunter Jr, 2010), or by hiding in deep soil cracks in paddocks (pers. obs). Therefore, it is likely that these species can opportunistically move around agricultural paddocks between harvesting periods. Thus, the patchy distribution of essential resources may have important implications for those individuals to persist in crop areas. We suggest that to fully understand the effects of mixed farming on the distribution of amphibians, there is a need for long-term monitoring of individual ranging behaviour (e.g. direct tracking; Cushman, 2006) at different times during the crop growing season and after harvest (Collins and Fahrig, 2017).

The presence of historical records for twelve additional frog species we failed to record in our surveys suggest that some species, including those with specialised habitat requirements, may have already been lost from our study landscape or are too rare to detect (our study area encompasses the edge of several species' ranges) (Flemons *et al.*, 2010, OEH, 2017). Two species notably absent were the threatened Sloane's froglet Cr*inia sloanei* and near-threatened Bibron's toadlet *Psedophryne bibronii* (Table S6). Both species are likely to be strongly affected by changes in habitat and require complex ground cover and connectivity via wet areas (e.g. inundated grassland, irrigation channels, drains) to move across the landscape (Cogger, 2014). The combination of the variable climate of inland Australia, and the replacement of intact native vegetation with open, exposed cropland and homogenous pastures is likely to have created unsuitable conditions for these species (Hazell *et al.*, 2004, Hero *et al.*, 2006). However, the low diversity of amphibians found within our study may reflect our survey focus on terrestrial environments located away from other landscapes elements such as riparian environments and water bodies. More broadly, the species we recorded (Table 1) are lentic waterbody breeders, and proximity to, and quality of, aquatic habitat could influence the occurrence and abundance of frogs within our terrestrial trap sites (Hazell et al., 2001). However, exhaustive surveys of aquatic breeding habitat were outside the scope of our study and would require a different approach due to the propensity for frogs to breed in small ephemeral ponds that are difficult to locate in our study landscape. Further work should focus on the effects of land use variation and breeding habitat availability to better understand the processes that lead to variation in amphibian composition and occurrence in human-modified landscapes.

4.2 Conclusions

The persistence of many amphibians in modified agricultural landscapes depends on their ability to traverse contrasting farmland types. The dominance of generalist species, regional scale of the study, and lack of species with specialised niche requirements may have reduced our ability to detect site-specific changes that may influence amphibian populations. However, our results suggest the influence of crop harvesting, and highly modified areas may be less detrimental, or less resource depleted, for some species than previously assumed. Farmland areas may provide good quality habitat allowing movement, dispersal, foraging opportunities and potentially contribute to amphibian conservation (Youngquist and Boone, 2014). Further, particular landscape elements like plantings may be important for facilitating maintenance, long-term persistence and movement of frogs in farmland by increasing shade cover and generating litter substrate. Several studies suggest conservation strategies for frogs should be based on protecting breeding areas, such as creating buffers around wetland, riparian and revegetated areas (Cushman, 2006, Rothermel and Semlitsch, 2002). While these areas are critically important habitat, our results suggest non-breeding habitat in modified farming areas also needs to be conserved.

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Table 1 The total number of amphibian species detected across sites and the number of species occupied by each site (n=10). C=crop farmland type; LP = linear planting farmland type; P= rested farmland type and WD=woody debris farmland type.

Species	**No. of captures (%)**	**No. of sites captured (%)**	**C**	**LP**	**P**	**WD**
Crinia parinsignifera (Eastern sign-bearing froglet)	2 (0.49)	2 (20)	0	0	2	0
Limnodynastes tasmaniensis (Spotted marsh frog)	153 (37.32)	7 (70)	46	28	34	45
Limnodynastes fletcheri (Long-thumbed frog)	18 (4.39)	5 (50)	3	3	11	1
Litoria caerulea (Australian green tree frog)	4 (0.98)	2 (20)	0	2	0	2
Limnodynastes interioris (Giant banjo frog)	45 (10.98)	9 (90)	13	20	3	9
Neobatrachus sudelli (Sudell's froglet)	21 (5.12)	6 (60)	9	3	6	3
Uperoleia laevigata (Smooth toadlet)	167 (40.73)	9 (90)	41	55	23	48

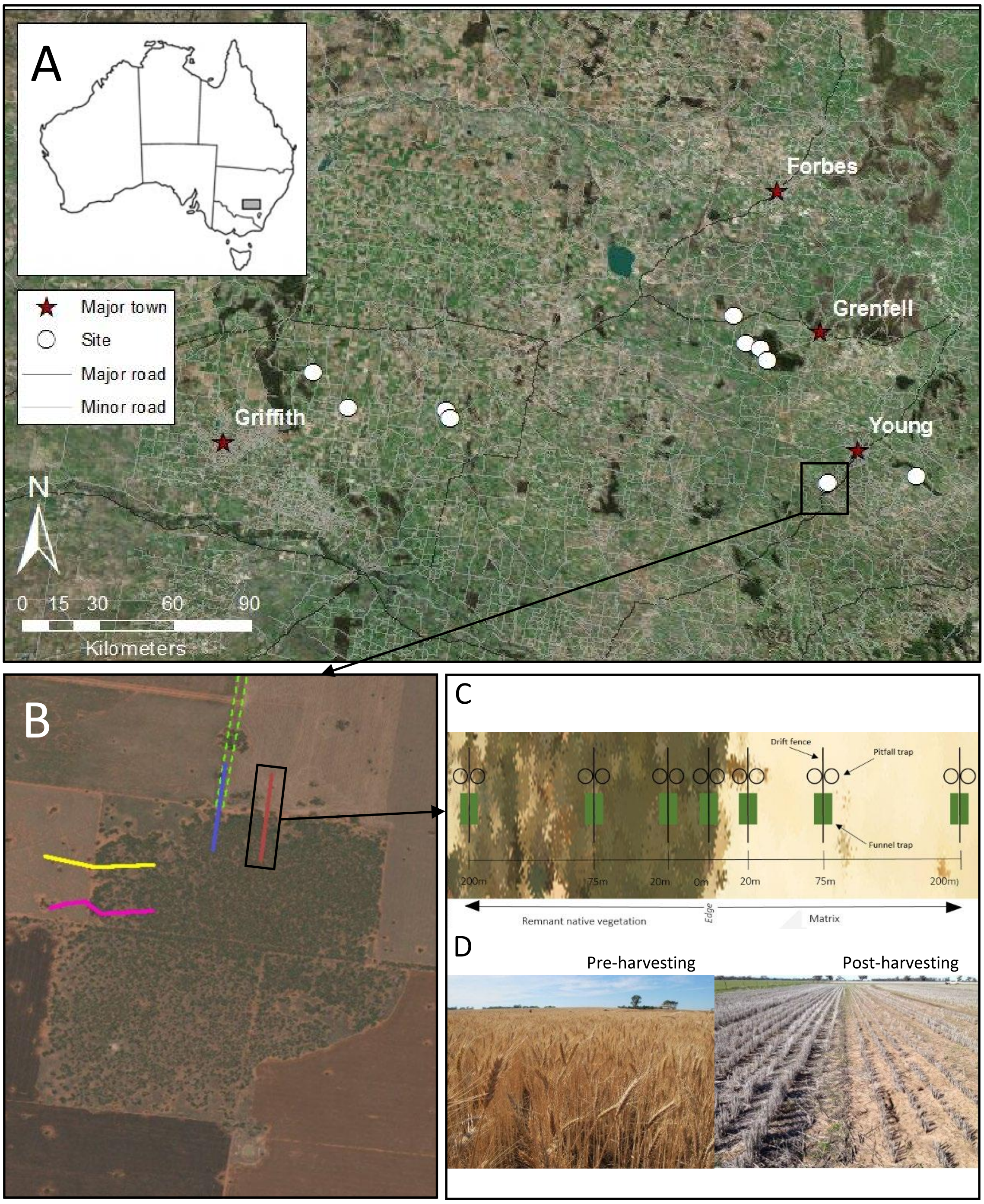
Fig. headings

Fig. 1 (A) Study region and location of ten study areas within New South Wales, Australia. (B) Site layout showing transects extending from a remnant patch into four farmland types (coloured lines). (C) Trap layout and configuration for each treatment. (D) Example of a crop paddock before and after harvesting.

Fig. 2 (A) Frog abundance and the relationship between habitat type and treatment. Error bars indicate 95% confidence intervals and fitted estimates are plotted on the x axis. Letters indicate post hoc comparisons for significant interactions; (B) *U. laveigata* abundance and the relationship between habitat and treatment. Letters indicate post hoc contrasts and error bars indicate 95% confidence intervals with fitted estimates are plotted on the x axis.

Fig. 3 (A) Body condition of *U. laveigata* and the relationship between treatment and harvesting. Letters indicate post hoc contrasts and error bars indicate 95% confidence intervals with fitted estimates are plotted on the x axis; (B) Body condition of *U. laveigata* between the habitat type and treatment. Letters indicate post hoc contrasts and error bars indicate 95% confidence intervals with fitted estimates are plotted on the x axis.

Fig. 4 (A) Body condition of *U. laveigata* and the relationship between habitat and harvesting. Letters indicate post hoc contrasts and error bars indicate 95% confidence intervals with fitted estimates are plotted on the x axis; (B) Body condition of *L. tasmaniensis* and the three-way interaction between treatment, habitat type and harvesting. Letters indicate post hoc contrasts and error bars indicate 95% confidence intervals with fitted estimates are plotted on the x axis.


A
Major town
Site
Major road
Minor road
Forbes
Grenfell
Griffith
Young
N
0
15
30
60
90
Kilometers
B
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Drift fence
Pitfall trap
Funnel trap
200m
75m
20m
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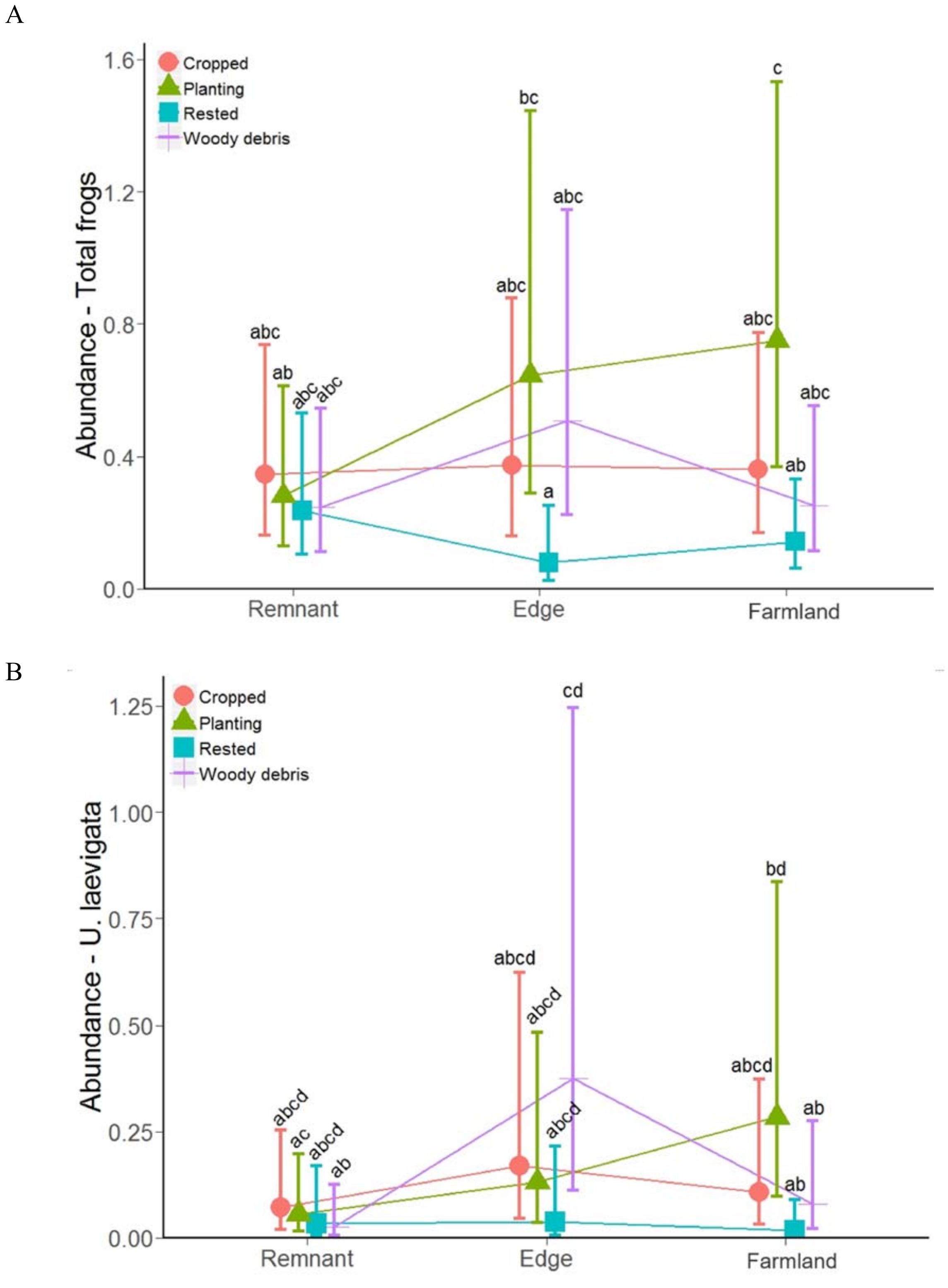
20m
75m
200m)
Remnant native vegetation
Edge
Matrix
D
Pre-harvesting
Post-harvesting

Fig.1


A
Cropped
Planting
Rested
Woody debris
Abundance - Total frogs
1.6
1.2
0.8
0.4
0.0
Remnant
Edge
Farmland
abc
ab
abc
abc
bc
abc
abc
a
c
abc
abc
ab
B
Cropped
Planting
Rested
Woody debris
Abundance - U. laevigata
1.25
1.00
0.75
0.50
0.25
0.00
Remnant
Edge
Farmland
abcd
ac
abcd
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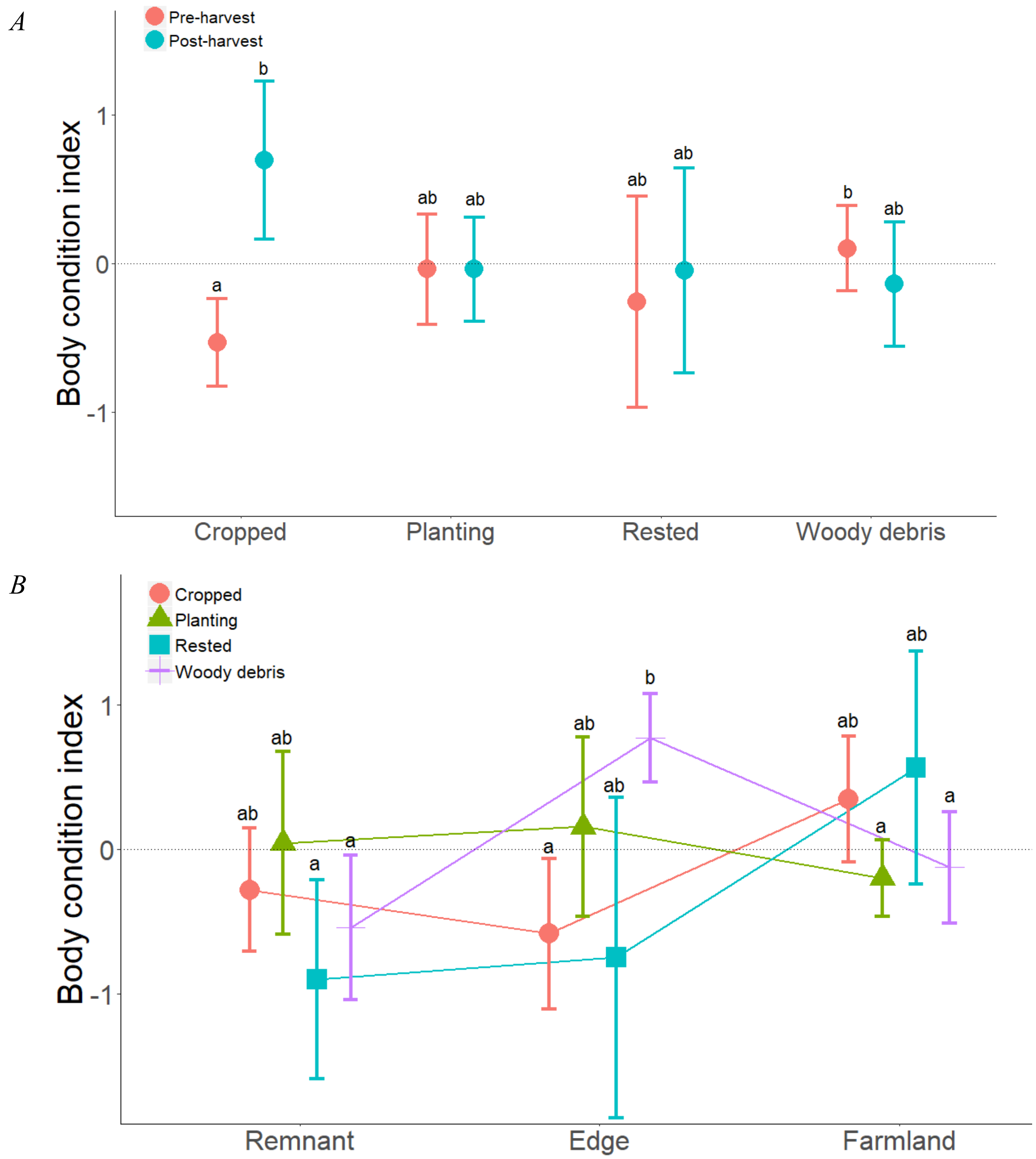
ab

Fig. 2


A
Pre-harvest
Post-harvest
Body condition index
1
0
-1
a
b
ab
ab
ab
ab
b
ab
Cropped
Planting
Rested
Woody debris
B
Cropped
Planting
Rested
Woody debris
Body condition index
1
0
-1
ab
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a
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ab
a
ab
b
ab
ab
a
a
Remnant
Edge
Farmland

Fig. 3

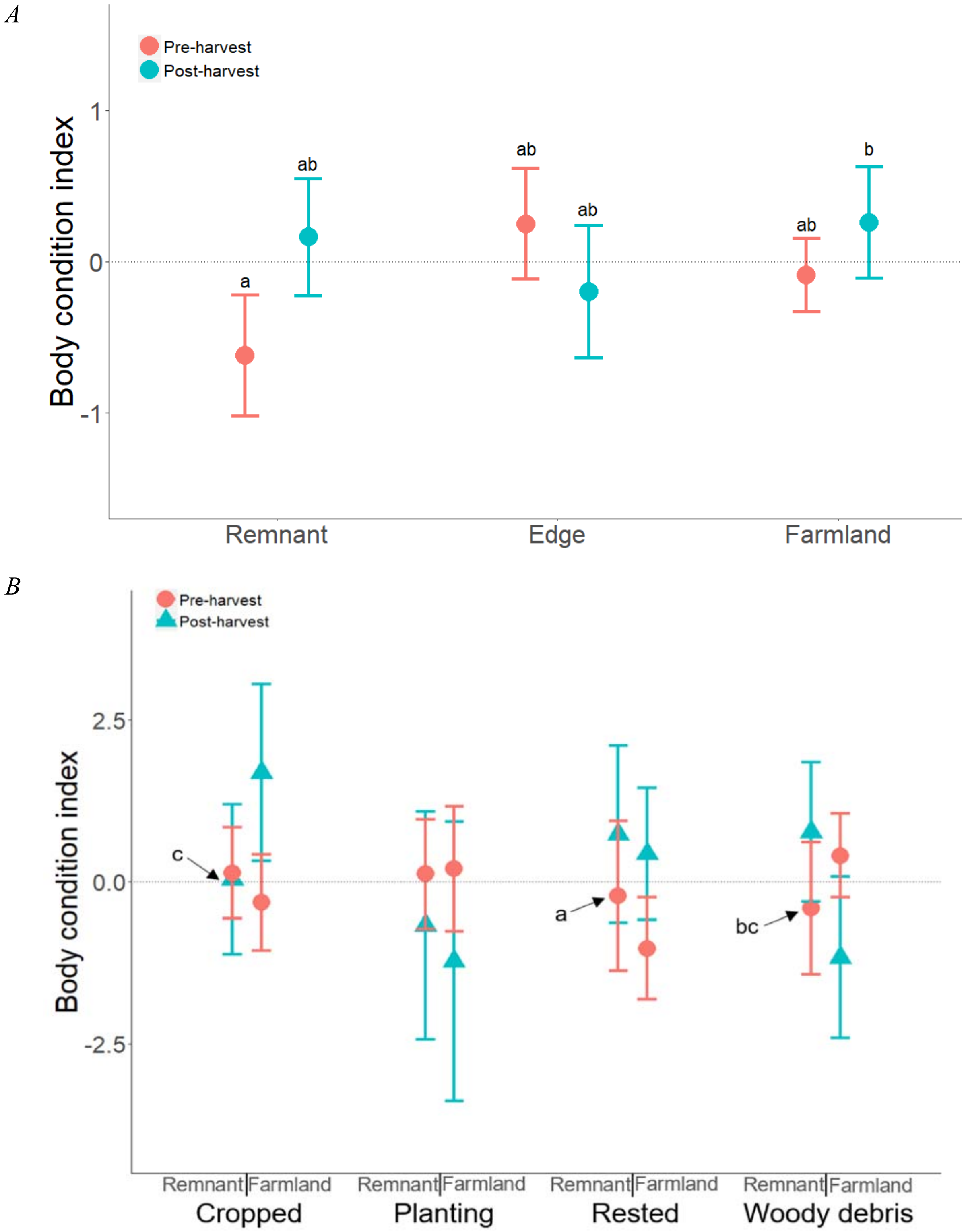
A
Pre-harvest
Post-harvest
Body condition index
1
0
-1
a
ab
ab
ab
ab
b
Remnant
Edge
Farmland
B
Pre-harvest
Post-harvest
Body condition index
2.5
0.0
-2.5
c
a
bc
Remnant
Farmland
Cropped
Remnant
Farmland
Planting
Remnant
Farmland
Rested
Remnant
Farmland
Woody debris

Fig. 4