Available online at www.sciencedirect.com

SCIENCE @ DIRECT®

Agriculture, Ecosystems and Environment 116 (2006) 289–292

Agriculture Ecosystems & Environment

www.elsevier.com/locate/agee

Short communication

Pollinators provide economic incentive to preserve natural land in agroecosystems

Lora A. Morandin *, Mark L. Winston

Department of Biological Sciences, Simon Fraser University, Burnaby, BC, Canada V5A 1S6

Received 24 May 2005; received in revised form 7 February 2006; accepted 23 February 2006
Available online 5 April 2006

Abstract

Natural habitats are considered inherently indispensable to the global economy by conservationists, but few natural ecosystems afford direct and quantifiable economic benefits. Quantification of natural land value can provide compelling evidence favoring preservation over development. Wild bees are important pollinators of many crop plants, and natural patches in agroecosystems enhance pollinator services and crop yield. Bee abundance was greatest in canola fields that had more uncultivated land within 750 m of field edges and seed set was greater in fields with higher bee abundance. A cost–benefit model that estimates profit in canola agroecosystems with different proportions of uncultivated land is presented. Yield and profit could be maximized with 30% of land uncultivated within 750 m of field edges.

Keywords: Pollination; Wild bees; Canola; Sustainable agriculture; Natural land reserves; Crop yield; Ecosystem services

1. Introduction

Conversion of land for agriculture is one of the major causes of diminishing natural ecosystems and biodiversity globally (Banaszak, 1978; Vitousek et al., 1997; Lambin et al., 2001). Natural patches within and surrounding cropland often are viewed negatively by producers as a source of weedy plants and other pest species. But conservationists view natural patches differently, as providing biodiversity refuges and habitat corridors (Tscharntke et al., 2002). Pollinating insects such as wild bees, benefit from natural areas in agroecosystems (Roubik, 1995), yet despite the economic contribution of wild bees to crop production (Kremen et al., 2002, 2004; Ricketts et al., 2004), they rarely are considered in agricultural landscape planning. Economic valuation of ecosystem services can be used as incentive for natural land preservation, benefiting biodiversity, agricultural production and ecosystem processes. The hypothesis that natural land preserves in agroecosystems can give significant economic benefit to growers by promoting wild bee populations that enhance seed production and yield was tested.

2. Methods

In July of 2002 and 2003, wild bee populations, surrounding habitat and canola seed production near La Crete, Alberta, Canada (~58°N, 116°E) were examined. The area was aspen parkland and was being cleared rapidly for agriculture. In 2002 four non-transgenic, conventional (cv. 45A71; Advanta Seeds, Winnipeg, MN, Canada), four genetically modified herbicide tolerant (GMHT) no-till (cv. DK3235; Monsanto, St. Louis, MO, USA), and four GMHT regularly tilled (cv. DK3235) canola fields (*Brassica napus* L.) were assessed. In 2003 five conventional (cv. CL289; Advanta Seeds, Winnipeg, MN, Canada) and five GMHT (cv. DK3235) canola fields were assessed. All fields were 800 m × 800 m (quarter section, 64 ha) and collection locations were measured from a chosen hedge row. In each field there were two collection locations at 20, 200, and 500 m from the hedge, 200 m apart and 300 m from either

* Corresponding author. Tel.: +1 250 388 0819.
E-mail address: lmorandi@sfu.ca (L.A. Morandin).

0167-8809/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.agee.2006.02.012

lateral edge of the field. Pollination effectiveness of wild bee populations was assessed by comparing seed set from open pollinated and supplementally pollinated flowers (Morandin and Winston, 2005). Six pairs of plants were selected at each collection location with three control flowers on each plant and three experimental flowers on one plant per pair, for a total of 324 flowers per field (216 control flowers and 108 experimental flowers) (Morandin and Winston, 2005). Control flowers were marked but not manipulated in any other way and experimental flowers were marked and manually pollinated with pollen from adjacent plants. Bee abundance was assessed using pan trapping and sweep netting (Morandin and Winston, 2005). Each field was sampled with yellow, blue, and white pan traps once during bloom for 48 h. Standardized sweep net samples were conducted in each field, on days that were mostly sunny, when the temperature was above 18 °C from the beginning to the end of the collection period (see Morandin and Winston, 2005 for more detailed description of methods).

3. Results and discussion

There was a strong, diminishing returns relationship between bee abundance estimates in fields and seed set (Fig. 1). A similar relationship was found in a subset of the 2002 data (Morandin and Winston, 2005). Fields with moderate to high bee abundance had close to maximum yields, with seed set deficits that approached zero. Canola varieties in this study had a mean (±S.E.) potential seed set of 25.0 ± 0.2 seeds/pod with full pollination (n = 2350 from 22 fields), but mean (±S.E.) actual set was 18.1 ± 0.2 seeds/pod (n = 4708 pods from 22 fields). Even more substantial losses of seeds due directly to lack of pollen transfer were evident in a number of fields. For example, one GMHT field in 2002 had a mean number of seeds/pod of 10.2 ± 0.7 from open pollinated flowers (n = 216), and 23.3 ± 0.6 from supplementally pollinated flowers (n = 108), a loss of greater than 50% of seeds due directly to poor pollination. This field also had one of the lowest bee abundance estimates (bee abundance index: 6).

Bee abundance previously was found to increase with increases in both weed cover in fields and uncultivated land around fields (L. Morandin, unpublished data). Uncultivated land amounts from a 250 to 1500 m scale around fields at increments of 250 m were analyzed in relation to bee abundance and it was determined that a scale of 750 m was most predictive of in-field bee abundance. In addition, a study on bumble bee (*Bombus*) foraging ranges in the UK, using microsatellite markers, found that maximum foraging ranges in agricultural areas were between 449 and 758 m (Darvill et al., 2004) and a study on foraging ranges of 16 species of non-*Bombus* bees showed maximum foraging ranges between 150 and 600 m (Gathmann and Tscharntke, 2002). Analysis of land within 750 m of field edges in conventional and GMHT canola fields in this study indicated that seed production and crop yield could be increased by greater amounts of uncultivated habitat (Fig. 2).

The importance of natural land to crop yield is not unique to canola crops. Similar relationships have been found in watermelon (Kremen et al., 2004) and coffee (Ricketts et al., 2004) agricultural landscapes where pollen deposition and crop yield were positively related to the amount of uncultivated land in proximity to fields, indicating a pervasive association between crop production and pollination services provided by wild bees from natural areas.

Given these relationships between bee abundance, seed deficit from inadequate pollination, and uncultivated land, the potential economic benefit of uncultivated area in a typical canola agroecosystem was calculated. Mean seed set in open-pollinated canola fields was 18.1 ± 0.2 seeds/pod. Mean amount of uncultivated land within 750 m of field edges was 91.1 ± 12.0 ha (n = 22 fields). The rest was composed primarily of tilled field crops. In 2002 and 2003,

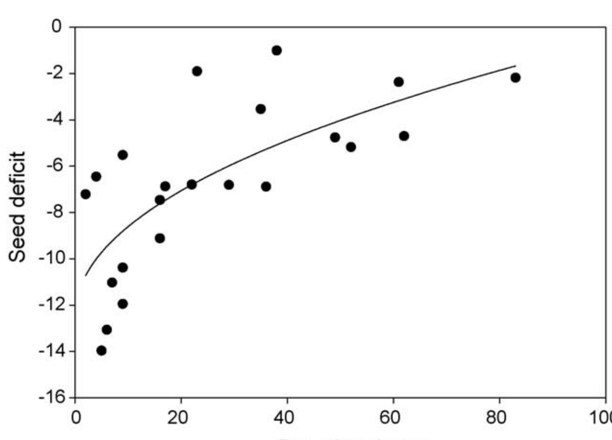

Fig. 1. Seed deficit in relation to bee abundance. There was a diminishing returns relationship ($f(x) = -12.54 + 1.29x^{0.48}$, $r^2 = 0.50$) between bee abundance and seed deficit.

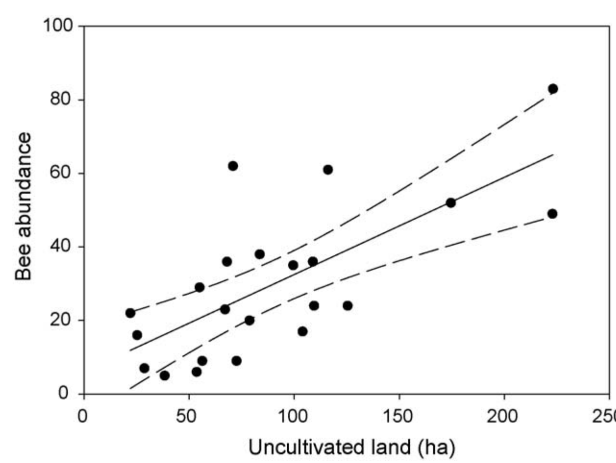

Fig. 2. Wild bee abundance in conventional and genetically modified herbicide tolerant canola fields in relation to the amount of uncultivated land within 750 m of field edges. $f(x) = 6.06 + 0.264x$, $r^2 = 0.51$, $F_{1,20} = 20.87$, $P = 0.0002$.

the GMHT and conventional varieties in the study area yielded an average of 1120, 1568, 1344 and 1568 kg/ha, respectively (AG, 2005). Taking an average yield of 1400 kg/ha, a typical quarter section (64 ha) of canola would yield 89,600 kg. Prices for canola seed have fluctuated between US$ 0.22 and 0.39 kg^{-1} for the last 5 years (ACPC, 2005). Using a typical but conservative price estimate for the 2002 and 2003 seasons of US$ 0.27 kg^{-1}, gross revenue was US$ 24,192 per quarter section. Approximately US$ 17,000 of this was input costs, resulting in a profit of US$ 7192 per section (AFRD, 2003; AG, 2005).

From this study area, a typical agricultural landscape with canola on a scale of 4 km^2 could have five 800 m × 800 m canola fields. If all five fields had approximately 64 ha of uncultivated land within 750 m of field edges, profit per field, at 1335 kg/ha yield and a market value of US$ 0.27 kg^{-1}, would be US$ 6069. The profit from the five canola fields in this landscape would be US$ 30,345. However, if a central section of 64 ha had not been cultivated or was allowed to revert to a semi-natural state, there would be 128 ha of uncultivated land within 750 m from the four remaining cultivated canola field edges, and the bee abundance index would increase from a mean 30.1 to 63.9 in each field, with a corresponding pollination deficit change of −6.7 to −4.9, an increase of 1.8 seeds/pod. Yield would increase from 1335 to 1467 kg/ha and gross revenue per field would equal US$ 25,350. Because wild pollinators provide a 'free' pollination service, input costs per field would remain the same (US$ 17,000 per quarter section) and profit would be US$ 8350 quarter section, a 38% increase in profit per field. Net value of canola in this second landscape scenario (four fields) would be US$ 33 400, a 10% increase in landscape profit over five fields without a central uncultivated area. Harvesting and transport costs may increase slightly with greater yields but this is not included in the analysis.

In order to assess optimum uncultivated land area, a generalized model of profit from canola in a 576 ha area (nine quarter sections) along a continuum, from all land being canola fields to the area made up entirely of uncultivated land is presented (Fig. 3). Agroecosystems were examined in this size area because it was a likely scale at which bees utilize their environment (Osborne et al., 1999; Steffan-Dewenter et al., 2001; Steffan-Dewenter, 2002). The model assumed that the area was a closed system and there was no outside uncultivated land from which pollinators could come into the landscape, and that addition of uncultivated land contributed pollinator services equally in all fields. Uncultivated land added predominantly to one side of the modeled landscape would have less of an impact on overall seed set if canola within bees' foraging range was already maximally pollinated. Rather than modeling unrealistic full seed set, the model was constrained, not allowing seed set greater than what was achieved with full pollination in this study.

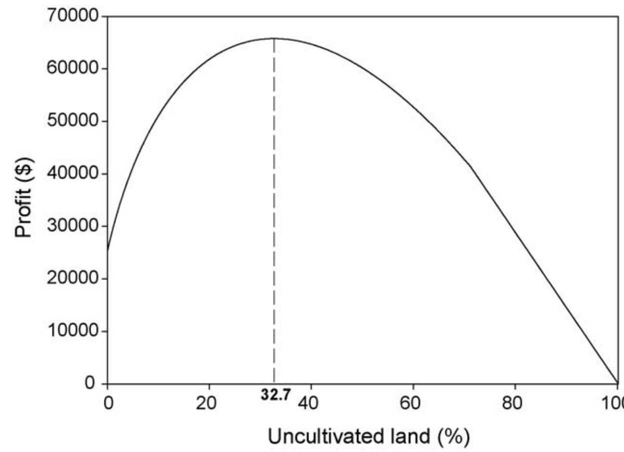

Fig. 3. Model of canola profit in a 576 ha landscape defined by the equation: $f(x) = (((([\{6.06 + 0.264x\}^{0.48}]1.29 - 12.54)1382.3 + 32900.4)/64)(576 - x) - (265.6[576 - x])$. Seed deficit was not allowed to increase above zero, creating the linear decline after 72% uncultivated land. Land was either canola or uncultivated.

Landscape profit rose sharply with an increase from 0 to approximately 20% uncultivated land. Rate of profit increase decreased from 20% to 30% uncultivated land, indicating that the most benefit of uncultivated land was seen when increasing from low to moderate amounts. Above 32.7%, declining amounts of cultivated canola outweighed the benefits of greater pollination from more uncultivated land. Thus, maximum landscape profit was achieved with just over 30% of the landscape uncultivated.

Acknowledgements

We thank Parrish and Heimbecker Ltd. for help locating fields. E. Fairhurst, N. Charrette, L. Klassen, J. Banman, and K. Thiessen helped with data collection. J. Mayko from the Canola Council of Canada provided advice on canola growing economics. Z. Punja, D. Green, E. Elle, C. Scott-Dupree, P. O'Hara, H. Higo, C. Ratti, V. Abbot, S. Hoover, N. Gervan, A. King, and J. Nadeau provided comments on the manuscript. Funding was provided by the British Columbia Honey Producers Association, a Research Partnership agreement with the Natural Sciences and Engineering Research Council of Canada (NSERC) and associated industry collaborators–Bayer CropScience, Monsanto, Dow AgroSciences Canada Inc. and Crompton Co./Cie, an NSERC postgraduate scholarship to LAM and an NSERC Discovery Grant to MLW.

References

ACPC, 2005. Alberta Canola Producers Commission; http://www.canola.ab.ca/index.cgi?futmon=May05&unit=b.

AFRD, 2003. Agriculture, Food and Rural Development, Alberta Government, Crop Enterprise cost and return calculator; http://www.agric.gov.ab.ca/app24/costcalculators/crop/getcrops.jsp.

AG, 2005. Alberta Government; Farmer reported variety yields for Peace River soil zone-canola; http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex2854.

Banaszak, J., 1978. The importance of bees Apoidea as pollinators of crop plants. Wiad. Ekol. 24, 225–248.

Darvill, B., Knight, M.E., Goulson, D., 2004. Use of genetic markers to quantify bumblebee foraging range and nest density. Oikos 107, 471–478.

Gathmann, A., Tscharntke, T., 2002. Foraging ranges of solitary bees. J. Anim. Ecol. 71, 757–764.

Kremen, C., Williams, N.M., Thorp, R.W., 2002. Crop pollination from native bees at risk from agricultural intensification. Proc. Natl. Acad. Sci. U.S.A. 99, 16812–16816.

Kremen, C., Williams, N.M., Bugg, R.L., Fay, J.P., Thorp, R.W., 2004. The area requirements of an ecosystem service: crop pollination by native bee communities in California. Ecol. Lett. 7, 1109–1119.

Lambin, E.F., Turnerb, B.L., Geista, H.J., Agbolac, S.B., Angelsend, A., Brucee, J.W., Coomesf, O.T., Dirzog, R., Fischerh, G., Folkei, C., Georgej, P.S., Homewoodk, K., Imbernonl, J., Leemansm, R., Lin, X., Morano, E.F., Mortimorep, M., Ramakrishnanq, P.S., Richardsr, J.F., Skåness, H., Steffent, W., Stoneu, G.D., Svedinv, U., Veldkampw, T.A., Vogelx, C., Xuy, J., 2001. The causes of land-use and land-cover change: moving beyond the myths. Glob. Environ. Change 11, 261–269.

Morandin, L.A., Winston, M.L., 2005. Wild bee abundance and seed production in conventional, organic, and genetically modified canola. Ecol. Appl. 15, 871–881.

Osborne, J.L., Clark, S.J., Morris, R.J., Williams, I.H., Riley, J.R., Smith, A.D., Reynolds, D.R., Edwards, A.S., 1999. A landscape-scale study of bumble bee foraging range and constancy, using harmonic radar. J. Appl. Ecol. 36, 519–533.

Ricketts, T.H., Daily, G.C., Ehrlich, P.R., Michener, C.D., 2004. Economic value of tropical forest to coffee production. Proc. Natl. Acad. Sci. U.S.A. 101, 12579–12582.

Roubik, D.W., 1995. Pollination of Cultivated Plants in the Tropics. Food and Agriculture Organization, Rome.

Steffan-Dewenter, I., 2002. Landscape context affects trap-nesting bees, wasps, and their natural enemies. Ecol. Entomol. 27, 631–637.

Steffan-Dewenter, I., Muenzenberg, U., Tscharntke, T., 2001. Pollination, seed set and seed predation on a landscape scale. Proc. R. Soc. Lond., Ser. B 268, 1685–1690.

Tscharntke, T., Steffan-Dewenter, I., Kruess, A., Thies, C., 2002. Contribution of small habitat fragments to conservation of insect communities of grassland–cropland landscapes. Ecol. Appl. 12, 354–363.

Vitousek, P.M., Mooney, H.A., Lubchenco, J., Melillo, J.M., 1997. Human domination of earth's ecosystems. Science 277, 494–499.