Model description – WP 2 - Kromme Rijn case study

Willem Verhagen, Emma H. van der Zanden and Peter H. Verburg

General overview

The calculations are based on a Land Use Land Management (LULM) map for the Kromme Rijn area at a 25x25 meter resolution. The map combines information on land cover, crop type, nature management, agricultural management and presence of green linear elements (GLEs).

Most of the environmental indicators were based on previously published models. Therefore we will only discuss the models that were developed for this study in full detail. Most models were based on both local characteristics and LULM in a buffer surrounding a cell. If buffers were used, we always used a LULM map with a 2km buffer surrounding the study area. The total value of each environmental indicator was however calculated only for cells within the study area (excluding the buffer). Thus cells in the buffer area affected the value of cells in the study area, but we did not calculate a value for those cells itself. All LULM in the buffer area were stable over time.

Pasture production for dairy cows

The quantification of pasture production for dairy cows (euro/ha/year) was based on a look-up table approach. We calculated the profit per cell based on average production values per ha pasture, costs of milk production and market prices for the Netherlands (agrimatie.nl 2014). All data were averaged over the years 2010-2014. We calculated the total profits of milk production for a six month period. We assumed no production on natural grasslands, although they need occasional grazing for maintenance. We started by calculating the area under production for each cell. In principle the area under production is stable (0.0625 ha) but the presence of GLEs reduced the area under production such that:

$$Area\ (ha)_i = 0.0625 - (GLEs_i * 0.0125) \tag{1}$$

The area under production (ha), *Area*, per cell, i, is a function of a fixed area of each cell and a binary value (0,1) determining the presence of GLEs. We assumed an average width of 5 meter per GLEs which is within estimates of previous studies using hedgerow widths of 3 to 10 meter (Teeffelen et al. 2015; Schulp et al. 2014).

We then calculated the total milk production per cell based on standard outputs for pastures in the Netherlands. All parameter values in the pasture production model are provided in Table S.3. We averaged the production statistics of milk cows on organic and conventional farm management from 2010-2014 (agrimatie.nl 2014). We then calculated the total production of milk on pastures such that:

$$Milk\ (kg)_{i,m} = Area_{\ i} * \ Cows_m \ * \left(\frac{MilkperCow_m}{100} * 0.5\right) \tag{2}$$

the total milk production in kg, *Milk*, is a function of the area under production, as calculated in equation 1, the number of cows per ha, *Cows*, which depends on farm management, *m*, and the average milk production per cow (100 kg/year), *MilkperCow*, which again depends on management, *m*. Both the number of cows per ha and the average milk production per cow is lower under organic management. The total milk production is calculated for a half year period by multiplying the milk production per cow by 0.5.

The profits of milk production per cell are calculated as a function of the total production, the market price for milk and the costs of milk production. To calculate the actual profits we multiplied the total milk production with the market price and costs of production such that:

$$Milk\ Profit\ (euro)_{i,m} = \ Milk_{i,m} \ * \ (marketprice_m - \ cost_m) \tag{3}$$

The total milk profit in euro/year, *Milk Profit,* is a function of the milk production, as calculated in equation 2, and the market price and costs of production (euro/ kg milk), which both depend on farm management, *m*. We used animal feed as the main cost measure for milk production, which is the largest cost associated with milk production. Both the market price and the cost of production are higher for organic milk production, but the price-cost ratio is best for conventional farms.

We calculated the total milk profit for a ten year period. Within this period we accounted for transition costs of conventional farms switching to organic production. During the transition period the farm already implements organic management, with associated costs, but can only receive a market price for conventional products. The total transition period for pasture production is three years but only the last six months the animals require organic feed (SKAL 2017). Given that we used animal feed as the main cost measure we used a total transition period of six months for pasture production. We assumed that farms switching to organic production do so for the full ten year period. We therefore calculated the total milk profit on organic farms and conventional farms separately such that.

$$Conv\ Profit_i = 20 * \ Milk\ Profit\ (euro)_{i,c} \tag{4}$$

$$OrgProfit_i = (19 * Milk\ Profit\ (euro)_{i,o}) \ + \Big(Milk_{i,o} \ * \ (marketprice_c - \ cost_o)\Big) \tag{5}$$

Here equation four calculates the profit for production, prices and costs related to conventional management, *c*, and multiplies this value by 20 to calculate it for a 10-year profit. Profit of organic farms is calculated in two steps where the left hand site of the equation 5 calculates the profit for production, prices and costs related to conventional management, *o*, and the right hand site of the equation calculates the profit in the half year transition period with production and costs for organic management, *o*, but a conventional market price, *c*.

We summed the profits of milk production for all pasture cells in the Kromme Rijn area. All restoration alternatives reduce pasture production. We were interested to maximize environmental objectives while minimizing the loss in milk production. We therefore calculated the potential milk profit, the milk profit if all pasture cells were under conventional management without GLEs. We then calculated the loss in pasture production due to restoration as the milk profit for the current LULM allocation minus the potential milk profit.

Table S. 1: parameters for pasture production model. The parameters differ for organic and conventional managed pasture. All values are 5-year averages (2010-2014) based on Dutch national statistics of pasture production (agrimatie.nl 2014)

	Organic pasture	**Conventional pasture**
Cows per ha	1.23	2.14
Milk production (100kg milk/cow/year)	6338	8082
Market price (euro/kg milk)	58.51	48.93
Costs for animal feed (euro/kg milk)	10.86	10.03

Orchard production

Fruit tree production (euro/ha/year) was quantified based the level of pollination per orchard coupled with a look-up table approach. Fruit tree production partly depends on pollination for fruit set. Pollination by wild bees and other pollinators is more effective and more resilient against diseases (Garibaldi et al. 2013; Potts et al. 2010). Assessing pollination potential based on land cover data is a common approach in literature (Verhagen et al. 2014; Lonsdorf et al. 2009; Zulian et al. 2013). The formulas used to link land cover data to pollination potential are well documented. We therefore primarily focus on how we calculated the fruit production profit in this study.

We adopted an existing model linking the landscape suitability of wild bees, based on nest suitability, floral resources and distance to orchards (Zulian et al. 2013). The first step is to create a nesting suitability and floral availability by reclassifying LULM types. Table S.4 provides information on the parameter values for the most important LULM categories. The diversity of pollinators and fruit set tends to increase on organic versus conventional orchards and extensively managed pastures tend to provide higher values for bee habitat and floral resources (Klein et al. 2012; Groot et al. 2016; Groot et al. 2015). In the absence of generalizable data for the effect of organic management on pollination, we approximated the effect of organic management by using the values for high nature value farmland (Zulian et al. 2013). GLEs can provide important habitat and floral resources for wild bees and are often the sole source of pollination in agricultural landscapes (Verhagen et al. 2016; Schulp et al. 2014). We approximated the effect of GLEs by using the parameter values for forest edges (Zulian et al. 2013). For GLEs we averaged the parameter values of GLEs and the dominant LULM based on the area occupied by each.

Forest edges are more likely to provide suitable nesting sites and floral resources (Verhagen et al. 2016). Following Zulian et al. (2013), we identified forest edges based on a 50 meter buffer. Forest sites further than 50 meters away from other LULM types are classified as forest interior and forest sites within 50 meter from another LULM type are classified as a forest edge.

Both the effect of floral resource availability and the distance to orchards depends on a distance decay function. For example, orchards closer to nesting sites receive higher pollination than orchards further away. We used the distance decay function from Lonsdorf et al. (2009). Following Verhagen et al. (2016) we used a maximum flight distance of 500 meters for wild bees. The combination of nesting quality, floral resources and distance from orchards resulted in a relative pollination potential (RPP) for each cell occupied by orchards. We used the RPP to calculate the contribution of pollinators to fruit orchard production.

Similar to pasture production, we calculated orchard production using a look-up table approach with different values for organic and conventional management. In contrast to pasture production, we could use more regional statistics on orchard production based on research that was partly conducted in the Kromme Rijn area. These studies were used in estimating the contribution of pollinators to fruit production and a detailed assessment of costs and market prices associated with fruit production (Heijerman-Peppelman & Roelofs 2010; Groot et al. 2015; Groot et al. 2016).

The main fruits produced in the Netherlands are apples and pears. The most common produced apple is “Elstar” whereas the most common produced pear is “Conference”. We based all our parameter values in the orchard production model on “Elstar” and “Conference”. We assumed a distribution of 54% apple production and 46% pear production for each orchard in the Kromme Rijn based on the distribution of fruit production area for apples and pears in central Netherlands (CBS 2013) .

Similarly to the pasture production model, we first calculated the total orchard production per cell based on the area under production, production losses and the contribution of pollinators to orchard production. The area under production for each cell is in principle stable (0.0625) but can be reduced because of the presence of GLEs. We calculated the area under production for orchards using equation 1.

Apple and pear production have a different dependency on pollination. We calculated the contribution of pollination to crop production using the crop pollination deficit (CPD) (Gallai et al. 2009; Zulian et al. 2013) such that:

$$CPD\ (\%) = \frac{\sum_{f=1}\left(DP_f * HY_{f,m} * (1 - RPP_i)\right)}{\sum_{f=1} HY_{f,m}} \tag{6}$$

Here, DP is the dependency of crop production on pollination which differs per crop type, *f*. We based the DP values on field experiments in the Netherlands estimating apple and pear production with and without pollination (Groot et al. 2015; Groot et al. 2016). HY is the high yield, i.e. the yield with pollination, which differs for organic and conventional orchards, *m*. RPP is the relative pollination potential, as explained before. We calculated high yield as the yield obtained for pears and apples with pollination (Groot et al. 2015; Groot et al. 2016).

Any production process inevitably involves production losses. For orchard production the losses are dependent on management system. We took production losses into account in the calculation of production such that:

$$maxProd_{f.m} = HY_{f,m} - \left(HY_{f,m} * ProdLoss_m\right) \tag{7}$$

Here, HY is equal to the parameter in equation 6. Production losses, *ProdLoss,* depend on management type, *m,* and were obtained from a report on standard calculations for fruit production in the Netherlands (Heijerman-Peppelman & Roelofs 2010). Production losses were only available for apples. We assumed similar production losses for pears.

The contribution of pollination to orchard production is then the difference between yield with maximum pollination and yield with actual pollination such that:

$$FruitTree_{f,m} = \left(maxProd_{f.m}\right) - \left(\left(maxProd_{f.m} * CPD\right)\right) \tag{8}$$

The orchard production is at its maximum in the case of full pollination and no presence of GLEs.

In a second step, we linked the fruit tree production estimates to data on costs and market prices of production, which differed for organic and conventional management (Heijerman-Peppelman & Roelofs 2010). The production costs entail harvest and sorting costs. Harvest costs depend partly on the area under production and partly on the actual fruit tree production. We used data on costs for a standard plantation of 3000 trees/ha for apples and 2500 trees/ha for pears (Heijerman-Peppelman & Roelofs 2010). The costs of orchard production are calculated such that:

$$LandCosts_{f,m} = \left(Area_{\,i} * LandCostsFixed_{f,m}\right) + \left(Area_{\,i} * LandCostsFlex_{f,m}\right) \qquad (9)$$

$$HarvestCosts_{f,m} = \left(\frac{FruitTree_{f,m} * \ Area_{\,i}}{FruitHarvest_{f,m}}\right) + \left(\frac{FruitTree_{f,m} * \ Area_{\,i}}{FruitSorting_{f,m}}\right) * 14 \qquad (10)$$

In equation (9) a distinction is made between land costs related to hourly wages for permanent employees (23.25 euro/hour) and hourly wages for seasonal employees (14 euro/hour) (Heijerman-Peppelman & Roelofs 2010). Equation (10) estimates the costs related to harvest and post-harvest sorting. Here the costs depend on the production and not on the land area. The parameters *FruitHarvest* and *FruitSorting* are taken as average kilogram of fruit harvested per hour for each activity. Most of the harvest and post-harvest is performed by seasonal employees and therefore we used an hourly wage of 14 euro (Heijerman-Peppelman & Roelofs 2010). The total production costs are then a sum of the land costs and the harvest costs.

We obtained data on market prices for organic and conventional produce of pears and apples (Heijerman-Peppelman & Roelofs 2010). The income related to fruit production is then calculated as:

$$FruitIncome_{f,m,i} = \ marketprice_{f,m} * \ Area_{\,i} * \ FruitTree_{f,m} \qquad (11)$$

Here the income of fruit production (euro/year) depends on the production per cell, the area under production and the market price for fruits, which depends on management and crop type.

Similar to pasture production, we calculated the total profit of fruit production for a ten year period. For organic orchards we accounted for a transition period. We used a transition period of three years for fruit tree production (SKAL 2017) and calculated profit of fruit tree production separately for organic and conventional orchards such that

$$Conv\ Profit_i = 10 * (FruitIncome_{f,c,i} - (LandCosts_{f,c} + HarvestCosts_{f,c}) \tag{12}$$

$$TransProfit_i = (marketprice_{f,c} * Area_{\ i} * FruitTree_{f,o)} - (LandCosts_{f,o} + HarvestCosts_{f,o}) \tag{13}$$

$$OrgProfit_i = 7 * (FruitIncome_{f,o,i} - (LandCosts_{f,o} + HarvestCosts_{f,o}) + 3 * TransProfit_i \tag{14}$$

Here conventional profit is calculated as the difference between the fruit income and fruit production costs for conventional management, *c*. Profits on organic orchards are calculated in two steps; the left hand side calculates the difference between fruit income and production costs for a period of seven years for organic management, *o*, whereas the right hand side of the equation calculates the profits during the three year transition period in which market prices are based on conventional management but costs and production quantities are based on organic management (equation 13). We assumed that orchards switching to organic production do so for the full ten year period. Total profits from orchard production for the Kromme Rijn area are calculated as the sum of profits of all cells occupied by orchards.

Table S. 2: Parameters used to calculate orchard production on conventional and organic orchards for apples and pears. We obtained all production values from two reports measuring the contribution of pollination to apple (Groot et al. 2015) and pear production (Groot et al. 2016). All estimates of costs and market price were obtained from Heijerman-Peppelman & Roelofs (2010)**.**

	Conventional		**Organic**	
	Apple	Pear	Apple	Pear
Crop dependency (%)	23.5	11	23.5	11
High yield (HY) (kg/ha)	50	55	35	38.5

Production loss (%)		0.03	0.03	0.05	0.05
Land Costs Fixed (hours)		129	151	262.5	224.25
Land Costs Flex (hours)	*Manual labour*	35	50	113	79.1
	Machines	63.5	49	99	128.3
	Preparation	19	19	16	16
Fruit harvest costs (kg/hour)		127.5	110	110	95
Fruit sorting costs (kg/hour)		225	210	200	178.7
Market price (euro/kg)		0.41	0.61	0.9	1.34

Carrying capacity for great crested newt individuals

The Kromme Rijn area is a focal area for the protection and restoration of habitat for the great crested newt (Utrecht Province 2016). We quantified the habitat suitability (number of individuals/pond) of the landscape for the great crested newt (Teeffelen et al. 2015). The newt model was previously designed and applied in the Baakse Beek, a Dutch agricultural landscape dominated by dairy farming (Teeffelen et al. 2015). Newt requires pond for reproduction but use the landscape surrounding a pond for feeding, shelter and hibernation in the juvenile and adult stage (Griffiths 1996; Müllner 2001). Following Teeffelen et al. (2015), we calculated the landscape suitability for newts based on the presence of ponds in combination with the LULM surrounding each pond.

The map used to identify the location of GLEs also contained information on the locations of ponds (Utrecht Province 2013). There were a total of 219 ponds in the Kromme Rijn area, mainly located in the northern part. We reclassified the LULM map into area of suitable habitat for newts. Following Teeffelen et al. (2015), (deciduous) forest was considered suitable habitat for the full area (625 m^2). Natural grasslands are suboptimal habitat and therefore only half of the area is considered suitable habitat (Teeffelen et al. 2015). Hedges and tree lines are considered suitable habitat but only cover part of the LULM cell (125 m^2). Organic managed pastures and conventional managed pastures are not considered habitat for newts.

For each pond, we summed the total available habitat within a 250 meter radius (Teeffelen et al. 2015). We used a buffer of 2km surrounding the study area to account for the suitable habitat surrounding each pond.

Following van Teeffelen et al. (2015), we used an optimal carrying capacity of 75 individual newt adult females per pond. Ponds with less than 2.5 ha within the 250 meter surrounding a pond were considered unsuitable habitat. Beyond 2.5 ha of suitable habitat the pond carrying capacity was assumed to increase linearly with the amount of terrestrial habitat, reaching maximum carrying capacity when at least 10 ha (52%) of the landscape surrounding a pond was considered suitable habitat. We calculated the total number of newt individuals for the Kromme Rijn area by summing the carrying capacity of all ponds. A full description of the newt model can be found in Teeffelen et al. (2015).

Landscape Aesthetics

We quantified the aesthetic quality of the landscape using a model specifically designed for the Kromme Rijn area (Tieskens et al., under review). The model links the distance to a set of natural and human made features to the amount of unique user uploads of landscape photos on social media platforms (Panoramia and Flickr). The authors found that the amount of landscape photos was significantly affected by the distance to forts, castles, river and other water bodies, cycling and hiking paths and heather and forests (Tieskens et al., under review). In addition the distance to GLEs and the distance to natural grassland significantly affected the amount of landscape photos. However, the added effect of natural grasslands and GLEs was relatively small. Orchards did not have a significant effect. The effect of organic management was not tested and therefore we assumed no effect of organic management.

We used their model and datapoints to calculate the landscape aesthetic value for the Kromme Rijn. All parameter values are given in Table S.5. The amount of landscape photos was approximated based on the distance to the landscape variables. We used a maximum distance of 500 meter and calculated the aesthetic value such that

$$Aesthetics_i = e^{-(var1*dist1+var2*dist2)} \tag{14}$$

In equation (14) *var* stands for the coefficient value per variable as depicted in Table S.5. The coefficient is multiplied by the minimum distance from the cell to that feature. Only the distance to GLEs and to natural grasslands changed for different landscape configurations. The other coefficients were fixed in the model. Switching to organic management did not have an effect on aesthetic value (Tieskens et al., under review). We calculated the aesthetic value for the Kromme Rijn area by summing the values of all cells with roads.

Table S. 3: Coefficient values for the landscape aesthetic model for the Kromme Rijn area. All values are based on Tieskens et al. (under review).

Indicator	**Coefficient**	**Indicator**	**Coefficient**
Intercept	0.31	Distance to heather	0.08
Distance to other water bodies	0.11	Distance to cycling path	0.27
Distance to natural grassland	0.05	Distance to hiking path	0.25
Distance to forts	0.18	Urban	-0.04
Distance to GLEs	0.06	Population in 7km buffer	0.01
Distance to River	0.19	Distance to forest	0.02
Distance to castles	0.32		

References

agrimatie.nl, 2014. kostprijs van melk (2010-2014). *Agrimatie - informatie over de agrosector*.

CBS, 2014. Basis Registratie Percelen. *Basis Registratie Percelen*, p.1.

CBS, 2013. Fruitteelt; oogst en teeltoppervlakte appels en peren per ras en regio. *Statistics Netherlands - StatLine*. Available at: http://statline.cbs.nl/StatWeb/publication/?VW=T&DM=SLNL&PA=71509ned&LA=NL.

CBS, 2015. Landbouw; bioogisch en/of in omschakeling, gewassen, dieren, regionaal. *Landbouw; bioogisch en/of in omschakeling, gewassen, dieren, regionaal*, p.1.

Gallai, N. et al., 2009. Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. *Ecological Economics*, 68(3), pp.810–821.

Garibaldi, L.A. et al., 2013. Wild Pollinators Enhance Fruit Set of Crops Regardless of Honey Bee Abundance. *Science*, 339(6127), pp.1608–1611.

Griffiths, R.A., 1996. *Newts and Salamanders of Europe*, London, UK: T & AD Poyser.

Groot, G.A. de et al., 2016. *De bijdrage van (wilde) bestuivers aan een hoogwaardige teelt van peren en aardbeien*, Wageningen, The Netherlands.

Groot, G.A. De et al., 2015. *De Bijdrage van (wilde) bestuivers aan de Opbrengst Van Appels En Blauwe Bessen*, Wageningen, The Netherlands.

Hazeu, G.W. et al., 2010. *Landelijk Grondgebruiksbestand Nederland versie 6 (LGN6); Vervaardiging, nauwkeurigheid en gebruik*, Wageningen, The Netherlands.

Heijerman-Peppelman, G. & Roelofs, P.F.M.M., 2010. *Kwantitatieve Informatie Fruitteelt 2009 / 2010*, Zetten, The Netherlands.

Klein, A.M. et al., 2012. Wild pollination services to California almond rely on semi-natural habitat. *Journal of Applied Ecology*, 49, pp.723–732.

Lonsdorf, E. et al., 2009. Modelling pollination services across agricultural landscapes. *Annals of botany*, 103, pp.1589–1600.

Müllner, A., 2001. Spatial patterns of migrating great crested newts and smooth newts: the importance of the terrestrial habitat surrounding the breeding pond. *RANA*, 4, pp.279–293.

Potts, S.G. et al., 2010. Global pollinator declines: trends, impacts and drivers. *Trends in ecology & evolution*, 25(6), pp.345–53.

Provincie Utrecht, 2017. *Natuurbeheerplan 2017. Herziene Versie*, Utrecht, the Netherlands.

Schulp, C.J.E., Lautenbach, S. & Verburg, P.H., 2014. Quantifying and mapping ecosystem services: Demand and supply of pollination in the European Union. *Ecological Indicators*, 36, pp.131–141.

SKAL, 2017. SKAL biocontrole. , p.1.

Teeffelen, A.J.A. Van et al., 2015. Is green infrastructure an effective climate adaptation strategy for conserving biodiversity ? A case study with the great crested newt. *Landscape Ecology*, 30(5), pp.937–954.

Utrecht Province, 2013. Kleine Landschappelijke Elementen. *Kleine landschappelijke elementen*, p.1.

Utrecht Province, 2016. NBP. *Natuurbeheerplan provincie Utrecht herziene versie*, p.91.

Verhagen, W. et al., 2014. Chapter 4. Mapping Ecosystem Services. In P. J. H. van Beukering & J. Bouma, eds. *Ecosystem Services: From concept to practice*. Cambridge (UK): Cambridge University Press, p. 22.

Verhagen, W. et al., 2016. Effects of landscape configuration on mapping ecosystem service capacity : a review of evidence and a case study in Scotland. *Landscape Ecology*, 31, pp.1457–1479.

Zulian, G., Maes, J. & Paracchini, M., 2013. Linking Land Cover Data and Crop Yields for Mapping and Assessment of Pollination Services in Europe. *Land*, 2, pp.472–492.