Chapter

An Economic Valuation and Mapping of Pollination Services in Ethiopia

Dawit Woubishet Mulatu

Abstract

An increasing degree of attention is being given to pollination ecosystem service. It has become a commonly mentioned example of how ecosystem services are economically valuable due to its linkage to the world food production. A notable bio-economic approach is applied to estimate the economic value of pollination and the production value loss attributable due to a decline in pollinator using the Ethiopian Annual Agricultural Sample Surveys (AgSS) data for the period 2003–2013. We are aiming to fill the research and knowledge gap with respect to spatial and temporal variation of economic valuation and mapping of pollination services in developing countries, by taking Ethiopia as an example. Result indicated that the mean economic value of pollination is about US$81.3 million for this period. Our estimated crop vulnerability ratio was approximately 8.4%, and pollination service contributes about 4.2% of the total farm gate value. The spatial analysis of our estimates revealed discrete patterns of zonal level variation in Ethiopia. Estimates and spatial analyses of pollination values and vulnerabilities provide vital information to determine suitable pollinator management strategies at different institutional and ecological scales. Accordingly, our findings have policy and management implications on the potential benefit of addressing pollinator decline at local level.

Keywords: pollination, ecosystem services, economic valuation, mapping and Ethiopia

1. Introduction

Pollination is an ecosystem service and a production practice [1]. At present, an increasing degree of attention is being given to pollination ecosystem service and its economic value due to its linkage to the world food production; on top, it has become a frequently mentioned example of how ecosystems services are economically valuable [2]. Pollination makes a very significant contribution for the production of a broad range of crops, in particular fruits, vegetables, fiber crops, and nuts. Its value is derived from its contribution to the maintenance of ecosystems as well as its impact on agriculture [3]. However, pollinators' decline all over the world has consequences in many agricultural areas and is a major global environmental concern [4]. Thus, it is necessary to assess the potential significant loss of economic value of pollination [5].

It is increasingly recognized that more studies are needed to enhance our understanding of pollination services [3, 6], their contribution to the ecosystem [2, 7, 8], and agriculture productivity [6, 9, 10]. As well, there is a limited scientific evidence to explain the ongoing debate on pollination ecosystem service and valuation [2, 11, 12], the spatial and temporal trends of pollination benefits [1, 13], landscape impacts on the stability of pollination ecosystem services [14], and the suitability of habitats for sustaining valuable pollinators [15]. There is also a wide variation placed in the economic value of pollinators, and the economic value of pollination services is still at its infancy stage [2, 7, 10, 16]. Likewise, valuation of pollination services is useful to justify the allocation of resources toward conservation practices [17].

Economic valuation of pollination services not only provides information on the economic impacts of pollination decline but also contributes to decision-making process concerning selection of alternative mitigation strategies [6]. The first global estimate of the economic value of pollination was provided by Costanza et al. [18]. There is an increasing trend in pollination dependency in both the developed and the developing world [19, 20] and crop yields might also be declined due to pollination shortages [5]. The increasing pollination dependency led to a decline in agricultural production, thereby the demand for agricultural land expected to rise due to pollination absence or decline, particularly in developing countries [21]. In most developing countries, managing pollination services is also limited due to limited understanding of its economic value [22]. Accordingly, pollination is far beyond ecological-economical settings, but rather is a service of global importance threatened by land-use change and agricultural intensification [13, 23]. Therefore, we are aiming to fill the research and knowledge gap with respect to spatial and temporal variation of economic valuation of pollination services. Specifically, the major objectives of this study are: the first one is to quantify the economic value of pollination (EVP), the crop vulnerability ratio (CVR) or the potential relative production value loss attributable to lack of or disappearance of pollinators, and the pollination's contribution to total farm gate value (PCV) or the potential relative agricultural sector production value loss attributable to lack of or disappearance of pollinators in Ethiopia. The second objective is to map and assess the temporal and spatial variation of EVP, CVR, and PCV in Ethiopia. Similar to Gallai et al. [5], our study is based on the hypothesis that the economic impact of pollinators on agricultural output is measurable through the use of dependence ratios quantifying the impact of a lack of or disappearance of pollinators on crop production value using a bio-economic approach. Thus, our study focuses on: the analysis of spatial and temporal variation in economic valuation of pollination services and the vulnerability of national economies on pollination benefits; and the use of zonal level data (at local level) to derive mapping of economic valuation pollination, pollination dependency, and vulnerability due to pollination decline.

2. Methods

A notable bio-economic approach is applied to estimate the economic value of pollination. It has been used to estimate the economic value of pollination, and the potential relative production and agricultural sector value loss attributable to lack of or disappearance of pollinators or the production value loss attributable to a decline in pollinator [5, 10]. The total economic value of pollination (EVP) is calculated as follows:

$$EVP = \sum_{i=1}^{n} P_i * Q_i * D_i \tag{1}$$

where for each crop i€ (1:n), (where n = 38 in our study), Q_i is the quantity produced, D_i is the pollination dependency ratio, and P_i is the price per unit of quantity produced. The potential production value loss attributable to lack of pollinators, which is the crop vulnerability ratio (CVR), is calculated as the ratio of EVP to economic production value of the crops in our study (EV). CVR is calculated as:

$$CVR = \frac{EVP}{EV} = \frac{\sum_{i=1}^{n} P_i * Q_i * D_i}{\sum_{i=1}^{n} P_i * Q_i} (\%) \tag{2}$$

We calculate the pollination contribution to total farm gate value (PCV). PCV measures the potential agricultural sector production value loss attributable to lack of pollinators. It is the ratio of EVP to total farm gate value (TFGV). In our case, the total farm gate value is reported for each zone and is a summation of values of all agricultural productions (m is the whole agricultural products). We did not include services and animal products in our total farm gate value calculation. PCV is calculated as:

$$PCV = \frac{EVP}{TFGV} = \frac{\sum_{i=1}^{n} P_i * Q_i * D_i}{\sum_{i=1}^{m} P_i * Q_i} (\%) \tag{3}$$

For Ethiopia, we estimate the EVP, CVR, and PCV for the period from 2003 to 2013. The spatial pattern and variation of EVP, CVR, and PCV of Ethiopia at the zone level for respective year are analyzed using geographical information systems (GIS). For a better understanding of the spatial and temporal pattern, maps were produced for the economic value of pollination, crop vulnerability ratio, and pollination contribution to total farm gate value. Spatially explicit analysis of these indices at local or national level show how pollination has fundamentally different regional significance and consequences in its absence [1].

3. Data

We used data of the Ethiopian Annual Agricultural Sample Surveys (AgSS) from 2003 to 2013 conducted by Central Statistical Agency (CSA) of Ethiopia [24]. The major part of the AgSS is the Main ("Meher")[1] season postharvest survey which consists of area and production, land-use, farm management practices, and crop utilization of private peasant holdings. The specific objectives of main season postharvest survey are to estimate the total crop area, volume of crop production, and yield of crops for main agricultural season in Ethiopia. The data covered the entire rural parts of the country except some of the non-sedentary population zones in Ethiopia (i.e., Afar and Somali regional states). The agricultural products data collection in AgSS surveys cover all cereals, pulses, and oilseeds and the most commonly grown vegetables, root crops and permanent (perennial) crops. Holders growing at least one or more of these and/or other crops are enumerated, and data on crop area and yield condition are recorded; hence data on production of these crops are acquired.

For each year, quantities of various crops production were directly computed from the survey data. These values were aggregated to national, regional, and zonal

[1] "Meher" is the local language in Ethiopia to indicate the main agricultural season.

Crop type	Yield/seed increase in the presence of animal pollinators 1	In the absence of pollinators yield maybe less by	Pollinators	Mean pollination dependency
Pumpkins	Essential	More than 90%	Honey bees	0.95
Apples	Great	40–90%	Wild bees	0.65
Avocados	Great	40–90%	Honey bees (*Apis* spp.)	0.65
Cardamom	Great	40–90%	*Apis cerana* Fabricius	0.65
Coriander	Great	40–90%	*Apis cerana* Fabricius	0.65
Fennel	Great	40–90%	*Apis florea* Fabricius	0.65
Mangos	Great	40–90%	*Apis* spp.	0.65
Peach	Great	40–90%	*Apis mellifera* L.	0.65
Coffee (Arabica)	Modest	10–40%	*Apis dorsata* Fabricius	0.25
Guava	Modest	10–40%	*Apis mellifera* L.	0.25
Horse beans	Modest	10–40%	*Xylocopa aestuans* L.	0.25
Sesame	Modest	10–40%	*Apis cerana* Fabricius	0.25
Rapeseed	Modest	10–40%	*Apis mellifera* L.	0.25
Soybeans	Modest	10–40%	*Apis mellifera* L.	0.25
Sunflower	Modest	10–40%	*Apis cerana* Fabricius	0.25
Cotton	Modest	10–40%	*Apis mellifera* L.	0.25
Chickpeas	Little	0–10%	Bumble bees	0.05
Citron	Little	0–10%	*Apis cerana* Fabricius	0.05
Green pepper	Little	0–10%	Honey bees	0.05
Ground nuts	Little	0–10%	*Apis dorsata* Fabricius	0.05
Haricot beans	Little	0–10%		0.05
Lemons	Little	0–10%	*Apis cerana* Fabricius	0.05
Line seed	Little	0–10%	*Apis mellifera* L.	0.05
Mandarins	Little	0–10%	*Apis cerana* Fabricius	0.05
Oranges	Little	0–10%	*Apis cerana* Fabricius	0.05
Red pepper	Little	0–10%	Honey bees	0.05
Tomatoes	Little	0–10%	*Apis mellifera* L.	0.05
Beans kidney	Little	0–10%		0.05
Barley	Does not show an increase in yields		Unspecified	0
Lentils	Does not show an increase in yields		Unspecified	0
Maize	Does not show an increase in yields		Unspecified	0
Millet	Does not show an increase in yields		Unspecified	0
Oats	Does not show an increase in yields		Unspecified	0
Rice	Does not show an increase in yields		Unspecified	0

Crop type	Yield/seed increase in the presence of animal pollinators 1	In the absence of pollinators yield maybe less by	Pollinators	Mean pollination dependency
Sorghum	Does not show an increase in yields		Unspecified	0
Sugar cane	Does not show an increase in yields		Unspecified	0
Wheat	Does not show an increase in yields		Unspecified	0
Field peas	Does not show an increase in yields		Unspecified	0

Table 1.
Crops identified in our study and their yield may decline in the absence or decline of pollinators (based on [5, 7, 27]).

levels. In order to get the value of each crop production, the volume of each crop production were multiplied by national average price of each crop item per year. The mean annual prices were computed for each crop item from the monthly producers' agricultural prices released by the CSA [25]. The dollar values of production were calculated by using data from the World Bank database [26]. Deflating the values of productions was also important for ease of comparing values across different years. We used information from the World Bank database [26] to correct the prices for inflation by considering 2011 as reference year. For all zones in respective years, the scope of our study is limited to 38 different types of crops (pulses, spices, vegetables, oilseeds, fruits, and cash crops). The detail on the type of crops, the crop pollinators, and the mean pollination dependency ratio of crops is presented in **Table 1**.

The crop pollination dependency ratio has been calculated based on the dependency ratio of the recently published for crops by [5, 7], and by using the FAO database[2] [27]. The mean value of pollination-driven yield reduction lying between 100 and 90% is 95% (i.e., pollination is reported as "essential"). The mean pollination-driven yield reduction ranging between 40 and 90% is 65% (i.e., pollination is reported as "great"). The mean pollination-driven yield reduction ranging between 10 and 40% is 25% (i.e., pollination is reported as "modest"). The mean pollination-driven yield reduction ranging between 0 and 10% reduction is 5% (i.e., pollination is reported as "little"). Pollination driven that does not show an increase in yields takes a zero dependency ratio [2, 7].

4. Results and discussion

Using the bio-economic approach, we estimate the economic value of pollination (EVP), the crop vulnerability ratio (CVR), and pollination's contribution to total farm gate value (PCV) for Ethiopia using the 2003–2013 zonal level production value data for 38 different type of crops. We calculate the annual mean value estimates of EVP, CVR, and PCV between 68 and 73 zones of the respective years from 2003 to 2013. For Ethiopia, the mean economic value of pollination, total farm gate value, and economic value of crops under study for the period of 2003–2013

[2] The Food and Agriculture Organization of the United Nations (FAO's), Global Action on Pollination Services for Sustainable Agriculture. http://www.fao.org/pollination/pollination-database.

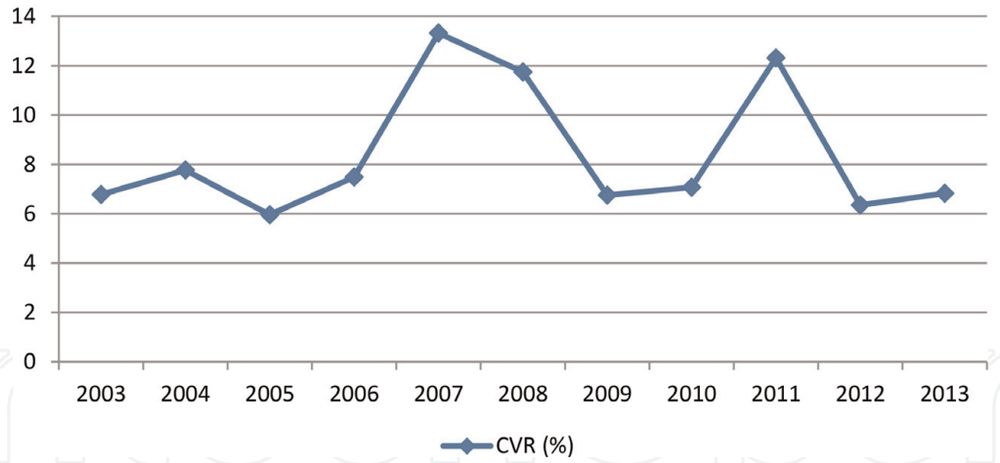

Figure 1.
Crop vulnerability ratio (CVR) (%) for the period of 2003–2013.

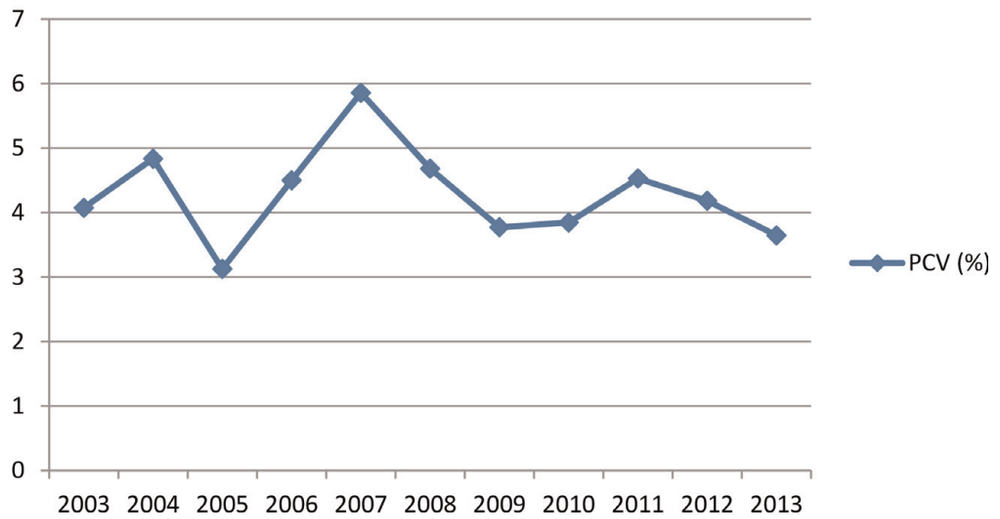

Figure 2.
Pollination contribution for farm gate value (PCV) (%) for the period of 2003–2013.

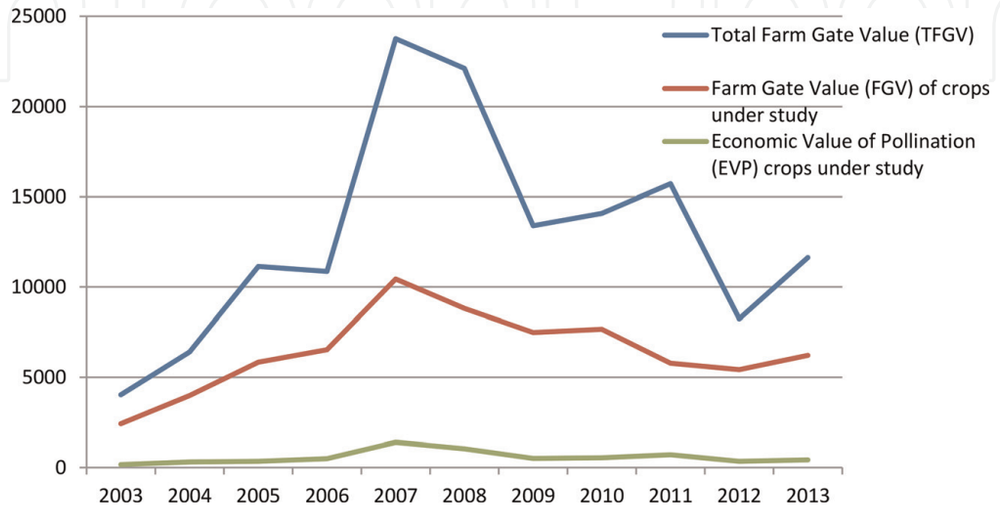

Figure 3.
Total farm gate value, farm gate value of crops under study and economic value of pollination in million USD for the period of 2003–2013.

were >US$81.3 million, >US$12.8 billion, and >US$6.41 billion, respectively. Our estimated crop vulnerability ratio indicates a potential production value loss for the crops studied of roughly 8.4% in the absence of pollinators. The CVR for the period of 2003–2013 is presented in **Figure 1** and it ranges between 6 and 13% which is comparable with [13] that showed the national dependency of the agricultural GDP

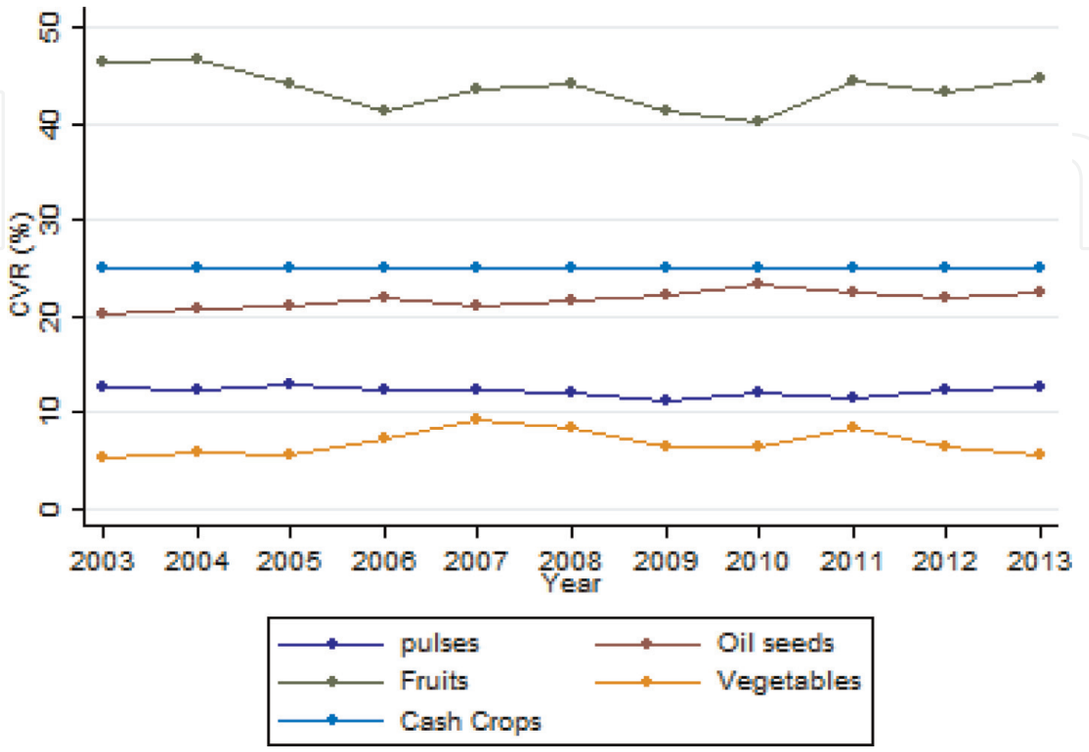

Figure 4.
Crop vulnerability ratio (CVR) (%) per crop category for the period of 2003–2013.

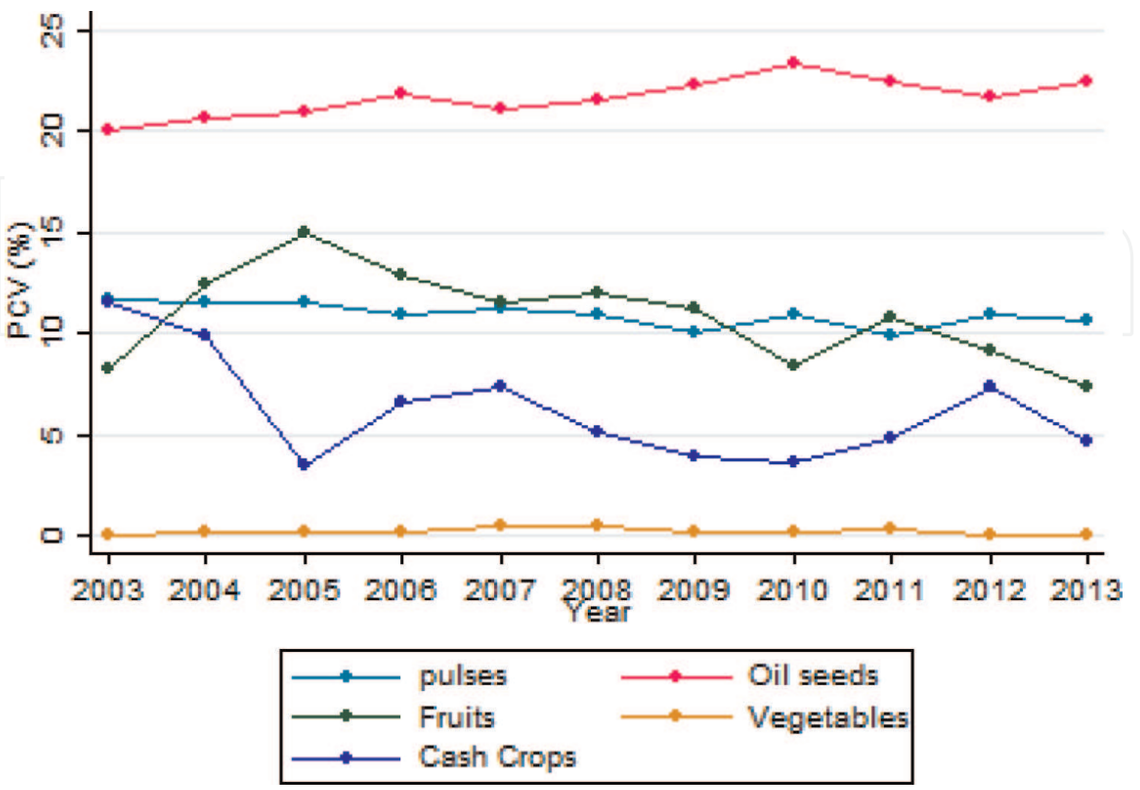

Figure 5.
Pollination contribution to total farm gate value (PCV) (%) per crop category for the period of 2003–2013.

on pollination in east Africa (including Ethiopia) which ranges between 5 and 7.5%. The mean PCV value indicated that the potential relative agricultural sector production value loss attributable to lack of or disappearance of pollinators in Ethiopia was 4.2% and the PCV values for respected year are presented in **Figure 2**. The highest value of CVR and PCV was found for the year 2007. Total farm gate values and economic value of pollination are presented in **Figure 3**. The CVR and PCV analyses have been done for different crop categories; fruits had highest CVR values due to their high pollination dependency followed by cash crops (e.g., coffee) and

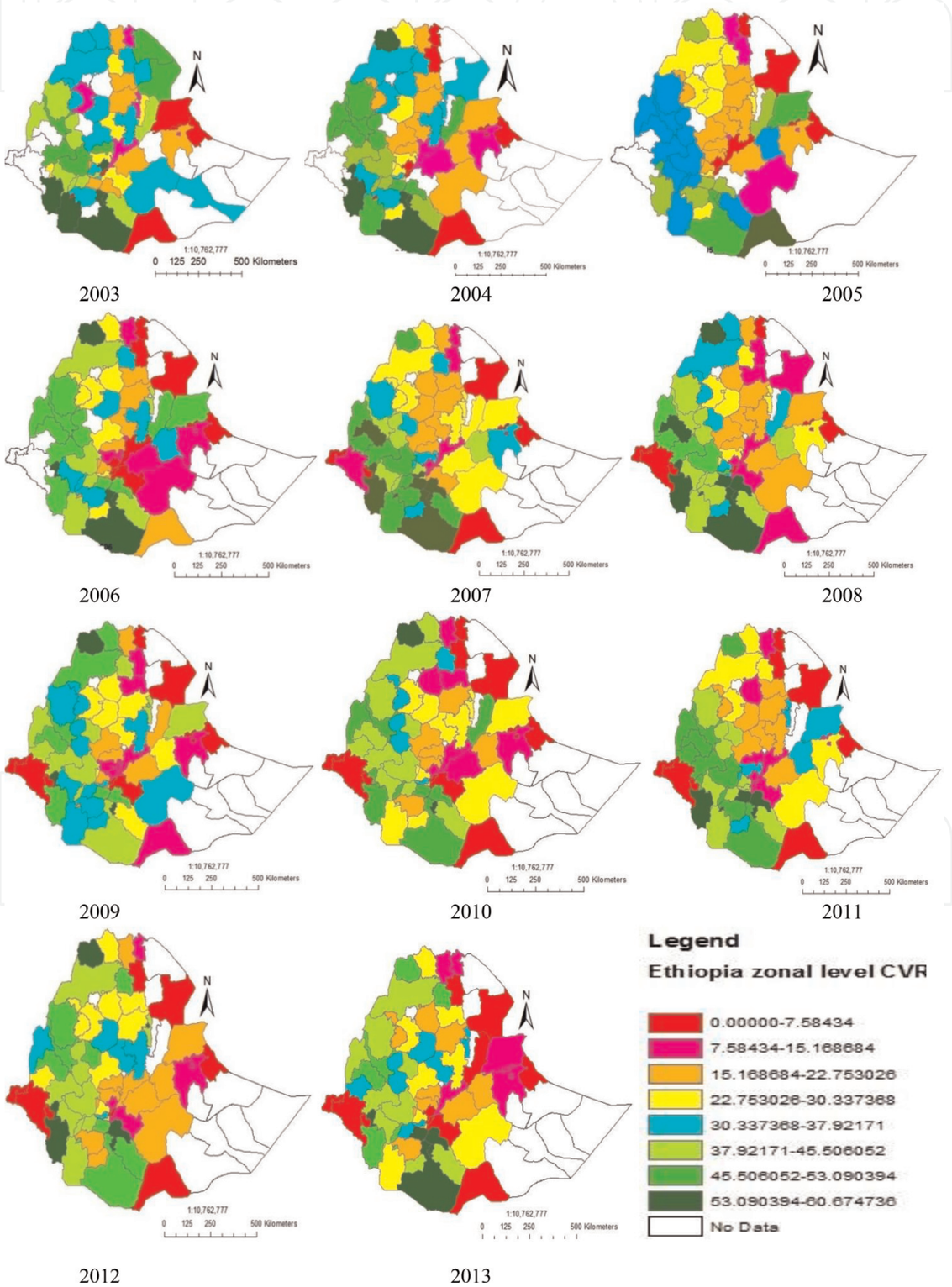

Figure 6.
Ethiopia zone level mapping of the crop vulnerability ratio (CVR) (%) for the period of 2003–2013.

oil seeds (**Figure 4**). Alternatively, the pollination contribution to farm gate value indicated the highest percentage for oil seeds followed by relatively in similar pattern for fruits and pulses (**Figure 5**).

Our geographic information system (GIS) analysis revealed the spatial variation of the crop vulnerability ratio (**Figure 6**), the economic value of pollination (**Figure 7**), and the pollination's contribution to total farm gate value

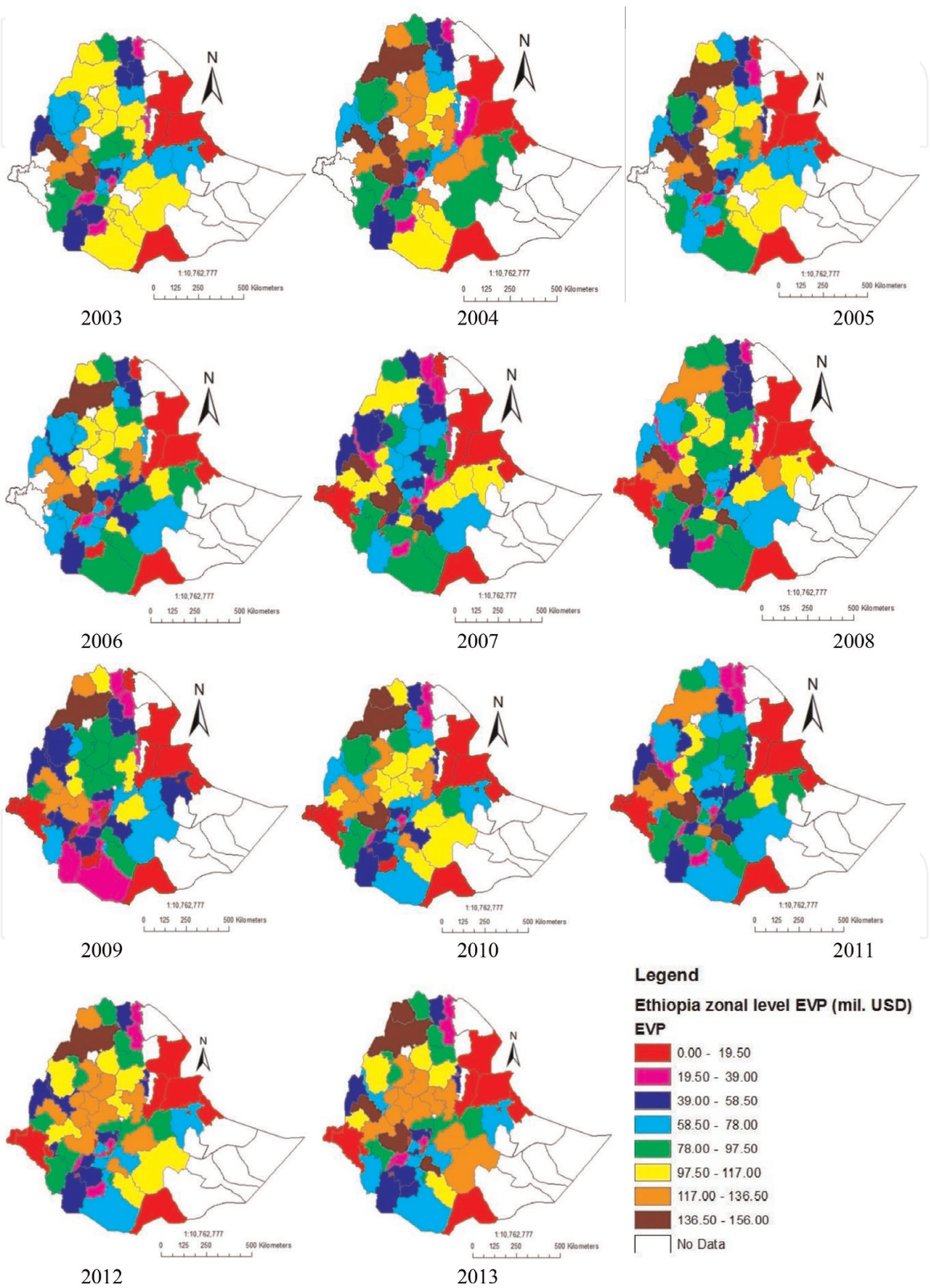

Figure 7.
Ethiopia zone level mapping of the economic value of pollination (EVP) in million USD for the period of 2003–2013.

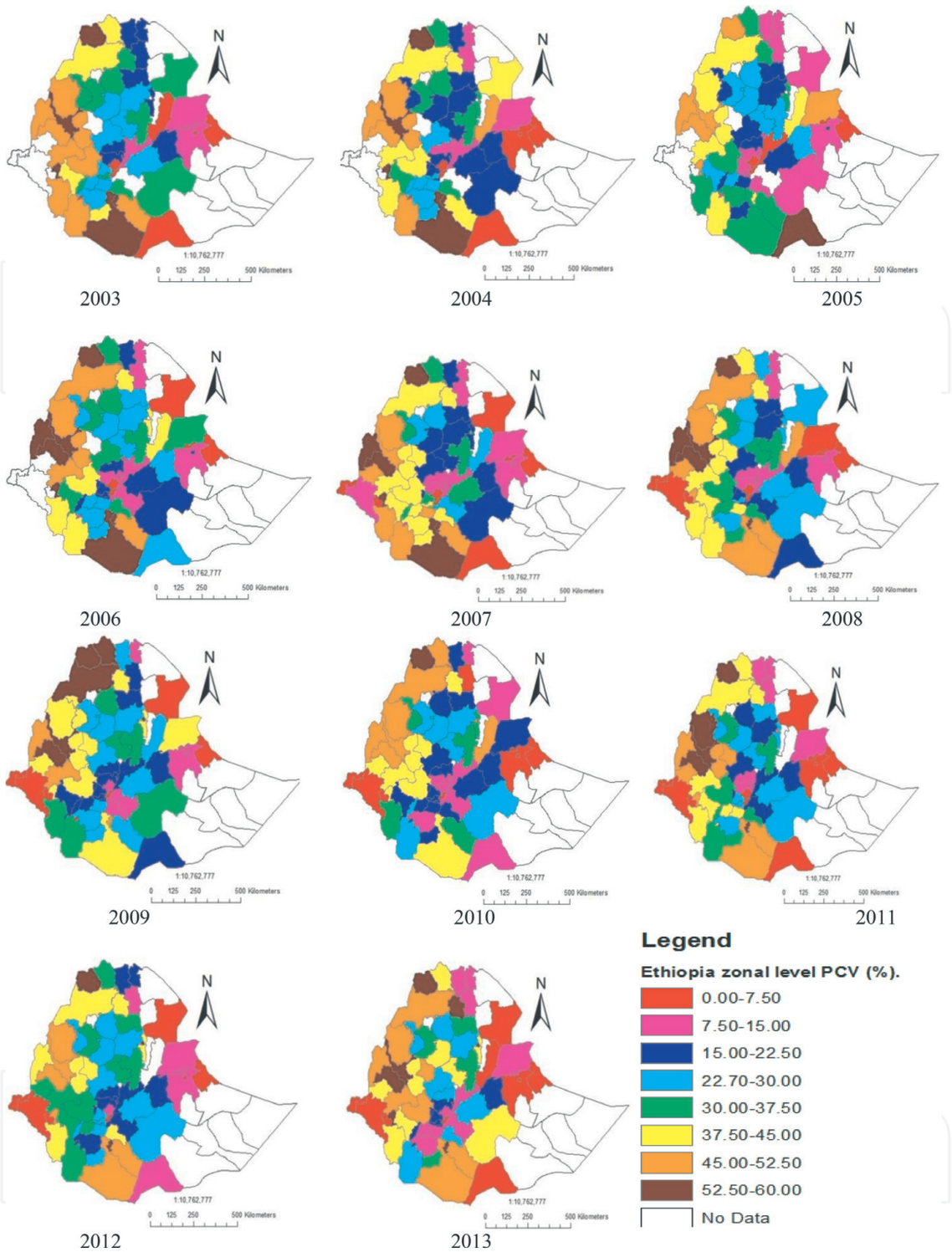

Figure 8.
Ethiopia zone level mapping of the pollination contribution to total farm gate value (PCV) (%) for the period of 2003–2013.

(**Figure 8**). Zones with the higher CVR values appear to be clustered in the west-central part of the country. The north-western part of the country revealed the highest CVR value; these areas mainly produce oil seed products for export market. Some parts of the south and eastern zones show the lowest CVR value because these areas are dry land and mainly livestock production zones rather than crop production. The result for the spatial pattern of the economic value of pollination shown that it is comparable for most parts of the north-eastern and the south-western parts of the country while it had a highest value in the north-western and the central parts of the country which predominantly produced oil seeds and cash crops.

Providing an estimate and spatial variation of the economic value of pollination is vital for cost-benefit analysis of planned interventions to perceived or anticipated pollinator decline [1]. The spatial analysis of our estimates revealed discrete patterns of zonal variation in pollination services and values within Ethiopia. Spatially explicit analysis of these indicators is important to support policies related to protection of abundant pollination sites for maintaining pollination services. Our results have policy and management implications on the potential benefit of addressing pollinator decline at local level. Similar to the findings of Barfield et al. [1], estimates and spatial analyses of pollination values and vulnerabilities provide information that is useful for the selection of the most appropriate pollinator management strategies at different institutional and ecological scales.

5. Conclusion

To understand the impact of pollinator decline on agriculture production in developing countries, empirical assessment of potential economic losses due to this decline is critical. As well, to support maintaining the pollination service in agriculture, there is a need to better understand the economic value generated by the pollination service. We estimated the economic value of pollination, and the potential relative production and agricultural sector value loss attributable to lack or disappearance of pollinators using bio-economic approach. We use the Ethiopian Annual Agricultural Sample Surveys (AgSS) data collected by Central Statistical Agency (CSA) for the period of 2003–2013. Result indicated that the potential production value loss attributable due to lack or decline of pollinators is nearly 8.4% and the potential agricultural sector production value loss attributable due to lack or decline of pollinators is about 4.2%. In this chapter, we have shown that spatial analyses of pollination values and vulnerabilities due to a decline in population of pollinators provide information that is useful for the selection of the most appropriate pollinator management strategies at different institutional and ecological scales. Therefore, spatially explicit analysis of these indicators is also important to support policies related to protection of abundant pollination sites for maintaining pollination services at different scales.

Acknowledgements

This chapter is an output of the Ecosystem Services Accounting for Development (ESAfD) project, jointly conducted by the EfD initiative and the Swedish Environmental Protection Agency (SEPA) and funded by the Swedish International Development Cooperation Agency (Sida). We are very grateful to Ethiopia's Central Statistics Agency who assisted us in providing and coalition of the available data.

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