Economic analysis of the pollination service in blueberry production in the Argentinean Littoral region.

RESUMEN

Los servicios ecosistémicos de polinización desempeñan un papel crucial en la producción de alimentos. Uno de los principales focos de atención ha sido la estimación del valor de los polinizadores en la agricultura. Aunque la mayoría de los estudios se han centrado en estimar el valor de la polinización para la agricultura, hay pocos conocimientos sobre cómo abordar el valor económico de los servicios ecosistémicos que proporciona. Este tema es importante tanto para los responsables de la toma de decisiones como para la comunidad científica, pero, hasta la fecha, no existe ningún método adecuado que capte la complejidad de esta dimensión. Para lograr una evaluación lo más precisa posible, este estudio propone un método que introduce nuevas aportaciones a las metodologías existentes.

La ecuación fundamental de la mayoría de los modelos es la misma, nuestro modelo propuesto asume que la polinización puede afectar a todos los insumos, no sólo al rendimiento, sino también a los precios y los costes. Por el contrario, el método más aceptado hasta la fecha, el enfoque del ingreso neto atribuible asume que la polinización sólo afecta al rendimiento, influyendo posteriormente en los ingresos y en los costes totales.

Nuestro trabajo contribuye a la adaptación de una ecuación que esboza explícitamente los múltiples impactos de la polinización sobre la producción, estimando una valoración económica del servicio de polinización mediante la incorporación de dimensiones no consideradas anteriormente. Mediante este enfoque, posibilitamos la toma de decisiones de forma comparativa. Nuestros resultados sugieren que el método propuesto se ajusta más a la realidad productiva que los modelos existentes.

ABSTRACT

Pollination ecosystem services play a crucial role in food production. One of the primary focuses has been on estimating the value of pollinators in agriculture. While most studies have focused on estimating the value of pollination for agriculture, there is little knowledge on how to approach the economic value of the ecosystem services it provides. This topic is significant for decision-makers and the scientific community alike, yet, to date, there is no suitable method that adequately captures the complexity of this dimension. To achieve the most accurate assessment, this study proposes a method that introduces new inputs to existing methodologies.

The fundamental equation of most models is the same, our proposed model assumes that pollination can affect all inputs, not just yield, but also prices and costs. In contrast, the most widely accepted method to date, the attributable net income approach, assumes that pollination only affects yield, subsequently influencing income and total costs.

Our work contributes by adapting an equation that explicitly outlines the multiple impacts of pollination on production and by estimating an economic valuation of the pollination service, incorporating dimensions not previously considered. Through this approach, we enable comparative decision-making. Our findings suggest that the proposed method aligns more closely with the productive reality than existing models.

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1. INTRODUCTION

The concept of ecosystem services is defined as the benefits received by human society from natural ecological processes. Pollination is one of the most globally studied ecosystem services, as it supports 78% of the global reproduction of flowering plants and enhances production in 75% of globally important crops (Breeze et al., 2016). From an economic perspective, Biotic pollination not only increases yields but also improves the quality of fruits and seeds of various plant species intended for either animal or human consumption (Imperatriz-Fonseca et al., 2006; Klein et al., 2007; Chacoff et al., 2010; Garibaldi et al., 2013; Stanley et al., 2013; Gianinni et al., 2015; Gatica Hernández et al., 2017; Basualdo et al., 2022; Siopa et al., 2023).

The impact of the ecosystem service of pollination on food production makes this contribution of interest within public policies. As of 2020, there are 24 government documents (Canada, France, the European Union, Australia, the United Kingdom, and FAO) addressing five main topics: (1) status, monitoring, and preservation of pollinators; (2) strategies for pollinator conservation; (3) reports and recommendations on the use of pesticides, especially neonicotinoids; (4) actions and recommendations for healthy environments for pollinators; (5) the value of pollinators in agriculture, ecological intensification, and sustainable agriculture (Porto et al., 2020).

From the period 2011-2018, nine positive policies have been in effect to protect pollinators and their contributions to agroecosystems. These nine policies were initiatives, laws, and decrees in France, Canada, Ireland, Australia, Puerto Rico, and the European Union. The measures deliberated on the five main topics covered in government documents (mentioned in the previous paragraph) but also addressed the improvement of knowledge about pollination and pollinators and established efforts to increase social awareness of the preservation of pollinators and their importance for human well-being (Porto et al., 2020).

While pollinators are an integral part of ecosystems and agricultural systems, and their role in food production is acknowledged, estimates of their contribution to productivity and farmers' profits are scarce (except for Latin America and Argentina, see Basualdo et al., 2022; Basualdo & Cavigliasso, 2023, respectively).

Technological packages used in agriculture generally do not include Biotic pollination as a factor of productive importance. In this sense, losses caused by poor comprehensive management, such as thinning, pruning, nutritional aspects, pest control, and irrigation management, are quantified, but losses caused by inadequate pollination are not considered.

Winfree, Gross & Kremen (2011) present the two most used methods in the literature to assess the contribution of pollination in productive systems, the replacement value, and the production value method, which are special cases of the same general equation (equation 1):

$$Vpollination = P * Y * D * \rho \quad (1)$$

Where: $Vpollination$ is the value of pollination service, P is the price paid per unit of product, Y is the potential yield when pollination is optimal, D represents the crop's dependence on insect pollination, ρ is the degree of pollination contributed.

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The value of total pollination is calculated by replacing ρ with 1. The value of pollination provided by specific taxa, such as the value of all native bee pollination (ρnb) or honeybee pollination (ρhb), is calculated by replacing ρ with ρnb or ρhb, representing the fraction of all pollen grains deposited by native bees or honeybees, respectively.

D represents the fractional reduction in fruit set that occurs when pollinators are absent (Klein et al., 2007, cited in Winfree, Gross & Kremen, 2011). D is measured as $1 - \left(\frac{fpe}{fp}\right)$, where fpe is fruiting under pollinator exclusion conditions, and fp is fruiting with pollinators present.

Subsequently, these authors propose an enhanced approach called "attributable net income" with the intention of improving the valuation of biotic pollination in economically important crops. This method subtracts the cost of inputs used for crop production from the value of pollination, thereby not attributing the value of these inputs to pollinators. The equation modeling attributable net income (equation 2) incorporates the effect of pollination on production costs into the previous equation (equation 1).

$$Vpollination = (P \cdot Y - C * Y) \cdot D \cdot \rho \tag{2}$$

Where: C denotes the variable cost per unit.

In recent decades, blueberry cultivation has expanded globally and emerges as a good study model to assess the impact of pollination on fruit production (Eeraerts et al., 2023). This is because, due to its high dependence on biotic pollination, a systematic management of professionalized pollination services is carried out, mediated by managed hives (of *Apis mellifera* and bumblebees of the genus Bombus depending on the region of the world where it is cultivated), for optimal fruit formation (Cavigliasso et al., 2020; 2021).

Considering the aforementioned conceptual framework, the objective of this work is to make an adjusted estimate of the economic value attributed to biotic pollination, using the production of blueberries in the Argentine Littoral as a case study. The evaluated benefits are attributed to: 1) a greater quantity of fruits produced, 2) a higher quality of these fruits, and 3) a greater uniformity in production, which impacts the harvest and destination of the berries. In this way, our work contributes, on the one hand, by adapting an equation that specifies the multiple impacts of pollination on production, and on the other hand, estimates the economic value of the pollination service by incorporating dimensions not considered before, thus enabling comparative decision-making.

2. METHODOLOGY

2.1. Study System

In the province of Entre Ríos, approximately 805 hectares of blueberry crops (*Vaccinium corymbosum* species) are planted, representing around 27.89% of the national cultivated area, according to a report from the Ministry of Agriculture, Livestock, and Fisheries in 2020. This region serves as one of the main export hubs to European countries and the United States (IBO, 2021).

The data were collected from one of the newer varieties available in the market, namely "Emerald," which already covered an area of 260 hectares in the Northeast of Argentina by the year 2015. There was a trend of increasing its cultivation area through the implementation of new plots or the

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replacement of varieties with low productivity value. The management of the plots, in all cases, follows conventional practices, including nutritional supplementation (fertigation and/or broadcast fertilization) and pruning, primarily aimed at export. This study utilized data from 9 productive plots for the seasons 2016 and 2021 (**Fig. 1**), taken from the same lots with plants of similar age (± 5 years of plantation in the 2016 season).

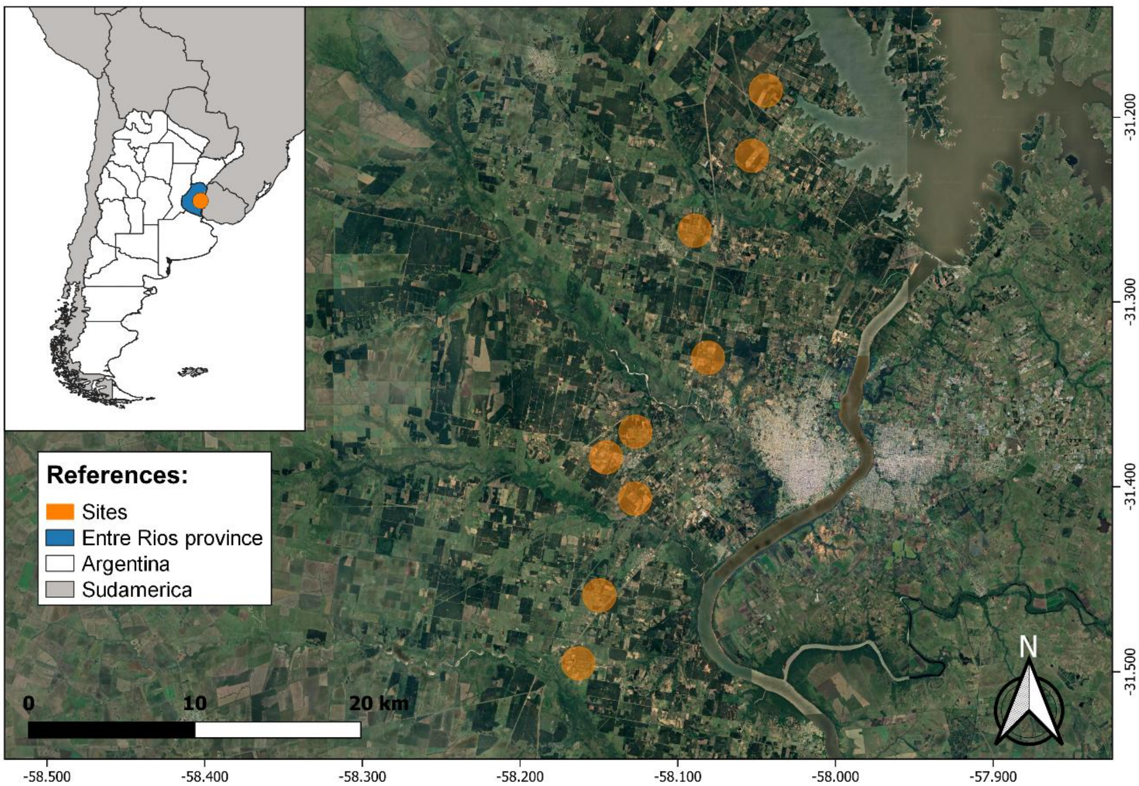

Figure 1. Geospatial distribution of *Vaccinium corymbosum* var. Emerald plots. The map corresponds to the surroundings of the city of Concordia (Entre Ríos, Argentina) and details the spatial location of the plots (n=9) under study.

Traditional pollination services were provided using *Apis mellifera* hives at an approximate density of 10 bee hives per hectare. During the 2017 season, precision pollination practices were implemented in 3 of these plots (see details in Cavigliasso et al., 2021). For clarification, precision pollination involves leveraging knowledge, technologies, and information to influence the behavior of commercial pollinators towards target crops, aiming to optimize the pollination service in different production systems.

2.2 Proposed Economic Valuation Model.

The equation representing the conceptual framework proposed by Winfree, Gross & Kremen (2011) is defined as follows:

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$$\frac{d\pi}{dq} = P * \frac{dY}{dq} - C'(Y) * \frac{dY}{dq} - Cq \quad (3)$$

Where: q is the quantity of pollination service utilized, π is the agricultural profits, so Equation 3 represents how the agricultural enterprise's profits varies with changes in the quantity of pollination service provided. $\frac{dY}{dq}$ is the change in yield resulting from the change in pollination, $C'(Y)$ is the marginal cost of production (the additional cost of producing one additional unit of yield), and Cq is the cost of the pollination service provided, P is the price of the product.

The method presented here considers that the price will also vary with the quantity of ecosystem service ($\frac{dP}{dq}$). This is because greater ecosystem service would enable achieving higher fruit quality. It also considers that total production costs can vary due to increased pollination ($\frac{dC(Y,q)}{dq}$), for example, by reducing fixed costs such as the number of times a plot is entered for harvesting. The term $\frac{dC(Y,q)}{dY} * \frac{dY}{dq}$ is equivalent to the term $C'(Y) * \frac{dY}{dq}$ in Equation 3.

$$\frac{d\pi}{dq} = \frac{dP}{dq} * Y + P * \frac{dY}{dq} - \frac{dC(Y,q)}{dq} - \frac{dC(Y,q)}{dY} * \frac{dY}{dq} - Cq \quad (4)$$

The variation in price with respect to the type of pollination service is due to the following equation, in the case of blueberries in Argentina:

$$P(q) = P_e * \alpha_e(q) + P_f * \alpha_f(q) + P_i * \alpha_i(q) \quad (5)$$

Where: P_e is the price paid per ton of exported blueberries. $\alpha_e(q)$ is the proportion of exported blueberry production, which is a function of the amount of pollination received, as more pollination implies better quality and a higher proportion destined for export. P_f is the price per ton of blueberries destined for fresh consumption. $\alpha_f(q)$ is the proportion of blueberries destined for fresh consumption, with an upper limit representing the highest quality fruit exported and a minimum quality requirement for acceptance. P_i is the price per ton of blueberries destined for the industry. $\alpha_i(q)$ is the proportion of blueberries that did not reach a quality level for fresh marketability.

2.3 Data used for estimation.

The relevant information for applying the proposed methodology falls into two categories: productive and economic. Productive data pertains to how the quantity and quality (weight and caliber) of the produced fruit change under two contrasting baseline situations: With vs. Without Biotic pollination (**Table 1**). Economic data relates to the prices and costs faced by the producers.

Based on the previously proposed dataset (Cavigliasso et al., 2020; 2021; and unpublished data), **Table 1** was compiled to quantify how the average quantity of blueberries produced per hectare

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changes across three different pollination systems: 1. *Sef-pollination*, total absence of pollinators; 2. *Traditional pollination*, where an average of 10 bee hives/ha is introduced into the system in addition to the pollinators available in the environment; 3. *Precision pollination*, where, in addition to the previous condition, strategic pollination is conducted using management techniques and technologies, along with monitoring the degree of interaction of pollinators on the flowers (Cavigliasso et al., 2021).

Table 1. Production and destination of fruit under different pollination scenarios

	Unit	Sef-pollination	Traditional pollination	Precision pollination
Fruit Quantity and Quality				
Formed fruits	%	23.3	69.9	82.9
Weight/berry	g	1.62	2.58	2.9
Firmness/berry	g strength	183.38	260.53	296.62
Fruit destination according to quality *				
Fresh market **	Kg	833.3	9,200.0	11,284.6
Industry	Kg	2,499.7	800.0	575.2

* Quality is assessed based on whether it meets the requirements for being marketed as fresh.

** The Fresh Market considers both fruit destined for the domestic market and the external market.

Through inquiries made to the Association of Producers (APAMA), harvest contractors in the study area, and sales values in the central market, prices and production costs were obtained. In this regard, the producer receives US$ 5.33[1] per kg when marketing fresh produce, whether destined for export or the domestic market. This value decreases to US$ 3 per kg when the fruit is directed towards the industry. The average harvesting cost is around US$ 0.82 per kg. The cost of traditional pollination services in Argentina is US$ 123.29 per hectare. The international precision pollination service, which includes the management of 10 bee hives per hectare, the use of enhancers (products that stimulate foraging in hives and increase the attractiveness of target flowers), and monitoring services, amounts to US$ 2,400 per hectare (**Table 2**).

[1] The price of US$ 5.33 is used for all fresh produce because US$ 5.33 is the average payment for fruit destined for the domestic market throughout the entire season. Meanwhile, US$ 5.16 is the average payment throughout the season for exported fruit. However, these are average prices for the season, and given that export fruit is of higher quality than domestic market fruit, we understand that if the export price is lower than the domestic market price, the fruit that would have been exported would be redirected to the domestic market until the market is balanced. For this reason, it is assumed that the fresh market price is US$ 5.33, coinciding with the domestic market price.

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Table 2. Summary of market and production information used for calculations.

Market information (US$ / Kg)		**Source**
Fruit harvest cost (payment to crew)	0.82	Contractors
Export sale (80 % total)	5.16	FOB Price
Domestic market sale (12 % total)	5.33	Central Market
Industry market sale (8 % total)	3	APAMA
Pollination service cost (10 bee hives/ha)		
Traditional – Argentina	123.29	Beekeepers in the region
Precision – International	2,400	International pollination company
Experimental information - berries according to size and reproductive system (%)		
Biotic pollination < 11 mm	4.85	
Biotic pollination >11 mm	95.15	
Sef-pollination < 11 mm	75.00	
Sef-pollination >11 mm	25.00	

3. RESULTS

Through the proposed model, it was possible to compare the value of pollination between production in the absence of pollinators and the two management scenarios of pollination through honeybee hives. In this way, the economic value of the contribution of pollination service was contrasted according to the specifications developed in the model.

In the case of the "method associated with production value or replacement value" as well as for the application of the attributable net income method, first, the weighted average price of the fruit in the case of traditional pollination was estimated (US$ 5.14). This price is obtained by multiplying the price that the fruit receives according to its destination by the quantity of fruit with that destination in the case of traditional pollination. All of this is then divided by the total quantity of fruit. This is estimated because in the mentioned models, the average price of the known situation is used to make the estimates. Equation 6 expresses the aforementioned.

$$\frac{9{,}200 * 5.33 + 800 * 3}{10{,}000} = 5.1436 \qquad (6)$$

Considering the estimated price of the pollination service, the value of traditional pollination service is estimated by comparing it with self-pollination. This value is approximately US$ 34,169 per hectare. If precision pollination practices are applied, this management approach increases the value of pollination compared to traditional pollination by approximately US$ 7,289 per hectare (**Table 3**).

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Table 3. Comparison of the different methods for estimating the economic value of the pollination service.

	Sef-pollination	Traditional pollination	Precision pollination
Production value method			
Total income	$ 17,143.6	$ 51,436	$ 61,002.1
Pollination service cost *		$ 123	$ 2,400
Margin	$ 17,143.6	$ 51,313	$ 58,602.1
Difference with base scenario (Traditional Pol.)	$ **-34,169.4**		$ **7,289.1**
Attributable net income method			
Total income	$ 17,143.6	$ 51,436	$ 61,002.1
Harvest costs **	$ 2,733.1	$ 8,200	$ 9,725
Pollination service cost *		$ 123	$ 2,400
Margin	$ 14,410.5	$ 43,113	$ 48,877.1
Difference with base scenario (Traditional Pol.)	$ **-28,702.5**		$ **5,764.1**
Proposed valuation method			
Total income ***	$ 11,940.5	$ 51,436	$ 61,872.5
Harvest costs **	$ 2,733.1	$ 8,200	$ 9,725
Pollination service cost *		$ 123	$ 2,400
Margin	$ 9,207.4	$ 43,113	$ 49,747.5
Difference with base scenario (Traditional Pol.)	$ **-33,905.6**		$ **6,634.5**

* Self-pollination scenario without costs. Traditional pollination scenario, cost of service for 10 bee hives/ha (without natural pollinator costs). Traditional pollination scenario, cost of international precision pollination service.

** Harvesting cost includes payment of US$ 0.82 per kg harvested, as reported by contractors.

*** In this scenario, the average price for each scenario changes, as the perceived average price is allowed to vary based on the quality of the produced fruit.

When applying the "attributable net income method" which includes changes in total costs due to increased yield, such as cost differentials associated with harvesting a different volume of fruit combined with pollination service costs, a discrepancy in valuation is observed. The value of traditional pollination service, equivalent to the increase in the quantity of fruit produced, considering harvesting costs, was approximately US$ 28,702 per hectare. When precision pollination practices are applied, the firms' benefit is increased by approximately US$ 5,764 per hectare (**Table 3**).

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When applying the economic valuation methodology of the pollination service proposed in this study, it is considered that the weighted average price in each scenario will differ because the proportions marketed to each destination change. Therefore, the average price remains the same for the traditional pollination scenario. The average price of production in the case of self-pollination is approximately US$ 3.58 per kg. In the case of precision pollination, the average price is approximately US$ 5.21 per kg (Table 3). This difference in the average price is entirely attributable to the change in fruit quality due to increased/decreased pollination.

The value of traditional pollination service, where not only the increase in the quantity of fruit produced considering harvesting costs is estimated but also how the average price of production varies according to different commercial destinations, was approximately US$ 33,905 per hectare. When precision pollination practices are applied, an income higher than traditional pollination is obtained, approximately US$ 6,634 per hectare (Table 3).

It should be clarified that the term $\frac{dCY}{dq}$ in the estimation was not incorporated because the necessary data for such an estimation are not available. Therefore, the analysis assumes that pollination is not affecting the value of variable production costs but is considering how total costs change with variations in production, assuming constant variable costs.

Comparing the different methods available in the literature with the methodology proposed in this study, it can be observed that, in contrast to the production value method, in the no pollination scenario, the loss would be underestimated, while in the precision pollination scenario, the gain would be overestimated. On the other hand, compared to the attributable net income method, in the no pollination scenario, the loss would be overestimated, while in the precision pollination scenario, the gain would be underestimated.

4. DISCUSSION

Through our work, we aim to evaluate an improved approach to assess the value of pollination services using an equation that allows the incorporation of metrics associated with management practices impacting this contribution. This enables the quantification of the baseline value of pollination and facilitates comparisons with pollination systems that aim to reduce pollination deficits or discriminate the value based on the contribution of different organisms or groups of organisms.

In the available literature, this topic is discussed by Winfree, Gross & Kremen (2011), who mention that the most used methods in the literature are special cases of a more general equation (replacement value and production value method). Considering that this method can be enhanced, they propose the attributable net income method. The attributable net income method improves the estimation by considering that, as production varies, so will production and harvesting costs, not just revenues. In this case, *Equation 1* is modified to include a term representing the rate of change in total costs with increased production, leading to the formulation of *Equation 2.*

Breeze et al. (2016) emphasizes the need for dynamic methods adaptable to different systems, regions, and contexts, allowing comparisons between models. The method proposed in our work improves the estimation of the economic value of pollination in a comparative manner, incorporating various inputs associated with different management practices (variations in price and production costs). Thus, we

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propose transitioning from *Equation 2* to the proposed *Equation 4*. To break down the models, in the case of the production value method, the assumptions are that total costs and the average price do not change with variations in the pollination service.

The attributable net income method aims to remove the assumption that total costs do not change with variations in the pollination service. The adopted assumption is that total costs are not directly affected by the pollination service but respond to changes in quantity produced, while the average price in this case is assumed to be constant. The model proposed in this study eliminates both remaining assumptions to obtain an estimation as close to reality as possible. It allows the average price to change with variations in fruit quality and for costs to change due to different characteristics in the production system with different pollination services.

Hence, it can be considered that the difference between the methods lies in the assumptions about which variables pollination affects. In the production value method, it is assumed that pollination only affects revenues through increased production. In the attributable net income method, it is assumed that pollination only affects yield, impacting both revenues and total costs, as price and cost are fixed. Lastly, in the proposed model, it is assumed that pollination can affect everything, not just yield, which would modify costs associated with a higher quantity of harvested fruit, as well as fruit quality, allowing access to better prices. Furthermore, pollination can affect fruit firmness, harvest timing, among other aspects that can enable more efficient harvesting, reducing storage and logistics costs, and even harvesting in temporal windows that yield better prices.

Regarding the assumptions of how pollination affects production, both the production value method and the attributable net income method assume a linear relationship between pollination and yield through the term "D". These methods consider that most plants require a finite number of pollen grains to establish a maximum fruit size, known as the plant's "pollination threshold." In these cases, additional pollen deposited beyond this threshold will not increase or decrease yield. Pollination thresholds can be surpassed in both agricultural and natural environments (Winfree, Gross & Kremen, 2011). For blueberries, the relationship between the amount of deposited pollen and fruit quality behaves as a quadratic function. This means that blueberry flowers have an optimal number of visits at which fruit size is maximum, and beyond that number of visits, the resulting fruit decreases in quality (Ramírez-Mejía et al., 2023; 2024). This information is relevant when considering the optimal hive load per unit area that will result in adequate pollination services and, thus, improve the quantity and quality of blueberries (Garibaldi et al., 2021) while reducing the impact of A. mellifera on wild pollinator communities (Torne-Noguera et al., 2016).

For these reasons, we consider that the proposed method is superior, improving the estimation of the value of pollination services and allowing for comparisons between different management practices and systems. Nevertheless, we understand that, due to the rigor of its calculation, accessing the necessary information for such estimates is not always possible. These limitations lead to adopting assumptions, which tend to align with the models proposed earlier (production value method and/or attributable net income method as applicable), being valid as they allow for a valuation close to reality. In this context, it is essential to consider that differences in values between the estimation

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methods presented may bias the results, highlighting that the production value method overestimates pollination gains, while the attributable net income method would underestimate these gains.

5. Conclusion

The results obtained highlight the importance of having adequate tools for the valuation of pollination services that consider real inputs in contrasting case studies. Given the global relevance of ecosystem services of pollination for the sustainability of quality food production, it is essential for decision-makers and the scientific community to have the most appropriate method for such assessment.

In this regard, our work contributes an equation with sufficient flexibility to absorb the variability presented by a shift in the productive paradigm, paying special attention to its different aspects in a changing market with diverse destinations based on quality and opportunity windows. This makes it more accessible to evaluate the profitability of incorporating new management practices associated with this service.

As a closing remark, its use is proposed as a decision-making tool when making relevant corrections to pollination services within productive areas (supplementing, removing hives, or maintaining initial levels) to improve food production by enhancing contributions from associated biodiversity and increasing profitability. In this context, it is necessary to consider the general context where crops are located, as it is in this context that resources serving as food and refuge for pollinators are found. This allows for the inclusion of the contribution of wild pollinators in this estimation.

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5. REFERENCES

Basualdo, M., & Cavigliasso, P. (2023). Economic assessment of Biotic pollination in crops from Argentina: possible effects of the pollinator crisis in agricultura. Revista de la Sociedad Entomológica Argentina, 82(1), 48-56.

Basualdo, M., Cavigliasso, P., de Avila Jr, R. S., Aldea-Sánchez, P., Correa-Benítez, A., Harms, J. M., ... & Salvarrey, S. (2022). Current status and economic value of insect-pollinated dependent crops in Latin America. Ecological Economics, 196, 107395.

Breeze, T.D.; Gallai, N.; Garibaldi, L.A.; Li, X.S. (2016) Economic Measures of Pollination Services: Shortcomings and Future Directions. Trends in Ecology & Evolution, Volume 31, Issue 12, 927-939. https://doi.org/10.1016/j.tree.2016.09.002.

Cavigliasso, P., Bello, F., Rivadeneira, M. F., Monzon, N. O., Gennari, G. P., & Basualdo, M. (2020). Pollination Efficiency of Managed Bee Species (and) in Highbush Blueberry () Productivity. Journal of Horticultural Research, 28(1), 57-64. https://doi.org/10.2478/johr-2020-0003

Cavigliasso, P., Negri, P., Viel, M., Graziani, M. M., Challiol, C., Bello, F., & Saez, A. (2021). Precision management of pollination services to blueberry crops. Scientific Reports, 11(1), 20453. https://doi.org/10.1038/s41598-021-00068-1

Chacoff, N.P., Morales, C.L., Garibaldi, L.A., Ashworth, L., & Aizen, M.A. (2010) Pollinator Dependence of Argentinean Agriculture: Current Status and Temporal Analysis. The Americas Journal of Plant Science and Biotechnology, 3(1), 106-116

Eeraerts, M., DeVetter, L. W., Batáry, P., Ternest, J. J., Mallinger, R., Arrington, M., ... & Isaacs, R. (2023). Synthesis of highbush blueberry pollination research reveals region-specific differences in the contributions of honeybees and wild bees. Journal of Applied Ecology, 60(12), 2528-2539. https://doi.org/10.1111/1365-2664.14516

Garibaldi, L.A., Steffan-Dewenter, I., Winfree, R., Aizen, M.A., Bommarco, R., Cunningham, S.A., ... & Bartomeus, I. (2013). Wild pollinators enhance fruit set of crops regardless of honey bee abundance. Science. 339(6127): 1608-1611. https://doi.org/10.1126/science.1230200

Garibaldi, L. A., et al. (2021). Negative impacts of dominance on bee communities: Does the influence of invasive honey bees differ from native bees?. Ecology. 102(12): e03526

Gatica Hernández, I, Soto, C., Basualdo, M., & Galmarini, C.R. (2017) Evaluación de la efectividad de *Apis mellifera* y *Bombus pauloensis* como polinizadores para la producción de semilla híbrida de cebolla (Allium cepa L.). Boletín de la Sociedad Argentina de Botánica, 52, 55-56.

Gianinni, T.C., Cordeiro, G.D., Freitas, B.M., Saraiva, A.M., & Imperatriz-Fonseca, V.L. (2015) The Dependence of Crops for Pollinators and the Economic Value of Pollination in Brazil. Journal Economic Entomology, 108(3), 1-9 DOI: 10.1093/jee/tov093

IBO (2022). International Blueberry Organization. Global state of the blueberry industry report. Last view 21/09/22: https://www.internationalblueberry.org/2022-report/

Imperatriz-Fonseca, V.L., Saraiva, A.M., & De Jong, D. (2006) Bees as pollinators in Brazil: assessing the status and suggesting best practices. Ribeirão Preto, Sao Paulo, Brazil.

Klein, A. M., Vaissiere, B. E., Cane, J. H., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C., & Tscharntke, T. (2007). Importance of pollinators in changing landscapes for world crops. Proceedings of the royal society B: biological sciences, 274(1608), 303-313. https://doi.org/10.1098/rspb.2006.3721

Ministerio de Agricultura, Ganadería y Pesca (octubre 2020). Arándanos: Evolución de los principales indicadores del sector productivo. https://www.argentina.gob.ar/sites/default/files/arandanos-oct-2020.pdf

Porto, R.G., de Almeida, R.F., Cruz-Neto, O., Tabarelli, M., Viana, B.F., Peres, C.A., Lopes, A.V. (2020) Pollination ecosystem services: A comprehensive review of economic values, research funding and policy actions. Food Sec. 12, 1425–1442. https://doi.org/10.1007/s12571-020-01043-w

Ramírez-Mejía, A. F., Blendinger, P. G., Woodcock, B. A., Schmucki, R., Escobar, L., Morton, R. D., ... & Chacoff, N. P. (2023). Landscape structure and farming management interacts to modulate pollination supply and crop production in blueberries. Journal of Applied Ecology. 00: 1-11. https://doi.org/10.1111/1365-2664.14553

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Siopa, C., Carvalheiro, L., Castro, H., Loureiro, J., & Castro, S. (2023). Quantifying crop pollinator dependence values--an updated compilation and discussion on methodological approaches. DOI: 10.22541/au.167828466.63884414/v1

Stanley, D.A., Gunning, D., & Stout, J.C. (2013) Pollinators and pollination of oilseed rape crops (Brassica napus L.) in Ireland: ecological and economic incentives for pollinator conservation. Journal Insect Conservation, 17, 1181-1189. DOI 10.1007/s10841-013-9599-z

Torne-Noguera, A., Rodrigo, A., Osorio, S., & Bosch, J. (2016). Collateral effects of beekeeping: Impacts on pollen-nectar resources and wild bee communities. Basic and applied ecology, 17(3), 199-209. https://doi.org/10.1016/j.baae.2015.11.004

Winfree, R.; Gross, B.J.; Kremen, C. (2011). Valuing pollination services to agriculture. Ecological Economics 71: 80–88. https://doi.org/10.1016/j.ecolecon.2011.08.001

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