

Economic analysis of a biotechnical control method against the Box tree moth (*Cydalima perspectalis*) in Türkiye

Análisis económico del método de control biotécnico contra la polilla del boj (*Cydalima perspectalis*) en Turquía

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SUMMARY

The box tree moth poses a threat to the Anatolian boxwood (*Buxus sempervirens*) which has significant economic and ecological value in Türkiye. This study aimed to determine the economic feasibility of pest control with solar-powered light-pheromone (SPLP) traps against the box tree moth in the Ağva Forest District of Şile Forest Enterprise, which is the only region in Türkiye with a management plan for boxwood shoot utilization. For the economic feasibility analysis, approaches including net present value, benefit-cost ratio, and the comparison of discounted finite cost of control with the capital value of infinite revenues were used. Considering the revenues of the Şile Forest Enterprise from the sale of the boxwood shoots in a finite period, it was found that pest control with the SPLP traps is not economical, producing a benefit-cost ratio of 0.371 with a net present value of -229,647.10 TL. In addition to the revenue of the enterprise, after taking into account regional income losses, water production value, and the benefits of other non-market ecosystem services provided by boxwood areas, the benefit-cost ratio increased to 2.688, and pest control became economically feasible. It was determined that the capital value of the infinite annual revenues from boxwood shoots was greater than the present value of the pest control costs against the box tree moth in a period.

Keywords: pest management, Anatolian boxwood, light trap, feasibility, cost-benefit analysis.

RESUMEN

La polilla del boj, representa una amenaza para el boj de Anatolia (*Buxus sempervirens*), que tiene un valor económico y ecológico significativo en Turquía. Este estudio tuvo como objetivo determinar la viabilidad económica del control de plagas con trampas de feromonas de luz alimentadas con energía solar (SPLP) contra la polilla del boj en el distrito forestal de Ağva de Şile Forest Enterprise, que es la única región de Turquía con un plan de gestión para la utilización de los brotes de boj. En el análisis de viabilidad económica, se utilizaron enfoques que incluían el valor actual neto, la relación costo-beneficio y la comparación del costo finito de control descontado con el valor de capital de los ingresos infinitos. Considerando los ingresos de Şile Forest Enterprise por la venta de los brotes de boj en un período finito, se encontró que el control de plagas con las trampas SPLP no es económico, produciendo una relación costo-beneficio de 0,371 con un valor presente neto de -229.647,10 TL. Además de los ingresos de la empresa, considerando las pérdidas de ingresos regionales, el valor de la producción de agua y los beneficios de otros servicios ecosistémicos no comerciales proporcionados por las áreas de boj, la relación costo-beneficio aumentó a 2,688 y el control de plagas se volvió económicamente viable. Se determinó que el valor de capital de los ingresos anuales infinitos de la utilización de los brotes de boj era mayor que el valor actual de los costos de control de plagas contra la polilla del boj en un período.

Palabras clave: manejo de plagas, boj de Anatolia, trampa de luz, factibilidad, análisis de costo-beneficio.

INTRODUCTION

The most common boxwood species in Türkiye is the Anatolian boxwood (*Buxus sempervirens* L.). Anatolian boxwood has a native distribution in the European continent, including Portugal, the Pyrenees region in Spain, the

island of Corsica in France, the island of Sardinia in Italy, southwest Germany (Baden - Württemberg), the Balkans (including Bulgaria, extending to Greece), and north Africa (Morocco, Algeria and Libya) (Gökmen 1973). Naturally grown boxwood, which was previously utilized as raw wood material, started to be sought as an ornamental plant

because of its structure is suitable for pruning as well as its aesthetic appearance, and was widely used in parks, gardens, and urban spaces (Ürgeç 1998).

Currently, florists commonly use boxwood shoots in products such as flower baskets, arrangements, and wreaths, and they typically choose shoots obtained from forests due to their low cost. According to the statistical database of Türkiye's General Directorate of Forestry (GDF), 560,677 kg (81,375 bales) of boxwood shoot utilization was permitted and an annual average of 37,378 kg yr⁻¹ (5,425.03 bales yr⁻¹) of boxwood shoot was consumed during 2000 - 2019 in Türkiye (GDF 2021). However, field studies have reported that florists just in İstanbul city consume 1,252,374.63 kg yr⁻¹ (181,767 bales yr⁻¹) of boxwood shoots (Atıcı 2012) and have shown extensive utilization of boxwood.

Despite its slow growth, boxwood has been subjected to significant damage from wood and shoot utilization, neglected in forest management plans, and has become a tree species that can be found in small micro-ecosystems (Türkyılmaz and Vurdu 2003). Further, it is now threatened by the box tree moth, *Cydalima perspectalis* (Walker 1859) (Lepidoptera: Crambidae). In Türkiye, the box tree moth was first reported in 2011 in parks and gardens in Sarıyer, İstanbul and then in Düzce, Artvin, Bartın, and Kastamonu between 2015 and 2018 (Hızal *et al.* 2012, Yıldız *et al.* 2018). It possibly entered Türkiye from China and Europe via imported plants (Hızal *et al.* 2012) and spread very rapidly, with its population reaching a size that may result in the extinction of boxwood.

In addition to the threats from humans and insects, boxwood needs to be preserved *in situ* due to its biophysical characteristics and ecological demands (Çolak 2003). Boxwood stands serve as nesting sites, shelter, and feeding areas for many animals, especially birds (Meister 1990). The density of its structures provides shade to the cool, loose, moderately calcareous soils where they usually grow and regulates water flow in streams. Due to the value of its wood or shoots and ecological benefits such as biodiversity and soil protection, further analysis of strategies for insect control on boxwood is required.

Chemical methods have not been used to control the box tree moth in Türkiye for ecological reasons. Biological techniques have been used in the control of box tree moth larvae, while biotechnical approaches are preferred for adult butterflies. Although there is no pheromone licensed in Türkiye yet (GDF 2016), a biopreparation with the trade name Foray 70B containing *Bacillus thuringiensis* var. *kurstaki* (Btk), an entomopathogenic bacteria that is a natural enemy of the pest, as the active component was used against box tree moth larvae in Karabük (Yenice), Kastamonu (Cide), and Zonguldak provinces. Initially, a biotechnical method called the pheromone delta trap was used against adult box tree moths. As this method was not successful at controlling pests in Artvin nor in Zonguldak, Kastamonu and Bartın provinces, solar powered light-

pheromone (SPLP) traps were used in areas of pest distribution in the western Black Sea Region. The solar energy panel in these traps stores energy by using daylight, then serves as a source of nightlight as required by the system. The SPLP traps that emit light at night attract mostly adult moths to the gathering funnel, and owing to the chemical the funnel contains, the pest that enters the system is prevented from exiting it.

Currently, there is no literature regarding the ecological consequences of using these pest control techniques. However, according to expert observations, it is considered that the SPLP traps in particular may cause less ecological harm than other control techniques. The SPLP traps are regarded as a technically feasible control tool, but they have been considered expensive due to their high installation and maintenance costs.

In the past, the economic cost of insect damage to forests was calculated based on the market price of wood and the change in value of forest land and growing stock over time (Fırat and Miraboğlu 1962). However, research of this issue and the implementation of study results have not been very common outside of North America. Holmes *et al.* (2009) stated that the economic dimension of insect damage is underestimated in many studies, because it is calculated by multiplying the price of the damaged product with its quantity or by using the value of the final products. It may be emphasized that employing pest control expenditures alone is an underestimation of the economic dimension of the damage. Theoretically, sound methods such as cost-benefit, cost-effectiveness, and economic impact analyses can be used in the economic analysis of insect damage in forests (Niquidet *et al.* 2016). In particular, cost-benefit analysis provides the opportunity to learn and compare the feasibility of alternative strategies for pest control. In cost-benefit analysis, the benefits provided by forests can be quantified using market prices (*e.g.* wood and non-wood products) as well as non-market values of ecosystem services. Rosenberger *et al.* (2012) reviewed 22 studies to estimate the economic value of insect damage to forest ecosystem services such as recreation, landscape, and biodiversity conservation in the United States of America. In these studies, methods of contingent valuation, hedonic pricing, travel cost, and choice experiments were applied. Various studies have been carried out in North America, including economic impact analyses (Holmes *et al.* 2009) and cost-effectiveness and threshold analyses (Fox *et al.* 1997) to measure the effects of forest pests on the regional or national economy, and macroeconomic indicators.

As stated by Gatto *et al.* (2009), the economic analysis of insect damage has not been sufficiently studied across the world. In the literature, a few economic analyses have been conducted on insect damage in European forests, which include a cost-effectiveness analysis of pest control strategies against bark beetles in England (O'Neill and Evans 1999), economic value of insect damage based on timber sales in the forests of Finland (Lyytikäinen-Saaren-

maa 2003) and Belgium (Franklin *et al.* 2004), and cost-benefit analysis of pest control strategies in Portugal's pine forests (Gatto *et al.* 2009). A detailed review of studies in Türkiye included examinations of bark beetles and blue rot and explanations of the impact on growing stocks and log sale prices, but these studies did not focus on methods for determining economic losses (Öztürk 2020).

However, the damages caused by insects to non-wood forest products and services, as seen in the example of boxwood shoot utilization, have not been elucidated in the literature. Furthermore, no studies have analyzed the economics of any control technique for the box tree moth in Türkiye or in any other country. An equally important issue is that of guiding forest resource managers by testing whether a technically feasible control method is also economically feasible. Research of the economic aspects of entomological problems was recommended in 2018 (ENFITO 2021) as a conclusion of the 3rd Türkiye Forest Entomology and Pathology Symposium (ENFITO). Therefore, the aim of this study was to investigate using different economic analysis methods whether using SPLP traps to control the invasive box tree moth, a boxwood pest whose distribution areas are declining rapidly, is economically feasible.

METHODS

Study area. The Şile Forest Enterprise is the main source of boxwood shoots annually used for floriculture in İstanbul (Ok *et al.* 2012). In consideration of this, the Boxwood Shoot Non-Wood Forest Products and Services Management Plan, Türkiye's first and only boxwood shoot management plan, was prepared in the Ağva Forest District (figure 1) of the Şile Forest Enterprise. Some additional examinations were conducted by Ok *et al.* (2012) in the same field, and 233.4 hectare (ha) of boxwood areas were identified within the boundaries of the Ağva Forest District. According to the management plan, sustainable shoot utilization for 143.8 ha boxwood area was planned for 2014 - 2021, considering the seven years required to grow shoots for market demand (Ok *et al.* 2012). 89.6 ha of the boxwood area was not utilized in this period due to factors such as road and land slope, and only maintenance work could be performed in that area (GDF 2013). Considering that a boxwood shoot of desired market quality can grow in seven years under local ecological conditions (Ok *et al.* 2012), Ağva boxwood forests were divided into seven utilization blocks, forest compartments where annual shoot yields were determined (table 1).



Figure 1. Study area: Ağva Forest District

Sitio de estudio: distrito forestal de Ağva

An attempt for shoot utilization has been initiated by implementing the plan covering the utilization area and levels shown in table 1. In addition to some administrative problems, the box tree moth spread rapidly to Ağva forests, leaving no remaining usable shoots and areas that appear as if burned by fire. The optimal boxwood shoots use areas that can be utilized after necessary maintenance work is carried out under the assumption that pest control could be implemented are also included in table 1. Ağva boxwood areas were chosen as the research area in this study, both because there is a utilization plan for this region and because it is hindered by insect damage.

Economic analyses. Until the issue in Ağva was understood and a pest control method was chosen, no usable shoots remained. On the other hand, pest control using light-pheromone traps, a biotechnical method, has been used in some regions of the country and has been deemed technically feasible but costly, limiting its use. The size of boxwood fields and shoot yield data of the regions where the technique is applied is limited compared to the area in Ağva, and the data are insufficient in terms of economic analyses. Therefore, the study was planned under the assumption that the cost data of the control technique using the SPLP traps were to be obtained from the regions where it was applied and a decision was to be made whether or not to implement a control plan in Ağva in 2014.

However, the economic analysis should consider all possible revenues from and benefits of pest control against the box tree moth finitely or infinitely. After the pest control is implemented, the boxwood may be salvaged and losses in shoot yield, wood yield increment, and ecosystem services may be encountered for just one period. If no control method is implemented, the boxwoods may not survive, thereby potentially resulting in permanent depri-

vation of revenues and benefits from boxwood. Therefore, an economic analysis of pest control against the box tree moth for a finite seven-year production period as part of the management plan of boxwood shoots, as well as an infinite analysis period, were performed separately.

In the economic analysis performed for the finite period, control costs, shoot sale revenues of the forest enterprise conducting pest control, harvesters and intermediary incomes from shoot sales, water production value of the boxwood forests, and the value of general ecosystem services were discussed separately and step by step. In the finite periodic analysis of insect control, net present value (*NPV*) for the forest enterprise and benefit-cost ratio (*BCR*) for the society were used. The *NPV* of pest control for the enterprise in the finite period was calculated using the following equation.

$$NPV = \sum_{i=1}^n (R_i - C_i) / 1.0r^i \quad [1]$$

where *R* refers to boxwood shoot sale revenues, *i* represents the number of years, *C_i* refers to the SPLP traps installation and maintenance costs, and *r* is the discount rate accepted as 3 % in forestry economics studies in Türkiye (Fırat and Miraboğlu 1962).

BCR was calculated using the equation (2) within the framework of social cost-benefit analysis of box tree moth control for the finite period. In the equation (2), while *n* and *r* represent the same variables with the equation 1, *B_i* denotes the annual benefits and *C_i* denotes the annual costs of pest control.

$$BCR = \sum_{i=1}^n (B_i / 1.0r^i) / \sum_{i=1}^n (C_i / 1.0r^i) \quad [2]$$

In the infinite analysis approach, the present value of insect control costs in one period and the capital value of

Table 1. Shoot utilization areas and yields in the Ağva Boxwood Management Plan.

Áreas de uso y rendimiento de los brotes de boj en el Plan de Manejo de Boj de Agva.

Harvest year	Utilization area	Quantity of shoot yield			Optimal utilization area	Optimal shoot yield
	ha	kg	Bunch ^a	Bale ^b	ha	Bale
2014	16.30	26,191	17,141	3,801	29.10	6,786
2015	16.60	26,640	17,435	3,866	29.40	6,848
2016	18.50	29,761	19,477	4,319	31.30	7,308
2017	18.90	30,384	19,885	4,410	31.70	7,396
2018	24.50	39,277	25,705	5,701	37.30	8,679
2019	23.50	37,691	24,667	5,470	36.30	8,450
2020	25.50	41,013	26,841	5,952	38.30	8,940
Total	143.80	230,957	151,150	33,521	233.40	54,407
Average	20.54	32,994	21,593	4,789	33.34	7,772

^a 1 Bunch = 1.528 kg, ^b 1 Bale = 6.89 kg (Ok *et al.* 2012)

infinite annual shoot revenues were compared. The capital value of the infinite annual shoot revenues (R_0) was calculated using the equation (3), and the present value of pest control costs (C) was calculated using the equation (4).

$$R_0 = \bar{R}/0.0r \quad [3]$$

$$C = \sum_{i=1}^n C_i/1.0r^i \quad [4]$$

In equation (3), designed by using a well-known formula in forest economics (Firat and Miraboğlu 1962), the capital (present) value of the infinite annual revenues (R_0) is calculated. It is accepted that the infinite annual revenues will start to be obtained after 7 years of insect control and R_0 is calculated considering the year 2020. R' denotes the infinite revenues that can be obtained by the forest enterprise from boxwood shoot sales in an average year, and r denotes the discount rate. On the other hand, C represents the present value of all pest control costs in 2014. In order to compare R_0 and C values of different times, R' was calculated by discounting the R_0 value to 2014 using the equation (5).

$$R' = R_0 \times (1/1.0r^n) \quad [5]$$

When the R' and C values were compared, $C < R'$ was accepted as an indicator that pest control is economical. As shown in the equation (6), the ratio of these two parameters was defined as the long-term cost-return ratio (CRR).

$$CRR = R'/C \quad [6]$$

CRR values were calculated for both actual and optimal shoot utilization areas (CRR_{actual} and $CRR_{optimal}$ respectively). $CRR_{optimal}$ was used to compare with the BCR values through a sensitivity analysis based on variability in the number of traps.

Shoot sale prices (table 2) used in revenue calculations for economic analyses were obtained from the results of the market research conducted by Ok *et al.* (2012) and were used after conversion to 2021 January real prices via Turkish Statistical Institute, Consumer Price Index. The sale price of one bale of boxwood shoots of the forest enterprise and the purchase and sales prices of the harvester, intermediaries, or end-consumer florists are different. It was considered that the shoots destroyed by the box tree

moth were to be cut with the permission of the forest enterprise, and the revenue of the enterprise (B_{ent}) was assumed 4.58 TL bale⁻¹. Local harvesters, who sell the same shoot to intermediaries with permission from the forest enterprise, also earn income (B_{har}). It has been accepted that this earning was 2.67 TL bale⁻¹, and the same bale would generate income for intermediaries (B_{int}) in a similar way.

As seen in table 1, 89.6 ha of boxwood areas in the region are excluded from shoot utilization. Boxwood areas in Ağva region generally span the Goksu and Yesilcay watersheds and are parallel to the stream slopes. They provide ecosystem services including water quality improvement and erosion control with coastal vegetation. However, no studies have reported on the value of ecosystem services of the forests of the Ağva region or boxwood areas within the scope of non-market values, and conducting such valuation studies with these techniques means conducting separate research. As a matter of fact, this issue was expressed in a study by Gatto *et al.* (2009) that aimed to determine the damage caused by pine beetles in Portugal using the benefit transfer method (*i.e.* transferring value estimates from original valuation studies in other sites). The same approach was applied in this study, and it was considered that the value of 317.19 TL household⁻¹ stated by the local community for the water produced by the forests in the Vize Pabucdere watershed (Şahin *et al.* 2021), located within the borders of Kırklareli with a similar socio-economic structure to the Ağva community, could be used in this study. The value estimated for Pabucdere was converted to 2021 as real value (522.09 TL ha⁻¹), and it was assumed that 233.4 ha area of the forests in the Ağva region could contribute to the water production of Yesilcay and Goksu watersheds at least as much as the forests in the Pabucdere region, resulting in a total water production value (B_{wat}) of 8,176.37 TL for approximately 1,075 households living permanently in these stream watersheds.

It is unrealistic that the 89.6 ha boxwood area, excluded from shoot production according to the management plan, could not produce any other value. Assuming that these areas can also produce an ecological value (B_{eco}) comparable to a similar field and no less than the market value of the shoots, the value of these areas was included in the analysis.

To calculate the costs required for the analysis, negotiations with the forest enterprises and the price offers they re-

Table 2. Shoot prices used in the economic analyses.

Precios de los brotes utilizados en los análisis económicos.

Years	Sale price by the forest enterprise (TL bale ⁻¹)	Sale price by harvesters (TL bale ⁻¹)	Sale price by intermediaries (TL bale ⁻¹)	Florist sale price (TL bale ⁻¹)
2010	1.58	2.50	5.33	6.66
2021	4.58	7.25	15.47	19.32

ceived were used. According to the price offers submitted to the forest enterprise, it was determined that one SPLP trap could be purchased for 1,750 TL and that remuneration was 2,000 TL unit⁻¹ for the installation and maintenance of the traps, the supply of necessary consumables, removal of the traps at the end of pest control, and delivery of the traps to the forest enterprise. It was found that the most basic elements of the SPLP traps were the solar cells, which have an average lifespan of 7 years. Therefore, it was assumed that the forest enterprise could use the purchased equipment for 7 years and receive installation and maintenance service in the first year, after which the maintenance would be conducted with a consumable cost of 25 % of the remuneration in the following years. Based on the experience of practitioners, it was assumed that pest control by setting up one SPLP trap per 4 ha may be sufficient and thus, 58 traps would be set for all boxwood areas, although there may be variations according to the slope of the land and the density of the forest cover at the site where it is set up.

In the analysis of the economic impacts of boxwood loss despite a period of box tree moth control, the present value of insect control costs (C) for 2014 - 2020 was calculated using equation (4). Then, if the insect control was successful, it was assumed that the annual shoot production (4,789 bales year⁻¹) in table 1 was infinite and that the forest enterprise could sell this product at a price of 4.58 TL bale⁻¹ (table 2). In order to calculate the CRR values, the average annual revenue of the enterprise for both the actual and optimal shoot areas were derived using the planned seven year shoot sales revenue.

RESULTS

Net present value of box tree moth control in the finite period. Considering that the Şile Forest Enterprise initiated the control program with the SPLP traps in 2014 to protect the boxwood shoots by predicting the box tree moth problem, which started to become widespread in 2012, the resultant revenue and expenses are shown in table 3.

As seen in table 3, even if pest control was successful and shoot revenues were obtained in the same period, and considering the price of 4.58 TL bale⁻¹ including the tariff price and distribution expenses, demanded by the forest enterprise in return for the shoots, purchasing, installing and maintaining the SPLP traps for seven years could not produce a positive NPV (-229,647.10 TL) and setting the traps was not economically feasible.

Cost-benefit analysis of box tree moth control in the finite period. The benefits that can be gained through boxwood moth control, the costs incurred and the present values were calculated to perform the cost-benefit analysis (table 4). Considering all the benefits of boxwood moth control in the finite approach, it is indicated in table 4 that the discounted benefits are higher than the discounted costs, so the net present value is positive.

The BCR values calculated using different benefit combinations by processing the findings in table 4 into equation (2), within the framework of a finite approach, are presented in table 5. As can be seen in table 5, in accordance with the NPV results (table 3), implementing a pest control plan against the box tree moth taking only the forest enterprise revenues (B_{ent}) into account results in a BCR of 0.371. However, the benefits of the shoots for the local community, the regional economy, and other social and ecological benefits should also be considered. Accordingly, the income of the harvesters from boxwood areas gained through cutting shoots and selling them to intermediaries was added to the analysis as a second benefit (B_{har}), which increased the BCR to 0.587 (table 5). When the B_{ent} and B_{har} benefits are considered together, it can be inferred that box tree moth control was not economically feasible in terms of the revenues to the forest enterprise and the incomes of the local community. However, as can be seen in table 5, when the benefits of the intermediaries from the shoots (B_{int}) were included in the calculations as a benefit of box tree moth control, the BCR increased to 1.564 and pest control became economically feasible.

Table 3. Net present value of box tree moth control.

Valor actual neto del control de la polilla del boj.

Years	R_i (TL)	C_i (TL)	$B_i - C_i$ (TL)	NPV (TL)
2014	17,409.98	218,813	-201,402.50	-195,536.40
2015	17,708.45	29,000	-11,291.60	-10,643.40
2016	19,783.07	29,000	-9,216.90	-8,434.80
2017	20,197.20	29,000	-8,802.80	-7,821.20
2018	26,108.66	29,000	-2,891.30	-2,494.10
2019	25,054.39	29,000	-3,945.60	-3,304.40
2020	27,262.30	29,000	-1,737.70	-1,412.90
Total	153,524.05	392,813	-239,288.40	-229,647.10

It was considered that Ağva boxwood forests also provide a benefit similar to the contribution of forests in the Pabucdere watershed to water production (B_{wat}), and including this benefit in the calculation resulted in a further increase in the BCR (1.704), making pest control economically feasible. A BCR of 1.704 is a result of the water production value of the 233.4 ha boxwood vegetation and the shoot production benefits of the 143.8 ha boxwood forest, indicating that the 89.6 ha boxwood field does not produce any benefits. In the expanded cost-benefit analysis, assuming that the 89.6 ha of non-production area provides the functions of soil conservation, biodiversity improvement, and carbon capture (B_{eco}) at least at the value produced by the shoot production areas, the final result shown in table 5 was obtained and the BCR increased to 2.688.

Economic analysis of the control method based on the infinite approach. As a pest control management option, an economic feasibility test for the strategy comprising the pest control expenses of the SPLP traps for 7 years (2014 - 2020) without any revenue from shoots, and infinite and continuous annual revenues starting from 2021 were conducted. With the success of moth control, the average annual revenue that can be obtained from the actual shoot

utilization area of 143.8 ha ($\bar{R}_{actual} = 21,932.01$ TL) and the average annual revenue ($\bar{R}_{optimal} = 35,598.34$ TL) that can be generated in the event that all boxwood fields become usable were calculated separately. By substituting the average annual revenue from the actual shoot utilization area in the equations (3) and (5), the R'_{actual} was obtained for actual boxwood utilization areas. When the same calculation was repeated for optimal utilization areas, the value of infinite annual shoot revenues ($R'_{optimal}$) to be obtained from the optimal areas by only changing the annual revenue level ($R'_{optimal}$) in the above equation was calculated. By using these values, the variables to derive the CRR values within the framework of infinite approach and the CRR values have been calculated and the results are shown in table 6.

The results shown in table 6 indicated that $C < R'_{actual} < R'_{optimal}$ and that finite pest control was economical with an infinite approach when both actual and optimal areas were considered.

To compare these findings with the BCR , CRR was calculated separately for the actual and optimal shoot areas. Since box tree moth control was performed in the entire area regardless of the utilization status, the capital value of the control expenses in the actual and optimal areas did

Table 4. Benefits and costs of boxwood moth control.
Beneficios y costos del control de la polilla del boj.

Years	B_{ent} (TL)	B_{har} (TL)	B_{int} (TL)	B_{wat} (TL)	B_{eco} (TL)	C_i (TL)	Discounted total benefits (TL)	Discounted total costs (TL)
2014	17,410	10,149	45,882	8,176	57,647	218,813	135,208	212,439
2015	17,708	10,323	46,668	8,176	57,647	29,000	132,457	27,335
2016	19,783	11,533	52,136	8,176	57,647	29,000	136,608	26,539
2017	20,197	11,774	53,227	8,176	57,647	29,000	134,181	25,766
2018	26,109	15,221	68,806	8,176	57,647	29,000	151,783	25,016
2019	25,054	14,606	66,028	8,176	57,647	29,000	143,638	24,287
2020	27,262	15,893	71,846	8,176	57,647	29,000	147,027	23,580
Total	153,524	89,500	404,593	57,234,59	403,528	392,813,00	980,902	364,962

Table 5. BCR values with different benefit combinations.
Valores de BCR con diferentes combinaciones de beneficios.

Benefits	BCR
B_{ent}	0.371
$B_{ent} + B_{har}$	0.587
$B_{ent} + B_{har} + B_{int}$	1.564
$B_{ent} + B_{har} + B_{int} + B_{wat}$	1.704
$B_{ent} + B_{har} + B_{int} + B_{wat} + B_{eco}$	2.688

Table 6. Variables and CRR values based on the infinite approach.
Variables y valores CRR basados en el enfoque infinito.

Variables	Values
R'_{actual}	594,424.33 TL
$R'_{optimal}$	964,823.61 TL
C	364,962.20 TL
CRR_{actual}	1.629
$CRR_{optimal}$	2.644

not change, and for each TL cost incurred due to this pest control, 1.629 TL was earned from the actual utilization areas and 2.644 TL from the optimal areas. According to these results, 7 - year pest control management is an economically feasible decision in the long term.

Sensitivity analysis. The results so far demonstrate the economic feasibility of the technique when one SPLP trap is used per 4 ha. A sensitivity analysis was conducted to see the effect of changing the number of traps on the results. It was deemed sufficient to perform the sensitivity analysis based on the current value of the control costs and the capital value of the infinite revenues to be obtained with this control, with the cost-benefit analysis that takes into account all the benefits in cases where the control was found to be economical.

As can be seen in figure 2, if one trap is placed per 4 ha of boxwood forest, it is necessary to set 58 traps for 233.4 ha. Using this number of traps produces 2.688 units of *BCR*, while producing 2.644 units of *CRR_{optimal}*. If the number of traps used is increased to one per 3 ha (78 units, 0.33 unit ha⁻¹), one per 2 ha (117 units, 0.50 unit ha⁻¹), one per 1.5 ha (155 units, 0.67 unit ha⁻¹), and one per 1 ha (233 units, 1.00 unit ha⁻¹), the resulting ratios are substantially comparable.

The number or frequency of traps that produce results above 1.0 in the ratio axis in figure 2 represent the economically feasible area. In other words, increasing the total number of traps in the 233.4 ha boxwood forest up to 117 (0.50 unit ha⁻¹) is an economically sound decision in terms of both *BCR* and *CRR_{optimal}*. However, if one trap is to be placed per hectare, this decision is not found to be economically feasible unless the calculated benefits and revenues increase. Although it seems possible to increase the total number of traps to 155, based on the *BCR* alone, this decision is not economical in terms of *CRR_{optimal}*. Therefore, pest control using more than 117 traps for the 233.4 ha boxwood forest in the Ağva region does not seem economically appropriate.

DISCUSSION

In the literature, there is no study regarding the economic damage caused by the box tree moth. Although Korycinska and Eyre (2011) reported that this insect causes great damage to boxwood grown with high costs in cities, they did not determine the economic extent of the damage in terms of shoot utilization for floriculture or decoration, loss of raw wood materials or forest ecosystem services. The economic analyses made in this study revealed that not implementing a pest control plan against the box tree moth in the Ağva district resulted in a loss of 171,413 TL (US\$1 equals 7.4024 TL as of January 2021) in terms of shoot sales revenues of the forest enterprise. Based on the present value of the infinite revenues lost by the enterprise, this loss increased to 731,066.95 TL. Undoubtedly, it is necessary to calculate the damage caused by the box tree moth in the Ağva district in consideration of the loss of all values included in the cost-benefit analysis. Considering the losses in harvesters' and intermediaries' income, water production, and ecosystem services in addition to the loss of the enterprise revenues, the total loss caused by the box tree moth in 2014 - 2020 increased to 1,242,577 TL with 2021 values. When the infinite capital value of the average annual revenue loss in the same period was calculated, the total loss was estimated to be 5,277,995 TL.

The loss due to the damage caused by bark beetles in Artvin Regional Directorate of Forestry's spruce timber sales in Türkiye in 2002 - 2007 was estimated to be nearly \$2 million (37,320,600 TL) according to a study by Öztürk *et al.* (2008). It can be assumed that a comparison can be made of the damage caused by the box tree moth in the Ağva region and that caused by the bark beetles. However, instead of comparing the level of damage calculated for a region or insect with damage to another region or by another insect, it is necessary to focus on comparing the benefits provided with the pest control costs. Similar to the

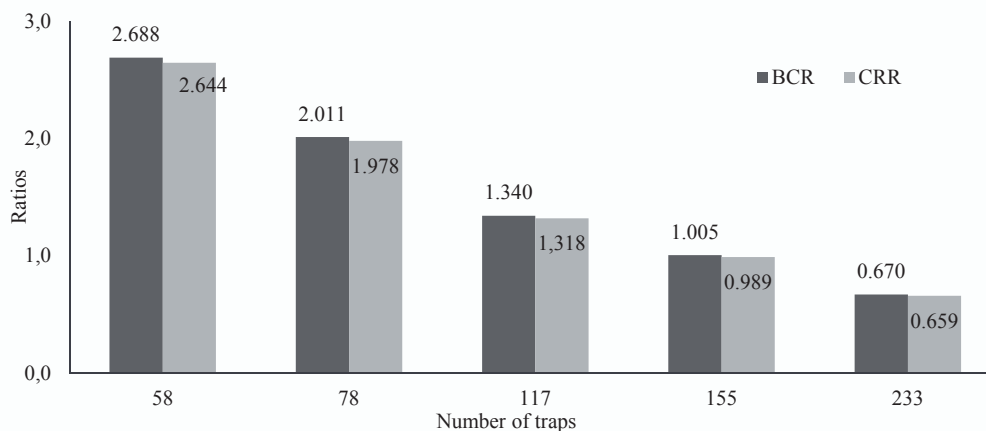


Figure 2. Economic effects of changing the number of traps used per unit area.

Efectos económicos de cambiar el número de trampas utilizadas por unidad de área.

example of private forest owners in Portugal reporting that pest control plans were costly (Gatto *et al.* 2009), it can be said that forest resources managers in Türkiye also consider such control methods as expenses that are uncompensated.

The principle of sustainability in forest management should be a guiding factor in determining the economic feasibility of pest control techniques. Incorrect outcomes are produced from analyses that consider tariff prices, which are kept low to support forest villagers and to encourage them away from illegal use, as the forest enterprises' only revenue. Therefore, it is not fair to claim that the technically and ecologically feasible control techniques are not economically feasible only after considering the production cost of the biological control material, *i.e.* the price of a single trap or a unit of pheromone to be purchased. Although advanced methods are required to determine the value of ecosystem services, it should be noted that the classical forestry economics valuation formulas used in this study can also be applied to the evaluation of losses from insects and the selection of pest control methods.

In a finite period and focusing only on forest enterprise revenues, box tree moth control may not seem economical. However, according to our study, given the benefits to the local community, intermediaries, and ecosystem service beneficiaries, pest control may be economical. Further, pest control may be economically feasible when long-term forestry enterprise targets are set in accordance with the sustainability principle of forestry. Gatto *et al.* (2009) also determined in the example they investigated that pest control, which was not cost-effective in the short term, could be economical in the long term. Therefore, when the findings of both studies are evaluated together, it is concluded that calculation approaches for a longer term should be preferred when deciding whether to implement pest control.

According to Öztürk (2020), one of the widely used approaches in determining the economic effects of insect damage in forestry is the cost-effectiveness approach based on a cost-benefit comparison of pest control. Indeed, in this study, the cost-benefit analysis approach produced a result that better reflects the real-world data compared with the results of the *NPV* or internal rate of return approaches. However, further cost-benefit analyses should include financial yields such as the value of boxwood wood, which was excluded in this study, and values that cannot be measured with market prices, which were theoretically included in our analysis. Boxwoods, which are about to become extinct under the threat of the box tree moth, may also contain monumental boxwood and their bequest, option, and existence values may also disappear. Hence, ways of integrating advances in valuation methods into such analyses should be attempted without causing any confusion about means and purpose. In other words, in cases where some benefits are not included in the analysis because their value cannot be determined, it should be noted that those options that are found to be economical, even without including these values, will continue to be economical when other benefits are added.

As seen in the example of pest control, in a project where benefits are collected in the first (last) years and costs are accumulated in the last (first) years, a feasible decision may become impossible when the discount rate changes. In this study, 3 %, a generally accepted rate of return in forestry, was used in analysis. On the other hand, Gatto *et al.* (2009) used a lower (2 %) discount rate for calculating the damage caused by pine beetle to industrial wood production. Although wood yield was not included in this study, it may be assumed that a smaller discount rate should also be used for a very slow-growing species such as boxwood. However, when the discount rate of the analysis was reduced to 2 % while keeping other conditions constant, the *BCR* calculated after considering all the benefits within the scope increased to 2.731. The discount rate is a variable that also affects the capital value of infinite annual revenues. Accordingly, when the analysis based on infinite annual revenues was repeated with a 2 % discount rate, the present value of the expenses made for box tree moth control was estimated to be 373,778 TL and the capital value of infinite annual revenues discounted for the same period was estimated to be 1,549,524 TL, indicating that the economic feasibility of box tree moth control remains unchanged. However, when the *BCRs* are calculated by increasing the discount rates to 6 %, 12 %, and 18 % in a way that better reflects the market costs of capital, ratios of 2.564, 2.343, and 2.155 are obtained, respectively. These results demonstrate that pest control against the box tree moth at the risk of incurring higher capital costs continues to be economical.

CONCLUSION

In conclusion, pest control against the box tree moth using SPLP traps, though seemingly expensive, is an economically feasible control technique in the long term, considering the losses in forest enterprise revenues, losses in harvest and intermediary incomes, and damages to ecosystem services. The fact that judgment of the economically feasible level of the SPLP traps as a pest control technique demonstrated in the study depends on the sustainability of ecological benefits justifies the need for further research to determine the economic value of ecosystem services exposed to insect damage. However, the purpose of valuation should not be to use more complex and expensive valuation methods, but to apply the method that produces enough information to make an informed decision. To decide which pest control techniques should be carried out in a limited time, infinite approaches, which are also compatible with the sustainability principle of natural resource management, should be preferred.

ACKNOWLEDGMENTS

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

AUTHOR CONTRIBUTIONS

All authors contributed to the study conception and design; K.O. and S.Ü. collected the data; K.O. performed the economic analyses; all authors interpreted the results; K.O. and S.Ü. wrote the first draft of the manuscript; all authors reviewed and edited the manuscript; all authors read and approved the final manuscript.

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Recibido: 17.10.21

Aceptado: 13.12.22