

SITUATION AND EVALUATION OF BIOLOGICAL AND CHEMICAL CONTROL APPLICATIONS FOR FOREST IN TURKEY

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Abstract. Pest insect species cause important economic losses in Turkish forests by feeding on various parts of forest trees. To combat them, control methods such as chemical, biotechnical, mechanical and biological applications are used. Among them, biological control is the most important method for the ecological aspect. Technically, the first biological control practice in Turkish forests was launched in the last part of the 1960s. This study aimed to evaluate current control methods for Turkish forestry. For this purpose, biological and chemical control applications in Turkey have been examined and compared. Necessary data were obtained from the 28 Regional Directorates of Forestry in Turkey using a developed data collecting method. Collected data were classified as insect production numbers, control areas and expenditures according to years. Subsequently, the total and unit costs were calculated and the gain and loss amounts obtained were estimated. Based on the comparison between chemical and biological control methods, chemical control is approximately 1.4 times more expensive than biological control in Turkey. This indicates that chemical control is causing economic loss in addition to ecological damages. In conclusion, the primary benefit of biological control is that it restores ecological balance and thus ensures the continuity of ecosystem services. The secondary benefit is savings from lower costs. Therefore, the use of biological control to mitigate damage from insects in forest ecosystems is important for the ecological and economic sustainability of forest ecosystems. To this end, predatory species such as *Rhizophagus grandis* Gyll, *Rhizophagus depressus* (F.), *Formica rufa* L., *Calosoma sycophanta* (L.) and *Thanasimus formicarius* (L.) have been used for biological control operations in Turkish forestry in recent years.

Keywords: *ecological-economic sustainability, pest control, natural balance, forest ecosystem*

Introduction

The forest ecosystem is the most fundamental and indispensable element of human life on earth. The history of utilization of forest resources is as old as humanity. Ecosystem services like carbon sequestration, non wood forest products, biodiversity and other attempts to address climate change have vital importance for humankind. For the sustainable management of an ecosystem, the factors that compose the ecosystem should also be in balance. From this perspective, insects that had a natural role in a forest ecosystem may proliferate excessively due to various reasons, including human impact. It is of great importance to restore the forest ecosystem back to its natural balance. In order to do so, it is necessary to identify the factors and take the required measures. It is imperative to protect and ensure the sustainability of this vital and indispensable element of life (Tolunay and Türkoğlu, 2014). Given that forest ecosystems constitute a whole with their specific soil structures, plant communities and other organisms, it is important to protect and develop forest ecosystems with a view to ensuring their long term sustainability (Akyol and Tolunay, 2014).

Insects are among the most crucial threats to forests. In recent years, biological control methods that do not harm trees were proposed and put in practice to address the disadvantages of chemical methods. The chemical insecticides that have negative effects and are dangerous for human health also lead to an insect resistance problem, which increases the pesticide cost because new compounds are needed. Today, it is understood that insecticides cannot provide a permanent solution for the control of insects. Biological control in which natural enemies of the pest insects are used avoids the negative consequences of chemical control on forest ecosystems.

Biological control can also be used to restore the natural balance from the human health perspective. The general principle of biological control is to protect, strengthen the natural enemy populations that have an impact on pest insects, and supplement them with imported species when needed. Technically, the first biological control practice in Turkish forests was launched in 1967 when *Formica rufa* was transplanted from the forest stands in North Anatolia to the Mediterranean region (Oğurlu, 2000). Predatory species such as *Rhizophagus grandis* Gyll, *R. depressus* (F.), *Formica rufa* L., *Calosoma sycophanta* (L.), *Thanasimus formicarius* (L.), as well as insectivore birds are used in biological control operations in Turkish forests; the rearing of predatory species was given priority after 2000s.

The ecological effects and consequences of insect control have been studied in the literature (Greatheat, 1976; Dijken, 1986; Brower, 1991; Van Lenteren, 2003; Orr, 2009; Uygun et al., 2010). However, there are only a limited number of studies that explore the economic aspects of insect control (Bokonon-Ganta, 2002; Born et al., 2005; Mc Fdyent, 2008; Fowler et al., 2016). In particular, there are very few studies in Turkey that explore the economic aspects of insect control methods. Existing studies mainly focus on the damage caused by insects to raw wood material and the associated economic loss. For example, Güngör and Daşdemir (2014) analysed the economic effects of *Pityokteines curvidens* Germ. on the sales of fir wood.

The native tree species in Turkish forests have lost many of their characteristics, especially in some regions, due to long years of irregular utilization and inappropriate interventions (Atmış et al., 2007). Besides raw wood materials, forests play an important role protecting biological diversity. Harmful insect species that lead to considerable economic losses in Turkish forests are controlled through various methods; the General Directorate of Forestry (GDF) spends a significant amount of money for that purpose. Therefore, this study evaluated the current status of biological control practices in Turkish forests and compared it with chemical controls method from the ecological-economical perspective.

Materials and methods

In this study, the insect control methods in Turkish forests were evaluated in general terms as a first step. Secondly, biological control methods and practices were examined. Finally, biological and chemical control methods were compared and analysed from an economical perspective. Data from 2004 to 2014 relating to these control methods, practices and economic expenditure in Turkey were evaluated. As it is difficult to express the benefits of sustainability of ecosystem services in insect control areas in economic and monetary terms, the costs of control methods were highlighted (Pak et al., 2010; Deniz and Ok, 2015).

Data were collected separately from 28 Regional Directorates of Forestry across Turkey in 2015 and 2016. The collected data included information about the size and cost of areas where chemical methods were applied, successful and failed cases for chemical and biological control methods and amounts of predatory species provided. Total and unit costs were estimated, and the amount of profit and loss was determined. Previous costs were converted to 2015 values using the Domestic Producer Price Index (D-PPI). Moreover, the Turkish Central Bank's data were used for international audiences and the unit costs were converted to USD. In general economic evaluations, all costs were taken into account, irrespective of the success status of insect control efforts in the relevant areas. However, the areas where the methods were successful or failed were taken into account when comparing the biological and chemical control methods; not only the economy of a method but also its success at the intended level is important. Therefore, biological and chemical control methods were evaluated from the perspective of cost minimization and cost saving regardless of their ecological impacts.

Results and discussion

Biological control practices in Turkish forests

The insect control methods that have been implemented in Turkey include chemical control with insecticides, biotechnical control with pheromone and pheromone traps, and mechanical control by way of collecting nest and egg batches of pine processionary moths (*Thaumetopoea wilkinsoni* and *T. pityocampa*) or trap trees for bark beetles (GDF, 2015). However, biological control methods appear to be preferred over these other control methods in recent years (Fig. 1); chemical control methods that cause harm to forests, organisms and people are largely abandoned.

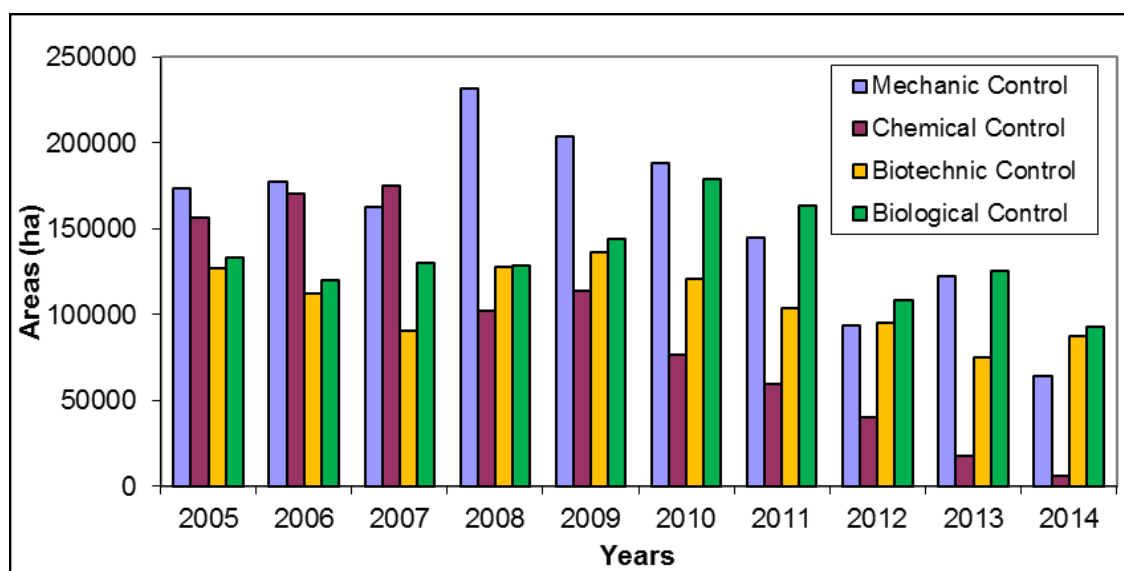


Figure 1. Distribution of control methods by areas in Turkish forests (2005-2014)

Formica rufa (Hymenoptera, Formicidae) is one of the important natural enemies used against the pest insects in Turkish forests. They can feed above and below the soil, and can reach the tops of the highest trees in an area with a radius of 25-100 m

depending on the individual. It was found that a *F. rufa* colony can kill 100.000 insects within 24 hours (Avcı et al., 2000). Therefore, four proper nests can control an area of one hectare. For that reason, it is important to use *F. rufa* ants for biological control with a view to protecting the health of forests and ensuring the continuity of the ecological balance (Oğurlu, 2000; Avcı et al., 2000). *F. rufa* is naturally distributed intensively in the West Black Sea region located in the northwest of Turkey, most parts of the Black Sea region, some parts of the Marmara, Central Anatolia, and the Inner Aegean region in the west. The forest in Senirkent-Kapıdağ of Isparta province in the southwest of the country constitutes the southern boundary of the distribution area of the species. Their presence in Turkey was identified at an elevation of 950-2000 m and mainly in *Pinus sylvestris* forests (Avcı et al., 2000). The transplantation of *F. rufa* nests started in the 2000s, and increased significantly; successful practices were observed (Fig. 2).

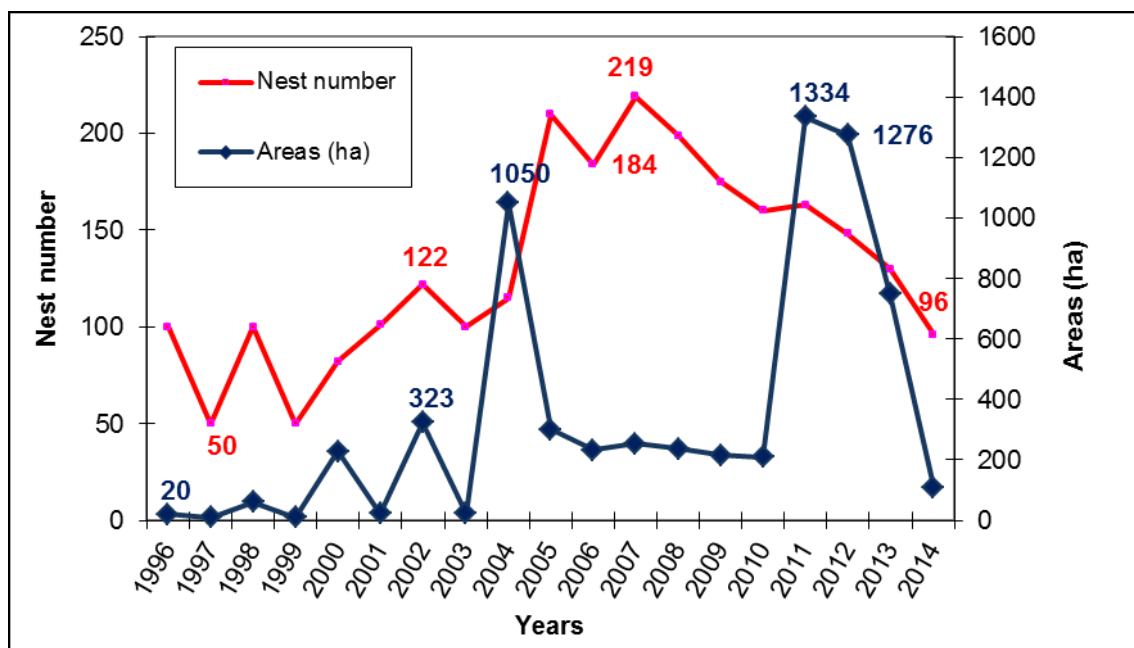


Figure 2. Transplantation of *Formica rufa* nests (1996-2014)

Calosoma sycophanta (L.) is on one of the most important predatory species for the forestry office in Turkey, produced in biological control laboratories established in different parts of the country and used against pine processionary moths (PPM). Mechanical control of PPM is expensive, while chemical control is known to have an adverse effect on the environment. In contrast, the adults and larvae of *C. sycophanta* that have a lifespan of 3–4 years affect the larvae and pupa of PPM *T. wilkinsoni*, which is very important for biological control. PPM causes physiological and primary damage on *Pinus brutia*, *P. sylvestris*, *P. pinea*, *P. halepensis* and *P. nigra* trees in Turkey. The adults of *C. sycophanta* can kill around 5-10 larvae per day. Considering that the adults can eat 7 PPM a day on average, an adult can kill 280 larvae a year on average, and around 900-1000 larvae on average throughout its life (Kanat et al., 2005; Anonymous, 2006). *C. sycophanta* is also a predator of *Lymantria dispar* and *Euproctis chrysorrhoea* that cause damage to beech, willow, linden and fruit trees. *C. sycophanta* feeds on the

larvae and pupa of the insects. GDF started rearing this species more intensively especially after 2004, in its biological control laboratories. The method of transplanting the larvae of *C. sycophanta* to the areas where PPM are distributed intensively has been very successful (Fig. 3).

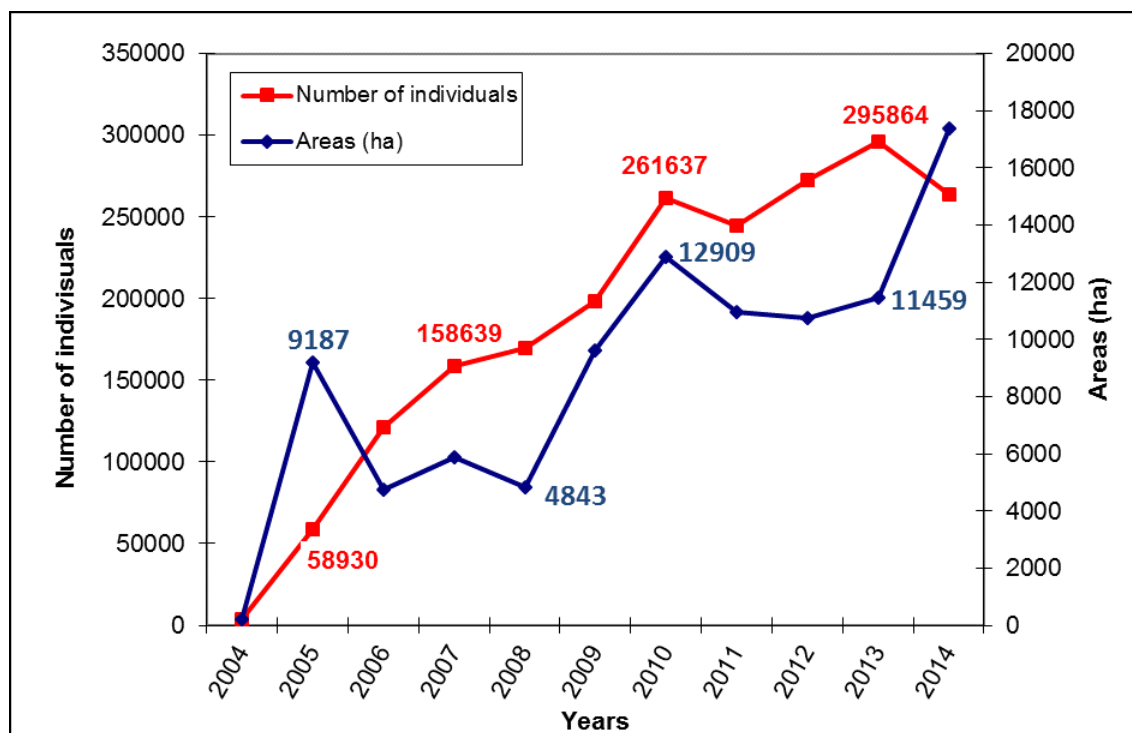


Figure 3. Rearing and application areas of *Calosoma sycophanta* (2004-2014)

One of the most important predators for bark beetle species in Turkey is *Thanasimus formicarius* (L.) (Coleoptera, Cleridae). This predator feeds on the adults, caterpillars and pupa of the bark beetles (*Ips typographus*, *Pityokteines curvidens*, *I. sexdentatus*, *Orthotomicus erosus* and *Tomicus minor* etc.) that cause damage to all coniferous forests (pine, fir, spruce) (Anonymous, 2006). *T. formicarius* is an important natural enemy, as it moves fast and thus can capture and kill the bark beetles. *T. formicarius* produces one generation per year in the East Black Sea region (180–1800 m) located in the northeast of Turkey and the Erzurum Sarıkamış location (2000–2400 m) in the east. The flying period of the insect is March–April at 180 m in the East Black Sea region, and extends from May to September at an elevation of 2000 m in Erzurum Sarıkamış. Studies show that *T. formicarius* can consume around 10 adult bark beetles per day and around 300 adult bark beetles throughout its lifespan (Akbulut et al., 2005). *T. formicarius* is a very important predator of *I. typographus* by feeding on its larvae, pupa and adults. *T. formicarius* is considered to be an important factor for the stabilization of *I. typographus* populations. Studies have reported that 81% of *I. typographus* in West Germany and 53% in Switzerland die in the logs where it coexists with *T. formicarius*. The number of *T. piniperda* also decreased by 92% in the environment where it coexists with *T. formicarius* (Yüksel et al., 2001). Akbulut et al. (2005) reported that *T. formicarius* had an effect on all bark beetles, though limited, and it had the most successful proliferation and attack on scotch pine (*Pinus sylvestris*) and oriental spruce

(*Picea orientalis*) forests. *T. formicarius* is found intensively on the main galleries of *I. sexdentatus* in scotch pine forests, and prefers primarily *I. typographus* in the oriental spruce forests and then *I. sexdentatus*. It is determined that it prefers *P. curvidens* (%16.29) as a main target (Akbulut et al., 2005). *T. formicarius* is another important species farmed by GDF. This species is currently used in the field against bark beetles to a significant extent (Fig. 4).

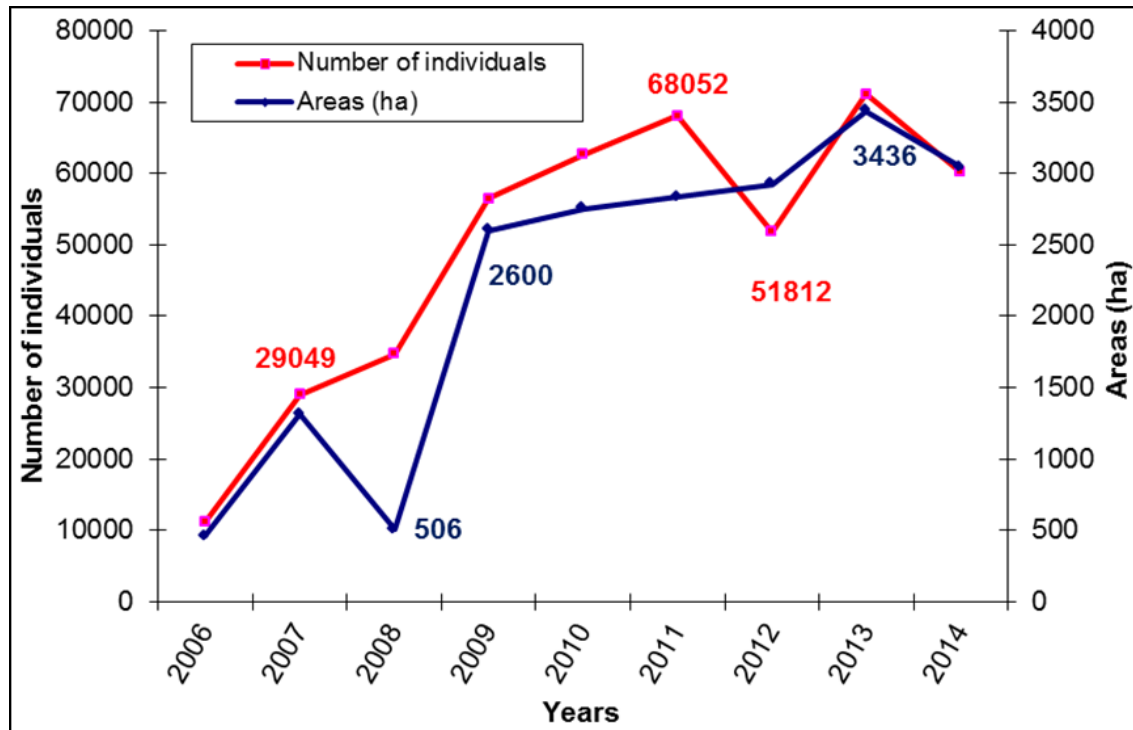


Figure 4. *Thanasismus formicarius* rearing and application areas (2006-2014)

Rhizophagus grandis Gyll. (Coleoptera, Rhizophagidae) is distributed in the Central and Northern European areas, Baltic countries and Siberia. In Turkey, *R. grandis* is an effective natural enemy of *Dendroctonus micans* Kug. which causes extensive damage to oriental spruce forests in an area of 75.000 hectares in Artvin and Posof located in the northeast. Bergmüller (1903) first reported that *R. grandis* was an important species in preventing the *D. micans* epidemics in Europe. Great achievements have been obtained with regard to the control of these insects in Turkey and many European countries. The epidemic of *D. micans* was mitigated with *R. grandis* by around 80–85% (Yüksel and Koçyiğit, 2001). Özcan et al. (2005) found that *R. grandis* could control *D. micans* by 78%.

R. grandis is being reared for the first time in Turkey, and has been used successfully for many years against *D. micans* that causes damage to oriental spruce (*Picea orientalis*) forests. In those treated areas, *D. micans* is no longer a significant threat and the natural balance has been restored in the spruce forests. As a consequence, the rearing of *R. grandis* has declined since 2009 (Fig. 5).

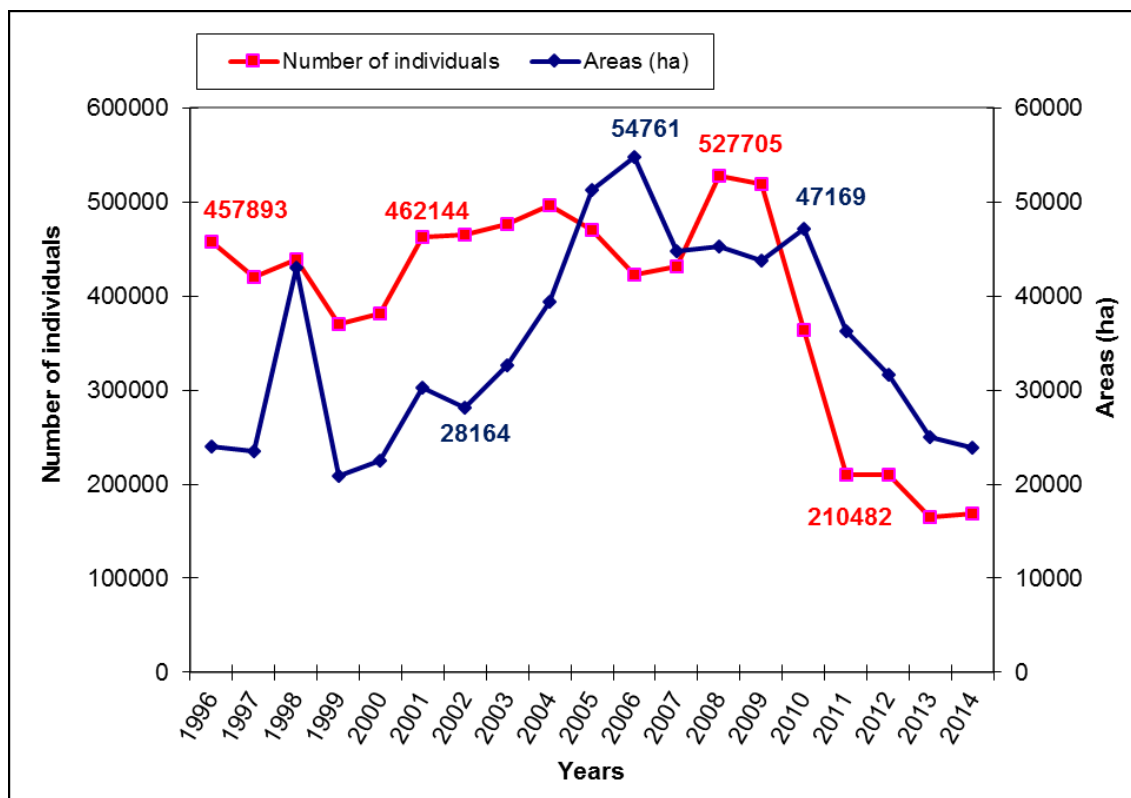


Figure 5. *Rhizophagus grandis* rearing and application areas (1996-2014)

Rhizophagus depressus (F.) (Coleoptera, Rhizophagidae) is another important predatory of bark beetles in Turkey. This species is distributed in the East Black Sea region at an elevation of 1000-2000 m, in Erzurum Sarıkamış at an elevation of 2000-2400 m., and in Bolu and Aladağ at an elevation of 1000-1700 m. with 2 generations per year. *R. depressus* attacks the nests of *I. sexdentatus* (58.43%), *I. acuminatus* (38.13%), *T. minor* (30.49%) and *T. piniperda* (29.52%) in *Pinus sylvestris* forests. The most important results of *R. depressus* were obtained against the insects that damaged *P. sylvestris* forests.

Particularly, *R. depressus* has been reported to have high efficacy on the populations of *I. sexdentatus* in Sarıkamış. The density of this predatory species in the nests of bark beetles in Sarıkamış is at minimum 31.89% and decreased the harmful population in *T. piniperda* nests by around 41%. The harmful insect species it prefers in the spruce forests are *Pityokteines spinidens*, *O. erosus*, and *I. typographus* (Yüksel et al., 2005). Meydan et al, (2005) reported that the density of *R. depressus* is 39% in the nests of *T. minor*, 33% in the nests of *T. piniperda*, 25% in the nests of *I. acuminatus* and 57% in the nests of *I. sexdentatus*. In the study, it was found to prefer mainly *I. sexdentatus*. While *R. depressus* was reared in the biological control labs of GDF and transplanted to nature in order to prevent the epidemics caused by this bark beetle in Turkey, a more effective species, *Thanasimus formicarius*, has been reared predominantly in recent years. Therefore, the quantity of *R. depressus* insects reared has declined significantly since 2013 (Fig. 6).

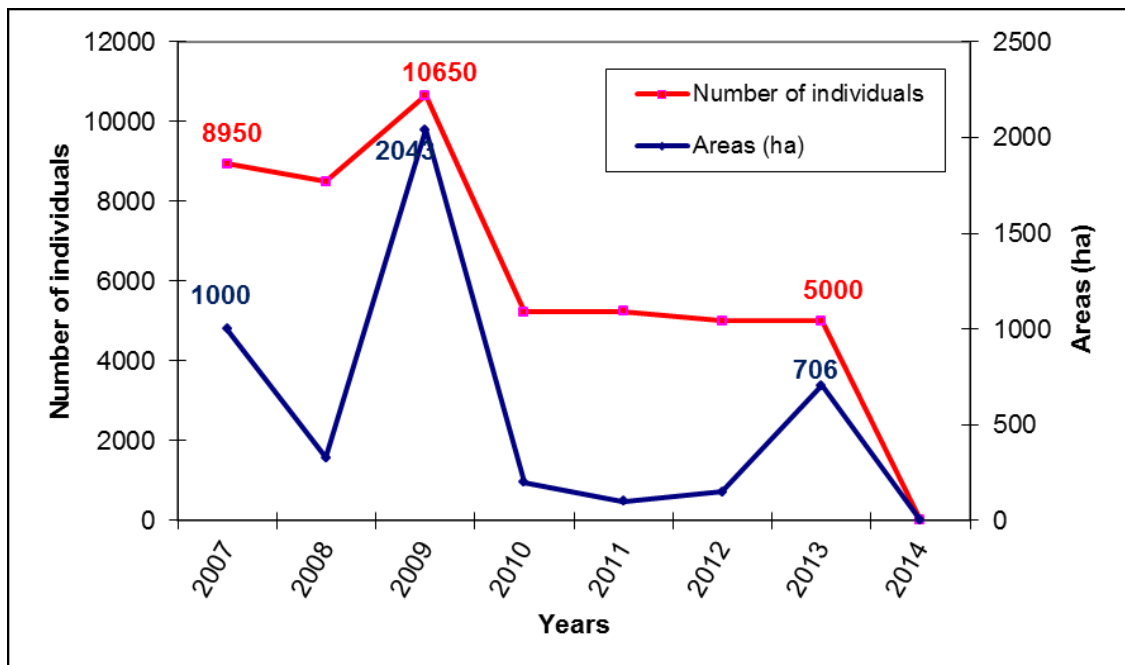


Figure 6. *Rhizophagus depressus* rearing and application areas (2007-2014)

Economic evaluation of biological and chemical control practices in Turkish forests

An analysis of the cost of insect control practices performed by the GDF reveals that mechanical control is one of the most expensive (Fig. 7).

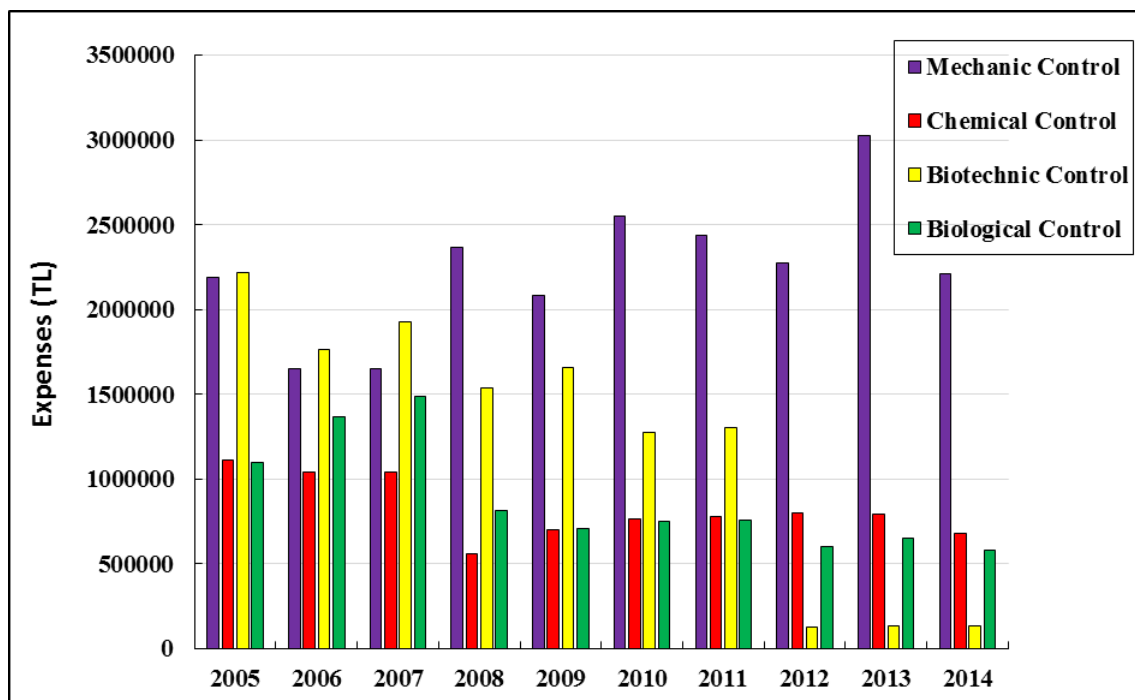


Figure 7. *Distribution of the costs of control methods used in Turkish forests (2005-2014)*

This is followed by biotechnic control methods. *Fig. 7* shows that the expenditures have declined in recent years thanks to the success of biotechnical control. As for chemical control, the expenditures of GDF fluctuated from 2005 to 2014; overall it had a declining trend. However, as shown by *Table 1*, although the surface area where the GDF applied chemical control decreased from around 150 thousand ha to 10 thousand ha, it is noteworthy that the expenditures incurred for chemical control did not decline at the same rate. On the other hand, the cost of chemical control declined significantly from 1.113.000 TRY in 2005 to 680.125 TRY in 2014 (*Table 1*). In other words, although the area where chemical control was applied decreased by 15 times, the money spent for it decreased by only 1.6 times. One of the most important factors leading to that result was that almost all pesticides used for chemical control were imported and the TRY-USD exchange rate was high. Another factor is the need to reapply pesticides in the areas where chemical control failed.

Table 1. Area-cost chart for biological and chemical control practices (2005-2014)

Years	Chemical control			Biological control		
	Areas (ha)	Control costs (TRY)	Adjusted to 2015 (TRY)*	Areas (ha)	Control costs (TRY)	Adjusted to 2015 (TRY)*
2005	156.103	1.113.000	2.290.658,05	133.430	1.100.000	2.263.902,83
2006	170.379	1.038.499	1.915.544,61	120.153	1.366.706	2.520.932,92
2007	174.741	1.039.411	1.809.675,40	130.099	1.489.248	2.592.867,95
2008	102.415	557.000	897.047,74	128.475	814.000	1.310.945,90
2009	113.550	700.195	1.064.523,23	144.109	709.527	1.078.710,89
2010	76.184	763.515	1.066.188,16	178.897	752.145	1.050.310,86
2011	59.681	780.326	961.530,45	163.279	760.145	936.663,09
2012	39.741	800.269	962.497,97	108.641	602.589	724.744,67
2013	17.257	790.562	888.856,37	125.670	651.235	732.206,18
2014	5.729	680.125	718.970,33	120.751	576.956	609.908,84
Total	915.780	8.262.902	12.575.492,31	1.353.504	8.822.551	13.821.194,13

*Domestic Producer Price Index (D-PPI) was used for conversion (TUIK, 2017).

Regarding biological control, the expenditures increased from 2005 to 2007, while decreasing in subsequent years (*Fig. 7*). This is because the GDF increased biological control practices by increasing the rearing of *C. sycophanta* in 2005, *T. formicarius* in 2006, and *R. depressus* in 2007. The decrease in the cost of biological control starting from 2008 was associated with the effectiveness and success of the control efforts (*Table 1*). Another point is that the average size of the areas where biological control methods were applied also varied significantly over the years. The average size of these areas decreased over the past years, while the reduction in the costs was more remarkable. This shows that the cost of biological control decreased as the natural balance was restored over the years (*Table 1*). As *Table 1* indicates, the costs in different years were converted to 2015 values for a more robust and accurate interpretation of the total costs of biological and chemical control over a period of years. At that stage, the unit costs were also calculated in order to determine the estimated amount of savings when biological control was preferred over chemical control (*Table 2*). To calculate the estimated amount of savings, it was assumed that biological control

was preferred to chemical control. Thus, it was presumed that chemical control method was abandoned in the areas where biological control was applied, and the opportunity cost derived was retained by the GDF as savings. Accordingly, the estimated amount of savings in 2015 when the GDF preferred biological control to chemical control was around 1.75 million USD. Furthermore, in addition to this economic profit, the GDF also improved the effectiveness and success of control efforts from 2005 to 2014 on a continuous basis.

Table 2. Unit costs of chemical and biological control and total savings

Control Method	Total Control Cost (TCC) TRY	Total Area (TA) ha	Control Unit Cost ¹ (CUC) TRY/ha	Control Unit Cost* (CUC) USD/ha	Total Savings ² (TS) USD
Chemical Control	12.575.492,31	915.780	13,73	5,05	
Biological Control	13.821.194,13	1.353.504	10,21	3,75	1.751.840,23

¹CUC = TCC / TA, ²TS = TBCA * (CCUC-BCUC)

TBCA: Total Biological Control Area, CCUC: Chemical Control Unit Cost, BCUC: Biological Control Unit Cost

*Central Bank of Turkey average TRY-USD exchange rate of 2015 (1 USD = 2.72 TRY)

The economic analyses on biological and chemical control show that the cost of biological control is 3.75 USD per ha, compared to about 5.05 USD per ha for chemical control. These findings indicate that chemical control is 1.4 times more expensive than biological control in Turkey. An evaluation reveals that one of the most important factors affecting this difference is that the pesticides used for chemical control are imported and expensive. Moreover, harmful insects became resistant to the insecticides, requiring supply of new chemical compounds. This factor increases the cost of every new insecticide. For chemical control to succeed, pesticides have to be applied to the area until results are seen, which is another reason for the increased cost. Furthermore, special protective clothing, equipment and tools are needed to apply the pesticides in the field during chemical control. Annual periodical maintenance also increases the cost of chemical control. The cost of biological control is high initially, but decreases as the balance of the ecosystem is restored over time. The predators left in the area reproduce on their own and reduce the pest insect population below the economic loss threshold. Typically, it is not necessary to transplant the predators to the site every year. In other words, repetition is either not needed or very limited, which decreases the overall cost significantly. Another point related to cost is that the GDF employs its own laboratories and technical staff for the rearing of predators. Contrary to chemical control, they are not imported; therefore, the cost of rearing predators is low. Moreover, there is no need to use special clothing and equipment during the field application of biological control, which also decreases the cost.

Conclusions

In this study, the current status of biological control practices addressing pest insects in Turkish forests was analysed and compared with chemical control methods from an economic perspective. The first biological control was applied in Turkish forests in 1967, when *Formica rufa* was transplanted. However, the efforts regarding biological

control were not that extensive until the 2000s. Turkish forestry organizations needed to take action because: the pesticides used with chemical control were harmful for the forests and human health, the chemical compounds used for the preparation of these pesticides were expensive, and the insects developed resistance against the pesticides. As a result, biological control efforts were increased especially after 2000 in Turkish forests, while the chemical control practices were eventually abandoned. This indicates the importance that the Turkish forestry organization attaches to the biological control method especially in recent years.

In particular, *C. sycophanta* since 2004, *T. formicarius* since 2006 and *R. depressus* since 2007 have been predominantly reared and extensively used during biological control operations. The quantity of these species and the areas where they are used have increased over the years and significant achievements were obtained. It is important from the ecological perspective that natural balance is restored gradually in these areas where biological control is applied. However, the economic aspects of insect control efforts are as important as the ecological aspects. From this perspective, an important finding of this study was that significant economic savings were obtained in addition to the ecological benefits as the chemical control was abandoned. The successful results including cost savings obtained by biological control practices add to point to the fact that the ecological balance in Turkish forests is gradually being restored.

The economic analyses revealed that the cost of biological control was around 3.75 USD per ha as compared to around 5.05 USD per ha for chemical control. Thus, when the ratio of the unit costs are calculated, it was found that the chemical control method was around 1.4 times more expensive than the biological control method. It is estimated that the economic savings will further increase as the areas where biological control is applied are extended, and the areas where chemical control is applied are reduced. Indeed, as the ecosystem gains back its natural balance in time through biological control, the cost of biological control per unit area will decrease; therefore, it is estimated that the economic savings will further increase. Thus, biological control is the most economic method for Turkish forests. The analyses revealed that the economic saving derived by abandoning chemical control methods is estimated at around 1.75 million USD in 2004-2014.

In conclusion, the primary benefit of biological control is that it restores ecological balance and thus ensures continuity of the ecosystem services. Its secondary benefit is the cost savings it brings. Therefore, the use of biological control methods to address pest insects in Turkey's forest ecosystems contributes remarkably to ecological and economic sustainability.

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