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Ecological, social and economic benefits of organic olive farming outweigh those of intensive and traditional practices

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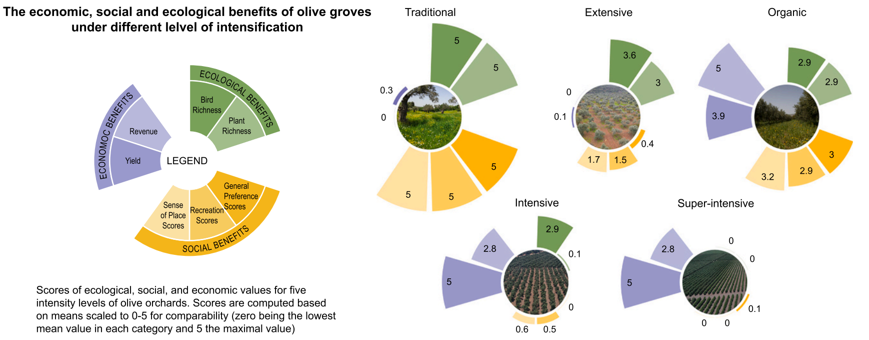
HIGHLIGHTS

- Intensive groves maximize yield and profit, while socio-ecological values peak in traditional groves.
- Organic olive groves increase multi-functionality and optimize economic, ecological, and social values.
- Maintaining vegetation cover in groves contributes to their high ecological and social values.
- Subsidies and branding are required to sustain traditional olive orchards with high ecological value.

GRAPHICAL ABSTRACT



The economic, social and ecological benefits of olive groves under different lelvel of intensification

Scores of ecological, social, and economic values for five intensity levels of olive orchards. Scores are computed based on means scaled to 0-5 for comparability (zero being the lowest mean value in each category and 5 the maximal value)

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ABSTRACT

Olive farming has vastly intensified across the Mediterranean basin recently. This ongoing process has detrimental social and environmental outcomes, but it also represents a unique opportunity to study the impacts of intensification and identify solutions for sustainable management of this iconic and culturally important crop. This interdisciplinary study jointly explores the ecological, social, and economic consequences of olive farming intensification, to identify solutions for sustainable agriculture. During 2017–2019 we conducted ecological, social and economic surveys in 50 olive groves plots, each representing different intensification levels (super-intensive, intensive, organic, extensive, and traditional olive groves) and plots with natural vegetation as ecological control. Birds and plants were sampled to assess biodiversity under each intensity level. Landscape preference was assessed using an online survey ($n = 299$) targeting the general public, featuring representative images for the different intensity levels. Data on yield, revenue, profit, and costs in the olive groves was collected from farmers for two seasons ($n = 44$). Our results demonstrated a trade-off between economic and socio-ecological benefits. Intensive and super-intensive groves maximize the economic values at the expense of the socio-ecological values, whereas the opposite is true for traditional groves. However, within this gradient we found few opportunities to promote sustainable olive farming. Organic groves demonstrated an optimal solution, with an economic value similar to intensive plots, rich biodiversity and high appreciation by people. On the other hand, extensive olive farming represented a non-sustainable situation, in which socio-ecological values were similar or lower than organic groves, while yield and profit were the lowest found in this study. Traditional

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groves were the most appreciated landscape, hosting bird and plant communities similar to nearby plots with natural vegetation. Building on these results we highlight several policy directions that can help reconcile olive production, biodiversity conservation and social values to conserve this important cultural landscape sustainably.

1. Introduction

Reconciling agricultural production and biodiversity conservation is key to addressing the ecological and environmental crisis, as agricultural ecosystems, now covering nearly 40 % of terrestrial land, have expanded at the expense of natural ecosystems like forests, savannas, and shrublands (Phalan et al., 2011; Foley et al., 2005). This agricultural growth involves transitioning from traditional-extensive farms with low inputs to intensive systems with high inputs, also entailing reduced crop diversity, fewer natural vegetation remnants, and greater mechanization (Tilman, 1998; Uccello et al., 2017). Although the latter has significant benefits, notably increased yield per unit of area, it also has far-reaching social, ecological and environmental consequences that undermine the resilience of agricultural systems (Tscharntke et al., 2005). For instance, agricultural land can produce various ecosystem services, such as carbon sequestration and biodiversity conservation (Corbacho et al., 2003; Donald and Evans, 2006), and particularly cultural services that contribute to people's health and well-being (Gołębiewska and Pajewski, 2018; van Berkel and Verburg, 2014). Yet, the global agricultural intensification process reduces its capacity to deliver these ecosystem services (Butler et al., 2007; Landis, 2017; Pingali, 2012). Thus, understanding how to meet the rising global food demand in a sustainable manner that provides ecosystem services remain a major contemporary challenge (Bommarco et al., 2013). Olive farming, which has been and still is undergoing a rapid and substantial intensification process across its historical range (Morgado et al., 2022), represents a unique opportunity to explore this challenge.

Olive has been an iconic crop and key feature of the Mediterranean region for millennia, significantly influence the region's economy, society, and culture, shaping its landscapes and identity (Infante-Amate et al., 2016; Besnard et al., 2018; Duarte et al., 2008). Olive groves were traditionally grown on mountain slopes, characterized by water-retaining stone terraces, old trees in low density, low agrochemical inputs and minimal mechanization, harmonizing rainfed agriculture with the natural ecosystem (Loumou and Giourga, 2003; Morgado et al., 2020). This heterogeneous landscape, blending human activities with natural habitats, was economically and environmentally sustainable for centuries (Herrera et al., 2015; Stroosnijder et al., 2008). Today, olive groves cover over 10 million hectares globally (FAO, 2023) and over 95 % of the global olive production is produced in the Mediterranean basin (Beaufoy, 2000). However, the shift from rural to urban living and the decline of family farms have led to the abandonment of many terraced farms, where mechanization is unfeasible and economic competitiveness is diminished (Infante-Amate et al., 2016; Salmon and Shipley, 2013; Agnoletti, 2014; Duarte et al., 2008).

In recent decades, olive farming has undergone significant intensification, marked by the adoption of irrigation systems, artificial fertilizers, and pesticides to meet rising global demand. (Infante-Amate et al., 2016; Lavee et al., 2014; Moreira et al., 2019; Romero-Gámez et al., 2017). The intensification process accelerated even more by the introduction of the super-intensive methods, characterized by high-density planting of dwarf varieties and increased use of mechanical harvesters, greater reliance on agrochemicals and irrigation (Morgado et al., 2020). Such intensification, while aiming to enhance productivity, has raised environmental concerns, especially in drought-prone areas like the Mediterranean (Guerrero-Casado et al., 2021). To mitigate the harmful effects of intensification, European policy and consumer's demand for environmentally friendly and healthy produce gave rise to the irrigated organic olive farming, offering an alternative to intensive groves (Parra-López et al., 2007; Pleguezuelo et al., 2018; Tsakiridou et al., 2006). Organic olive farming is expanding, as small traditional and intensive farms adopt organic practices to compete with large production systems (Lodolini et al., 2013; Milgroom et al., 2007). Overall, the olive cultivation system in the Mediterranean basin is characterized by an agricultural mosaic representing a gradient of intensity levels, from traditional-extensive rainfed farming, through organic farming to intensive and super-intensive olive agriculture. Therefore, the olive farming system provides a unique opportunity to explore the ecological and social consequences of agricultural intensification.

The intensification of olive farming has significantly impacted biodiversity across the Mediterranean. Studies have consistently shown declines in various species as farming intensity increases. In Portugal, for example, intensification has led to reduced bat activity (Herrera et al., 2015). This pattern of biodiversity loss is echoed in findings on birds, arthropods, herpetofauna, plants and their seed bank across the region (Allen et al., 2006; Assandri et al., 2017; Bouam et al., 2017; Carpio et al., 2016, 2017, 2019, 2020; Hevia et al., 2019; Martínez-Núñez et al., 2020; Morgado et al., 2022; Tarifa et al., 2021). Super-intensive farming, while similar or lower in biodiversity to intensive groves, shows a marked decline compared to traditional extensive groves (Landi et al., 2022; Morgado et al., 2020, 2021; Vasconcelos et al., 2022). Yet, the magnitude of impact is not consistent and some species (e.g., frugivores birds) can even benefit from super-intensive farming (Morgado et al., 2021). Conversely, organic farming, like traditional management, often supports more biodiverse communities than intensive olive farming (Cotes et al., 2010; Myers et al., 2019; Puig-Montserrat et al., 2021; Ruano et al., 2004; Sánchez-Fernández et al., 2020; but see Gkisakis et al., 2016). However, the entire range of intensity levels, including various non-intensive management options, is rarely studied collectively. Additionally, studies often lack a control habitat with natural vegetation to estimate the magnitude and composition of local biodiversity lost under each management option. Quantifying the effect of multiple intensive and non-intensive management options on biodiversity compared to the local potential of habitats with natural vegetation is essential to weighing and choosing among these alternatives.

The transformations in olive cultivation also carry significant socio-economic implications. Intensive olive production generally produces higher yield per unit area and revenue compared to traditional-extensive farming (Beaufoy, 2000; Colombo et al., 2020; Todde et al., 2019). However, the profitability between intensive and super-intensive farming varies, with the latter not always proving more profitable (Freixa et al., 2011; Romero-Gámez et al., 2017), possibly due to higher input costs and shorter crop lifespans in super-intensive systems. Inconclusive results were also found in studies that compared organic and intensive olive farming. In Sicily (Italy) organic farming allows better profitability, due to higher market prices and European subsidies, while in Andalusia (Spain) subsidies are not sufficient to sustain viable olive farming (Guzmán et al., 2011; Sgroi et al., 2015). Despite being less yielding, traditional olive farming has provided an important source of income, rural development, and employment in marginal Mediterranean regions for centuries (Duarte et al., 2008). Furthermore, traditional olive groves create scenic landscapes that provide cultural heritage and aesthetic services, attract tourists and contribute to the local economy (Pulido-Fernández et al., 2019; Torquati et al., 2019). Few studies have also shown that landscapes with traditional-extensive or organic olive farming are perceived to provide more services to people (e.g., cultural, pollination, soil and water conservation) and are generally favored compared to landscape dominated by intensively managed olive groves

(Bidegain et al., 2020; Martínez-Sastre et al., 2017; Nekhay and Arriaza, 2016).

To date, studies on olive farming intensification often focus on single aspects without integrating ecological, social and economic considerations comprehensively, across the spectrum of intensity levels. Such an approach is important to promote sustainable agriculture that finds the subtle balance between food security, farmers' livelihood, conservation of nature and the cultural benefits it provides to humans (Garibaldi et al., 2017). In this context, Israel offers an interesting case study. Its olive farming, occupying 27 % of Israel's permanent cropland and covering about 34,000 ha with 73 % being traditional and rainfed, echoes the Mediterranean trend of agricultural expansion and intensification (Fattal, 2014; Lavee et al., 2014), yet the broader impacts of this intensification remain understudied. Thus, the goal of this interdisciplinary study is to understand how different levels of intensification of the olive production industry in Israel influence the ecological, social, and economic value of these landscapes. During 2018–2019 we conducted ecological, social (online survey) and economic surveys in 50 plots covering a gradient of super-intensive, intensive, organic, extensive, and traditional olive groves, and habitats with natural vegetation as ecological references. Specifically, we aimed to understand how olive farming intensity levels influence: (1) bird and plant diversity; (2) cultural services provided by olive groves; and (3) olive oil production and profit.

2. Materials and methods

2.1. Study site and experimental design

The study was conducted in the lower Galilee and Jezreel Valley in northern Israel (the average annual precipitation is 450–700 mm) over an area of ~300 km^2 (Fig. 1). The area is a mosaic of rural settlements, traditional and intensive agriculture, Mediterranean forest and scrubland. About 34 % of this area is used for agricultural production, with a high percentage of olive groves, mostly rain-fed traditional and extensive groves and a smaller but growing section of intensive irrigated production (Fattal, 2014).

The study consisted of a total $N = 50$ plots distributed across four locations (Sakhnin valley, Tzipori, Sde Ya'akov and Megiddo; Fig. 1). Olive plots ($N = 38$) were classified into five intensity levels (traditional, extensive, organic, intensive, and super-intensive; Table 1, Fig. 2) according to tree density, tree height, tree age, irrigation, weed control, pest control, and fertilization (Kizos and Koulouri, 2010; Morgado et al., 2020; Romero-Gámez et al., 2017; Tzouvelekas et al., 2001). Traditional groves ($N = 8$) consisted of old trees with wide spacing, relaying on rain-fed and grazing-based traditional management to remove vegetation and use animal manure as fertilizers. Extensive groves in Israel are owned by family farmers and are characterized by younger trees in closer rows than traditional groves, using soil ploughing, minimal pesticides, limited artificial fertilizers and no or very minimal irrigation ($N = 10$; Table 1). Essentially, extensive management marks a transition from traditional to more intensive agriculture. Organic groves ($N = 7$) were managed with organically certified inputs and included irrigation. Intensive groves (N = 10) and super-intensive groves (N = 3) also utilized irrigation, with intensive groves receiving higher conventional inputs and super-intensive groves characterized by the highest amount of agrochemicals and minimal space between trees (Table 1, Fig. 2).

In each area we selected at least one control plot with natural vegetation as a reference for semi-natural areas under no production ($N = 12$; Fig. 2). Control plots were characterized as natural oak park forest, Mediterranean garrigue, or mixed pine forest. Most lower areas in this region are cultivated, restricting the natural vegetation to higher elevations and steep slopes where cultivation is difficult. To minimize the differences between control and treatment plots, we selected control plots within a 2 km radius from olive plots. For each control and olive plot we recorded the soil type, slope (C^0), latitude (m), percentage of

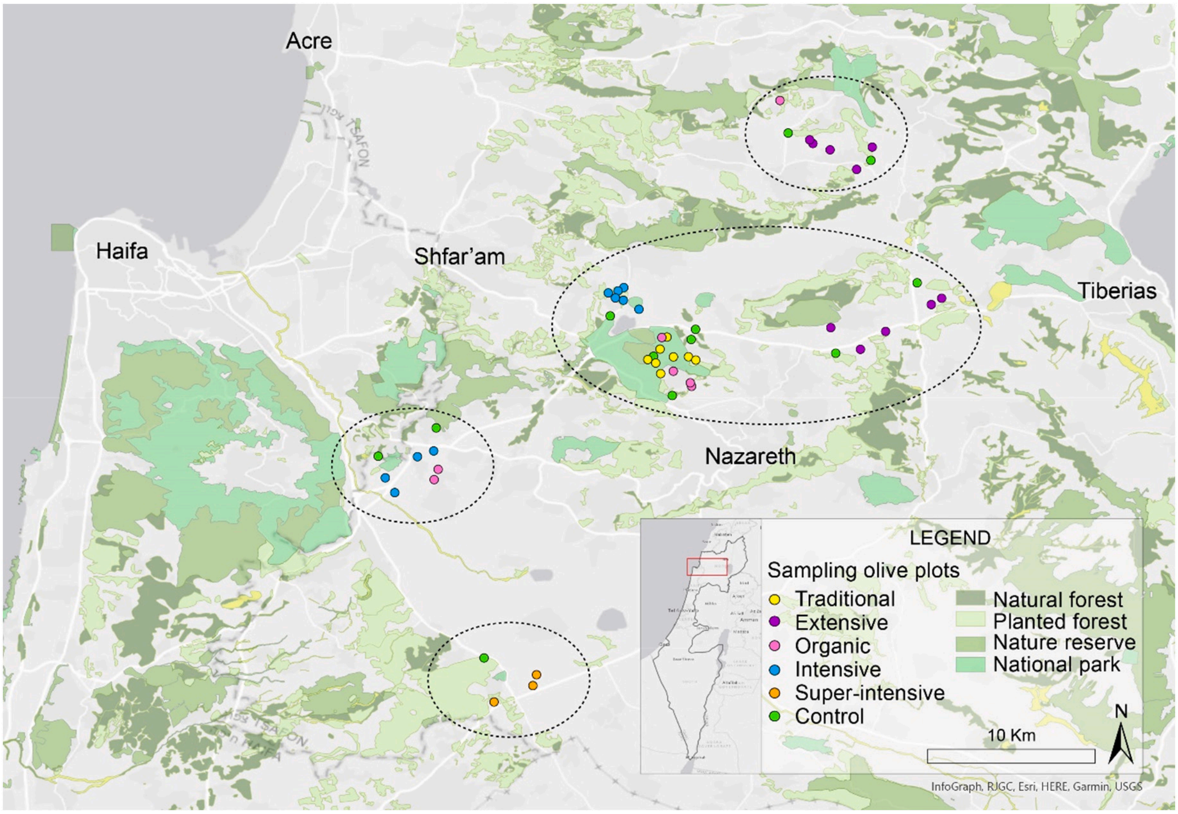

Fig. 1. Map of the study region and the four locations (from north to south: Sakhnin valley, Tzipori, Sde Ya'akov and Megiddo). The colors of the sampling plots represent their intensification level. Natural habitats around the plots are shown in green.

Table 1
Characteristics of the studied olive groves managed with different intensity levels, and a summary of their agronomic, economic, and ecological values (mean ± S·D). Numbers in brackets below the values of yield and profit (in NIS; 1 USD = 3.75 NIS), plant and bird richness represent the number of plots sampled and the sample size.

Intensity level	Distance between trees (m)	Irrigation	Weed management	Pest management	Fertilizers	No. of farmers	Yield (kg ha^{-1})	Profit (NIS/ha)	Plant richness	Bird richness
Control	–	–	–	–	–	–	–	-	94.4 ± 21.0 (12)	7.9 ± 2.4 (12,60)
Traditional	10*10	None	Herding	None	Animal Manure	1	284.3 ± 187.9 (4,8)	6577.2 ± 8401.3 (4,8)	44.4 ± 10.9 (8)	8.2 ± 2.3 (8,40)
Extensive	6*7	None	Ploughing	None- low inputs	None- low inputs	4	307.2 ± 182.6 (5,10)	-1255.1 ± 8119.4 (5,10)	28.6 ± 11.5 (10)	7.0 ± 2.2 (10,50)
Organic	6*7	Medium	Mowing	Organic low inputs	Compost	3	1179.5 ± 781.6 (9,18)	20,117.6 ± 27,275.7 (9,18)	27.7 ± 6.6 (7)	6.5 ± 2.4 (7,35)
Intensive	6*7	Medium	Herbicides	Pesticides- medium input	Chemical fertilizers- medium	2	1183.0 ± 606.8 (3,6)	12,371.9 ± 17,755.5 (3,6)	5.2 ± 4.2 (10)	6.2 ± 2.2 (10,50)
Super-intensive	3*4	Medium-High	Herbicides	Pesticides- High input	Chemical fertilizers- High	1	2226.4 ± 1043.7 (1,2)	17,955.8 ± 22,101.9 (1,2)	4.7 ± 2.1 (3)	3.9 ± 2.0 (3,15)

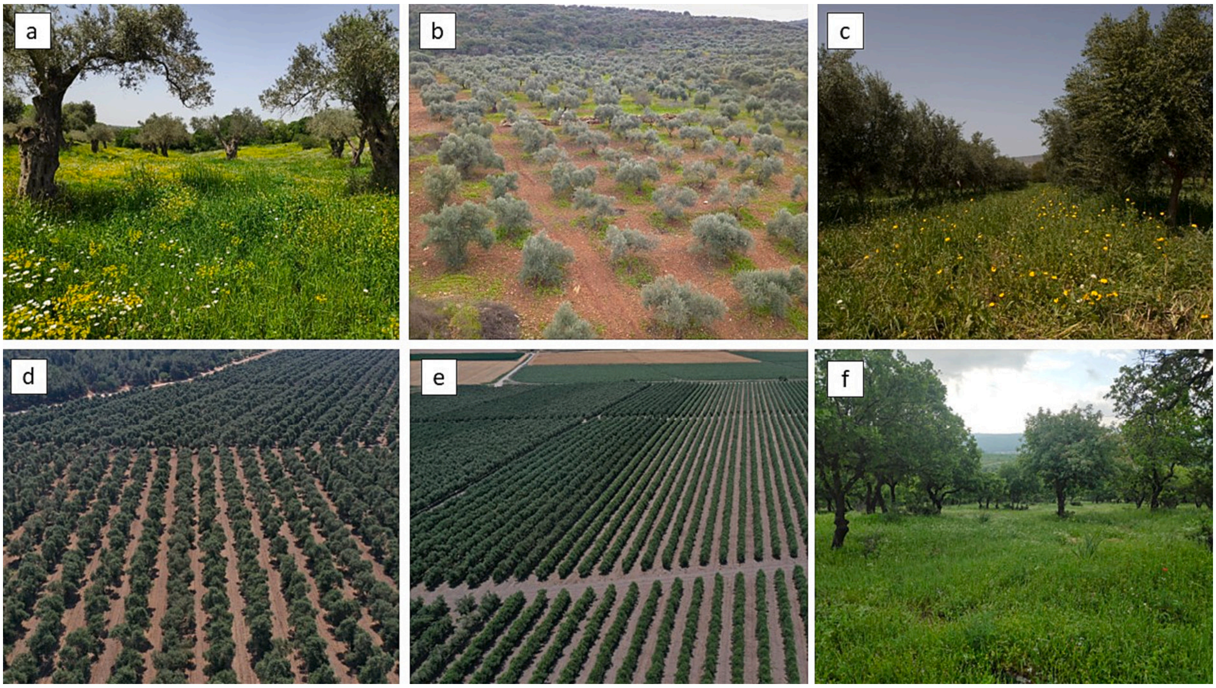

Fig. 2. Representative photographs of the five intensity levels of olive cultivation and semi-natural control plots surveyed in the study: (a) traditional; (b) extensive; (c) organic; (d) intensive; (e) super-intensive; and (f) natural oak park forest. More images are provided as Supporting Information (Fig. S3).

natural area in a 1000 m buffer around the plot (%), and the distance from a water source (m) (ArcGIS Pro, ESRI Inc.). All plots were > 0.5 ha, had a slope smaller than 15 %, and clay soil (see Table S1 and Fig. S1 in Supporting Information for more details on the distribution of habitats, soil types and landscape attributes across olive intensity levels).

2.2. Data collection

2.2.1. Ecological surveys

A trained ornithologist sampled birds five times in each plot between March and July 2019 from half an hour before sunrise to 3 h after dawn using standardized 100 m line-transect counts for 10 min. Transects were positioned in the middle of the surveyed plot to prevent edge effect and at least 350 m from the nearest transects to prevent double counting of the same individuals. We recorded all species seen or heard inside the sampling plot within a 100-m radius (Burnham and Anderson, 1984; Emlen, 1971), as well as temperature (c°), clouds cover (%), and wind level. We calculated for each visit the total species richness and abundance.

We sampled the vegetation once in March 2019 with a trained botanist. In each plot, we sampled six 1 m × 7.5 m quadrats to a total of 45 square meters (Peet et al., 1998). To capture the vegetation uniform dispersion (between olive rows), quadrats were spaced asymmetrically. Three pairs of quadrats were sampled in 24 m intervals along tree rows, with increasing distances within pairs (5, 10 and 15 m, Fig. S2). In each quadrat we recorded all present species and total plant cover. We calculated for each plot the total number of species observed and the average plant cover over all six quadrats.

2.2.2. Economic surveys

During the harvest seasons of 2018/19 we conducted in-person interviews of ~45 min with ten farmers that managed 22 plots (few farmers managed more than one plot) and obtained data on their crop incomes and expenses for the 2017/2018 and 2018/2019 growing seasons ($N_{tot} = 44$; Table S2). One farmer managing two plots was excluded as he was not willing to provide economic data. We also excluded two plots harvested for table olives since all other plots were harvested for olive oil. For some farmers economic data was only available at the plot level, preventing us from capturing within-orchard variance and leading to a smaller sample size than in the ecological surveys. This also resulted in two replicates for the super-intensive management, thus we merged it with the intensive management for the economic analysis.

All costs and revenues were reported in local currency (NIS; 1 USD = 3.75 NIS) per local unit area (1 dunam = 0.1 ha). Farmers were asked about their annual yield (kg ha^{-1} olive oil) and product price (NIS kg^{-1}) from which we calculated the yearly revenue per unit area (NIS ha^{-1}). We summed all the direct variable costs (fertilizers, pest control, weed control, water, fuel, manpower, oil pressing, and packaging) and fixed costs (bureaucracy and guidance) and calculated the total costs per unit area (NIS ha^{-1}), the variable costs per unit production (NIS kg^{-1}), and the profit per unit area (revenue – total costs; NIS ha^{-1}). In smaller farms, the practice of family members participating in agricultural work is common. To calculate manpower costs equally across management intensity levels, farmers estimated how many working days per land unit they invest in different actions (e.g., soil cultivation or pest management) and this figure was multiplied by the average salary per employee which stands at 300 NIS per working day. We did not include the initial investment costs since all groves were mature. Table S2 provides the summary and values of the variables collected.

2.2.3. Social surveys

An image preference survey was administrated to estimate general public attitudes towards olive landscapes at varying intensity levels ($N = 299$). This method is commonly used to explore landscape preferences and perception about ecosystem services (Bidegain et al., 2020; Wherrett, 2000). A questionnaire was delivered online for representative sample of the Israeli population (gender, age, ethnic group) in September 2019 by a market research company (iPanel). The key part of the survey consisted of 30 images representing the five intensity levels examined in this study (Table 1; Fig. S3), which were divided into six images per level of intensity: three images from eyesight perspective between the growing rows, and three aerial images (Fig. S3). During spring 2019 a professional photographer took about 1500 pictures from all five intensity levels in eyesight and aerial using a drone (DJI Mavic 2 Pro). All images were first scanned to identify the extent to which features of the given intensity level are adequately represented. Images for which the elements of agri-management did not stand out visually were excluded, and we ended up with about 150 images that met the set criteria of *visual features*. We then ran a focus group to select the final images that were used in the survey (see Text S1 for more details).

The main part of the survey included 30 images (six per level of intensity) that were presented to the participants in a random order. For each image participants were asked to indicate their level of agreement on the Likert scale (1 - strongly disagree and 5 – strongly agree) with the following items: (1) “I like the landscape in the picture”; (2) “I want to spend time in this place” and (3) “I feel connected to the landscape in the picture”. These statements were used to capture preference for the landscape presented in the image, *general preference*, attractiveness for recreation activity (*recreation*), and *sense of place*, respectively (following Orenstein et al., 2015; Stedman, 2003; Tveit, 2009). For each participant an average score was calculated for each of the three questions at each level of intensity after verifying that internal consistency were high (Cronbach's α scores>0.87). Thus, high scores represent high value of *general preference*, *recreation* and *sense of place* for a given intensity level. We then used the 6-item Nature Relatedness scale (NR) (Text S2; Nisbet and Zelenski, 2013) to measure the level of nature relatedness on a 5-point Likert scale. NR scores were averaged after high internal consistency was confirmed (Cronbach's α = 0.87). Finally, we collected some demographic information including gender, age group, ethnic group, present and childhood residence (large city, small town, rural locality), education (secondary school, professional diploma, bachelor's degree, master's degree, and above) and income level (rating from low [1] to high [10] compared to the average household salary in Israel that was provided in the middle of the scale [5]). We also asked participants to indicate which device was used to answer the questionnaire (computer or mobile phones).

Permission for this study was granted by the Technion Social and Behavioral Sciences Institutional Review Board (approval number: 045–2019), and the research was performed in accordance with relevant guidelines and regulations. All participants were provided a brief description of the study and gave informed consent for study participation. All responses were anonymous.

2.3. Data analysis

2.3.1. Ecological surveys

All analyses were conducted in R version 4.0.5 (R Core Team, 2021). The effect of intensity level on bird richness and abundance were analyzed using generalized linear mixed-effect models (GLMM) including slope, cover of natural habitats and temperature as covariates, and the plot number as a random effect (R package ‘lme4’). We used Poisson error distribution for richness and negative binomial for abundance. As the level of intensity was somewhat correlated with slope and natural habitat cover, and more so with soil type, we excluded the latter two from the models, and verified that the variance inflation factors ($GVIF^{1/2Df}$) were adequate ($VIF < 5$). Plant richness and cover were analyzed using a linear model with slope as a covariate; plant richness was square-root-transformed and plant cover model included unequal variances (different variance per intensity level, R package ‘nlme’) to control for heteroscedasticity. Model residuals showed no significant spatial autocorrelation (Moran's I test, R package ‘ape’). Intensity levels were compared using post-hoc pairwise comparisons with Tukey corrected *p*-values.

In order to explore how the composition of bird and plant communities vary across intensity levels, we first built two nMDS with Bray-Curtis dissimilarity index (R package ‘vegan’) to visualize species composition (999 iterations). We then used ANOSIM to test for differences between intensity levels (999 permutations). Since we did not have abundance data for plants, we used frequency of occurrence (the number of sampling quadrats a species occupied in each plot).

2.3.2. Economic surveys

The effect of intensity level on crop yield (kg ha^{-1}), total costs (NIS ha^{-1}(, variable costs (NIS kg^{-1}), revenue (NIS ha^{-1}) and profit (NIS ha^{-1}) were modeled. We build five Linear Mixed Models (LMMs) with unequal variance (different variance per intensity level, R package ‘nlme’), intensity level as a fixed effect, and the plot as a random effect. In these models, intensive management included both intensive and super-intensive management, as explained above. Larger fields reduce operation costs since they can be cultivated more efficiently, and they suffer smaller edge effects (which can reduce crop yield). This can increase their revenue and profit. However, intensive groves had larger plots than lower intensity levels; this resulted in high covariance between intensity level and plot size which prevented us from using the plot size as a covariate in our models. Likewise, we did not include the slope and the olive variety as covariates despite their potential effect on costs and revenue, since they were correlated with the intensity level.

2.3.3. Sociological surveys

Three LMM's with unequal variance (different variance per intensity level, R package 'nlme') were built to explore how scores of *general preference*, *recreation* and *sense of place* were related to intensity level. The model also included nine covariates (NR, gender, age group, ethnic group, present and childhood residence, education, income level and device used) and participant ID was added as a random effect. All variables were used in the models as predictors showed no important covariance (GVIF$^{1/2\mathrm{Df}} < 2$).

3. Results

3.1. Ecological surveys

A total of 4087 individuals of 69 bird species in 250 visits were observed. The lowest bird richness was observed in super-intensive groves, followed by intensively managed groves (Fig. 3a). Bird richness was highest in organic, extensive and traditional groves as well in natural control plots, in which bird richness was significantly higher than super-intensive groves but did not significantly differ from intensive groves (Table 2, Fig. 3a). Slope and temperature positively affected bird richness, but the effect was not significant for temperature (Table 2). Bird abundance was lowest in super-intensive groves compared to all other management types (Table 2, Fig. 3b). Bird abundance in intensive groves did not significantly differ from organic and extensive groves but was significantly lower than traditional groves and control plots (Table 2, Fig. 3b). Organic and extensive groves did not differ from traditional groves and control plots. Temperature positively affected bird abundance whereas slope had no effect (Table 2).

A total of 334 plant species were observed. Plant richness was lowest in the super-intensive and intensive groves, intermediate in organic, extensive and traditional groves, and highest in the control plots (Table 2, Fig. 3c). Slope did not affect plant richness (Table 2). Plant cover was lowest in the super-intensive groves, followed by intensive, and then extensive groves. Extensive groves had significantly higher plant cover than super-intensive, but intensive groves did not significantly differ from super-intensive groves (Table 2). The highest plant cover was observed in organic, traditional and control plot, with no significant differences among them (Table 2, Fig. 3d).

Intensity level explained 43.1 % of the variation in bird species composition and 61 % of the variation in plant species composition ($p = 0.001$). For birds, intensive and super-intensive groves show a different species composition whereas organic, extensive, traditional and control plots show a great overlap (Fig. 4a). Species composition of plants differed between intensity levels, showing a turnover in species from super-intensive to intensive to organic/extensive and finally to traditional and control. The greatest difference in plant species composition was observed between the super-intensive and intensive groves to the lower intensity levels (Fig. 4b).

3.2. Economic surveys

Traditional and extensive groves had lower yield than organic and intensively managed groves (Tables 1, Fig. 5a). Revenue was highest in organic groves, followed by intensive groves, which showed slightly but not significantly lower revenue (Table 1). Revenues were lower in the extensive and traditional groves (Table 1), but they significantly differed only from revenue in the intensive groves (Fig. 5b, Table 3). Similar to yield and revenue, the total costs were also lowest in traditional and extensive groves (Table 1). Organic management had the highest costs (Table 1), which was significantly higher than extensive and traditional groves, yet not significantly different from intensive groves (Table 3,

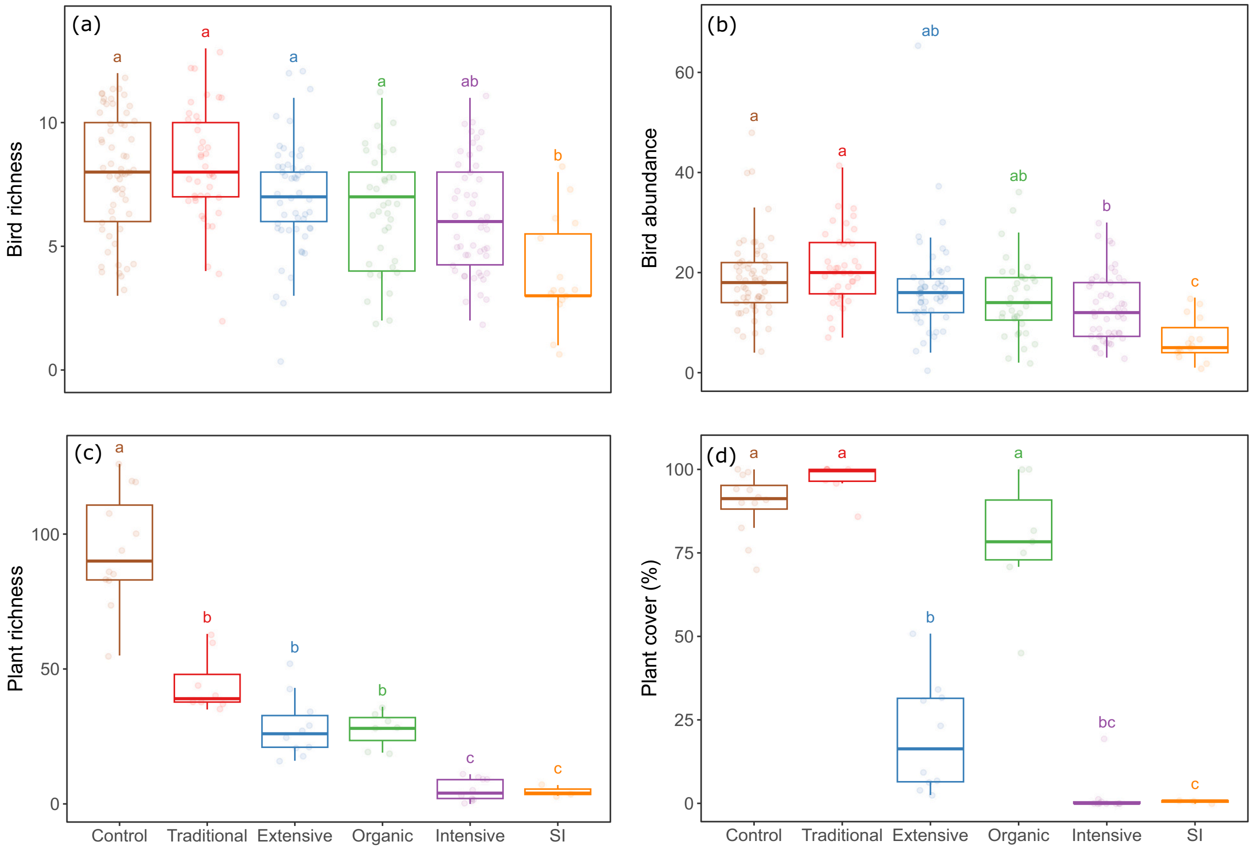

Fig. 3. Boxplot demonstrating the differences in bird richness (a), bird abundance (b), plant richness (c) and plant cover (d) between the different levels of olive management intensities (Super-intensive [SI]). Box boundaries indicate the 25th and 75th percentiles, the median is marked by the line inside the box, and whiskers extend to 1.5 times interquartile range. Raw data is presented underneath the boxplot (points). Different letters denote significant differences ($p < 0.05$) between intensity levels.

Table 2

Results of the ecological indicators models showing effects of intensity level, slope and temperature (for birds). Likelihood-ratio tests with χ^2 values are presented for the main effects, and Tukey-corrected multiple comparisons (t and z scores for Gaussian and non-Gaussian models, respectively) are shown for differences between intensity levels. Marginal-R^2 are presented for bird models, and R^2 for plant models. Sigificant variables are marked in bold with the following sigificnace levels: (***) $p<0.001$, (**) $p<0.01$, (*) $p<0.05$, (.) $p<0.1$.

	Bird richness		Bird abundance		Plant richness		Plant cover	
	χ^2 / z	df	χ^2 / z	df	χ^2 / t	df	χ^2 / t	df
Intensity level	**22.65*****	5	**41.62*****	5	**297.74*****	5	**3727.04*****	5
Control - Traditional	−0.80		−1.07		**6.68*****	43	−1.97	17.55
Control - Extensive	0.49		0.62		**9.59*****	43	**11.83*****	16.05
Control - Organic	1.37		1.56		**8.73*****	43	1.68	10.52
Control - Intensive	1.99		**2.94***		**16.34*****	43	**26.07*** **	18.66
Control - SI	**3.91****		**5.18*****		**11.28*****	43	**32.14*****	10.99
Traditional - Extensive	1.22		1.62		2.81$^{(.)}$	43	**13.78*****	13.1
Traditional - Organic	2.01		2.44		2.62	43	2.67	9.13
Traditional - Intensive	2.66$^{(.)}$		**3.85****		**9.50*****	43	**35.19*****	15.72
Traditional - SI	**4.33*****		**5.78*****		**6.61*****	43	**50.65*****	7.02
Extensive - Organic	0.96		1.03		0.05	43	**−6.59*****	13.19
Extensive - Intensive	1.57		2.44		**7.38*****	43	3.19$^{(.)}$	13.21
Extensive - SI	**3.70****		**4.90*****		**4.86*****	43	3.70*	10.49
Organic - Intensive	0.48		1.21		**6.65*****	43	**10.41*****	9.15
Organic - SI	**2.97***		**4.03*****		**4.60*****	43	**11.02*****	7.97
Intensive - SI	2.75$^{(.)}$		3.34*		−0.15	43	0.83	8.93
Slope	**3.99***	1	0.91	1	0.09	1	**243.58*****	1
Temperature	2.91$^{(.)}$	1	**4.57***	1				
R^2	0.18		0.26		0.90		0.93	

Fig. 5c). Contrary to the total costs, the direct variable costs were lowest in intensive groves (Table 1) and did not significantly differ among organic, extensive and traditional groves (Tables 1 & 3, Fig. 5d). Finally, organic groves showed the highest profit, and extensive groves showed the lowest (Fig. 5e, Tables 1 & 3). Intensive and traditional groves showed an intermediate profit that did not significantly differ from either organic or extensive management (Table 1; Fig. 5e). However, the variance in profit within management intensity levels was extremely high.

3.3. Sociological surveys

Traditional groves scored highest for *general preference*, *recreation*, and *sense of place*, followed by organic groves (Fig. 6). Extensive groves scored slightly lower scores for all three measures, and intensive and super-intensive groves scored the lowest with an exception of *general preference*, for which they did not differ significantly from the extensive groves (Fig. 6; Table 4). NR positively affected scores of all three measures and computer devices contributed higher scores than phone devices for *general preference* and *recreation* (Table 4). The former was also affected by age group (Table 4).

4. Discussion

The ongoing intensification of olive groves across the Mediterranean basin (Morgado et al., 2022) presents a unique opportunity to explore the economic, ecological and cultural implications of agricultural intensification. The Mediterranean is home to olive groves for centuries, and they play an important role in the Mediterranean landscape, culture and economy (Infante-Amate et al., 2016; Loumou and Giourga, 2003). Increasing demand for olives and olive oil, the selection of certain varieties, abandonment of traditional practices, improved machinery, irrigation and application of agrochemicals have resulted in a massive intensification of olive farming in the last decades (Moreira et al., 2019). Although this process increases production, it also simplifies landscapes, degrades habitats, contributes to the decline of wildlife populations and alters the value of these traditional agroecosystems for people and nature (Colombo et al., 2020; Herrera et al., 2015; Romero-Gámez et al., 2017; Torquati et al., 2019; Vasconcelos et al., 2022). Here we jointly explored, for the first time, the economic, ecological and cultural consequences of the olive grove intensification, covering traditional, extensive, organic, intensive and super-intensive farming systems. Our results highlight a general trend of trade-off between the economic function and the ecological and cultural functions, which was previously shown for various crops (Beckmann et al., 2019; Gong et al., 2022; Segre et al., 2022). Extreme trade-offs were found in the extremes, in highly intensified or highly extensified practices. Our results present an example of how multiple outcomes change over the intensity gradient and highlight few opportunities to promote more ecologically and socially sustainable olive production, which we discuss below.

4.1. Organic grove as an opportunity for culturally and ecologically sustainable production

Organic groves demonstrated an optimal balance between ecological, cultural and economic functions. They maintained relatively high richness of birds and plant cover, similar to the traditional groves and semi-natural control plots, where biodiversity peaked, and intermediate level of plant richness. These results were consistent with previous studies demonstrating higher species diversity (mostly arthropods) in organic olive grove compared to intensive farming (Pleguezuelo et al., 2018; Puig-Montserrat et al., 2021; Sánchez-Fernández et al., 2020). By implementing mowing and cover crop instead of herbicides or tillage, organic groves maintain diverse herbaceous communities that provide resources for birds that also benefit from the absence of pesticides in these groves (Castro et al., 2021). From a social perspective, organic groves scored second after traditional groves in terms of general preference, attractiveness for recreation and contribution to sense of place. This result coincides with findings from Spain where organic groves with grass vegetation were favored over intensive ones (Nekhay and Arriaza, 2016). Yield and profit analyses revealed similarities between organic and intensive groves, with organic groves being more profitable despite higher input costs, supported by the premium pricing of organic olive oil. Studies that compared both yield and profitability of organic and intensive olive farms did not find consistent results, yet most studies shows that organic were more profitable due to higher prices of organic olive oil (Berg et al., 2018; Guzmán et al., 2011; Sgroi et al., 2015; Volakakis et al., 2022).

Organic olive production appears to be the best option for multifunctional agriculture in our system and potentially in others (Berg et al., 2018; Sgroi et al., 2015), balancing yield, profit, and social and ecological externalities. Avoiding yield and profit loss is key in industrial

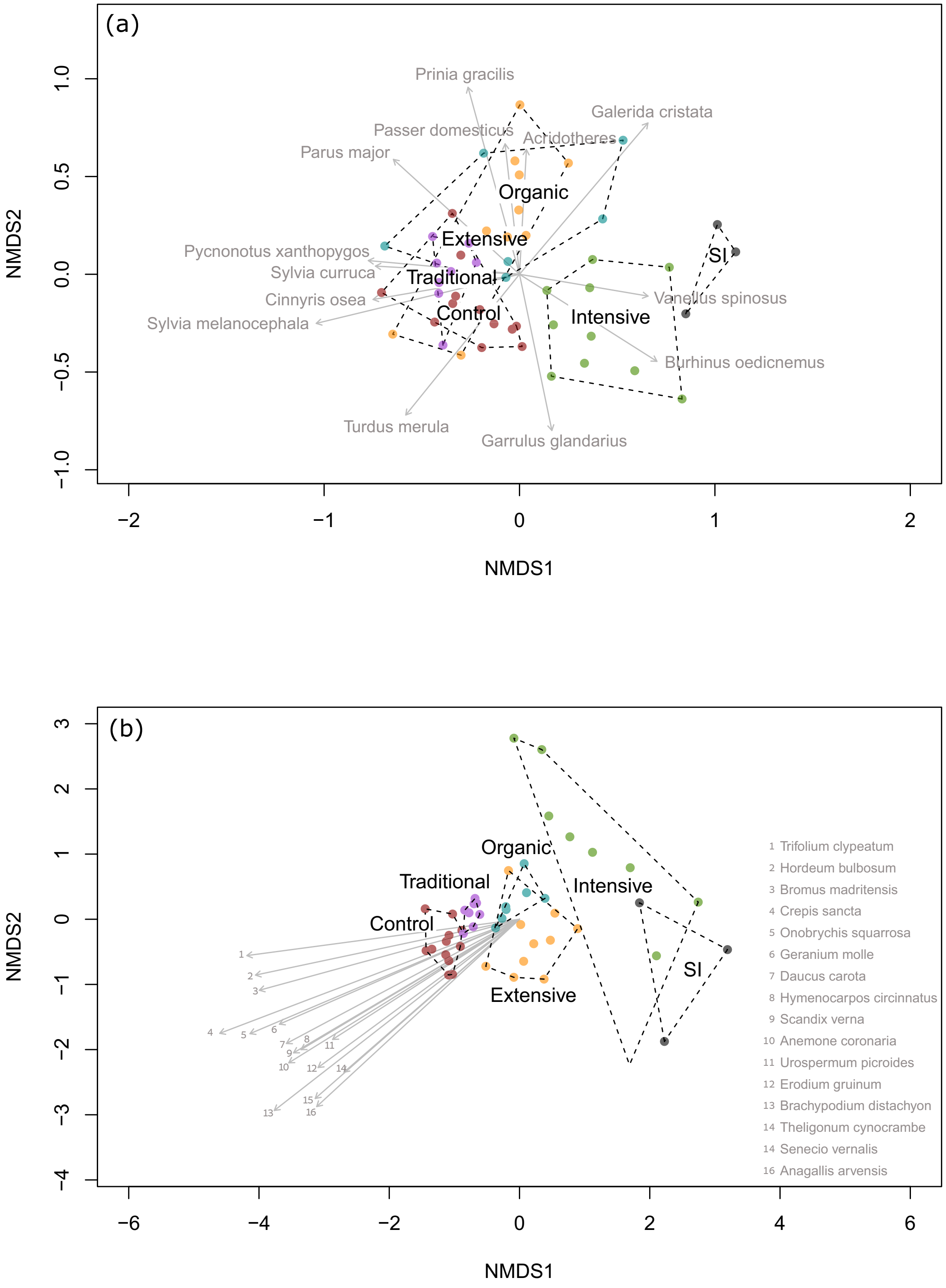

Fig. 4. Bird (a) and plant (b) species composition under different management intensity levels in olive groves. To avoid clutter, only species which are highly correlated with the MDS-axes are shown ($p < 0.01$ for birds and 0.001 for plants). Stress = 0.18 for birds and 0.14 for plants. The color schemes represent the different types of plots studied: semi-natural habitats (red), traditional (purple), organic (turquoise), extensive (orange), intensive (green) and super-intensive (black).

farming where economic output is a major goal, as reduced yields may lead to intensified farming to minimize losses. The common trade-off between biodiversity and yield in organic vs. intensive farming (Gong et al., 2022; Ponisio et al., 2015) was not found here. The small yield loss for organically managed compared to intensively managed groves was negligible and completely compensated by the high premium price received. Organic olive farming also reduces runoff and soil erosion in hilly systems (Zuazo et al., 2020). Although we collected economic data over two years, this may not be sufficient, since organic, traditional and extensive yields tend to fluctuate over time more severely than intensive

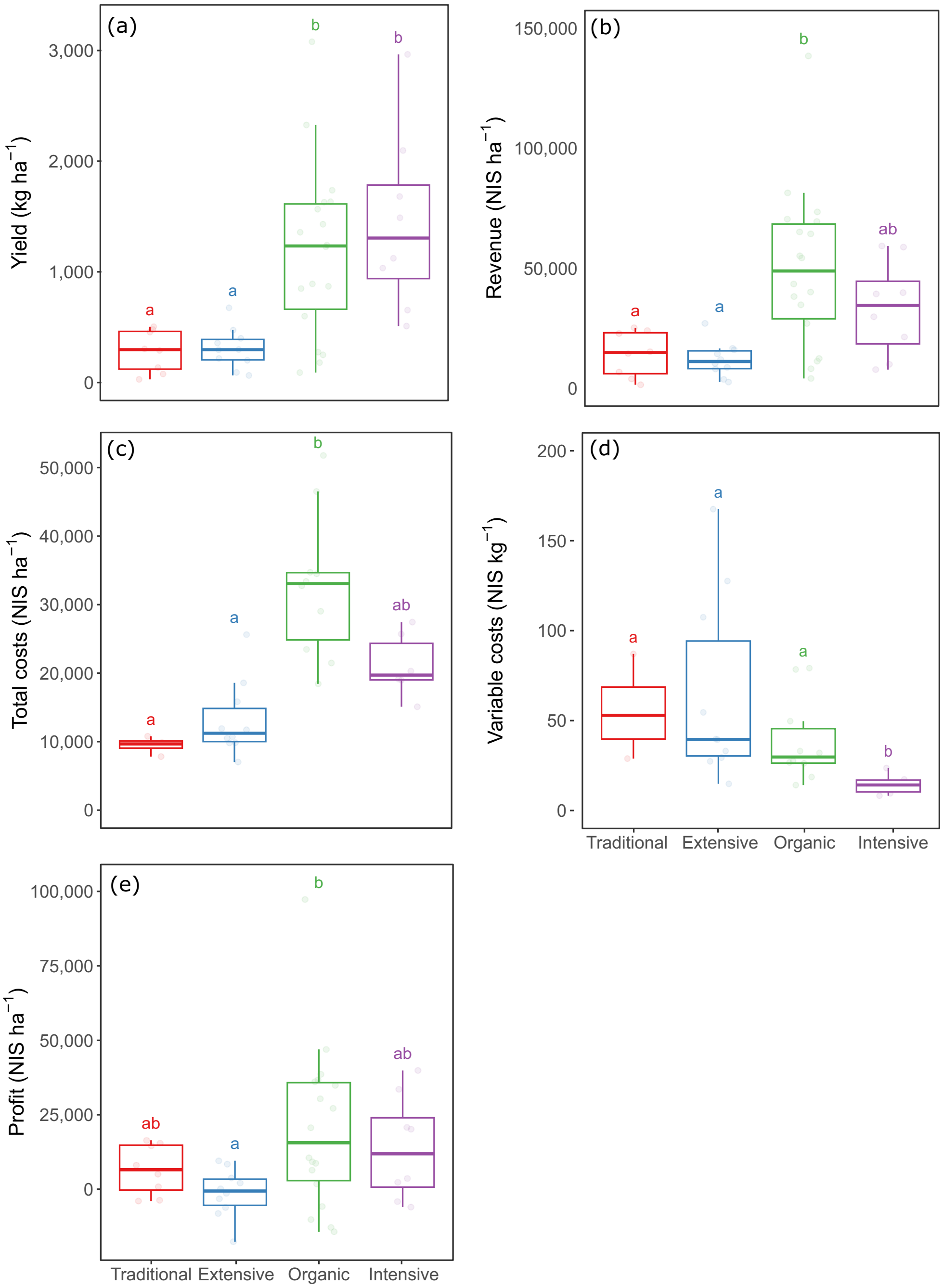

Fig. 5. Boxplot demonstrating the differences in olive oil yield (a), revenue (b), total production costs (c), direct variable costs (d) and profit (e) between the different levels of olive management intensities (in NIS; 1 USD = 3.75 NIS). Box boundaries indicate the 25th and 75th percentiles, the median is marked by the line inside the box, and whiskers extend to 1.5 times interquartile range. Raw data is presented underneath the boxplot (points). Different letters denote significant differences ($p < 0.05$) between intensity levels.

yields (Knapp and van der Heijden, 2018). Thus, more holistic research is still needed to further establish the socio-economic, environmental and ecological value of organic olive farming.

Although there are no subsidies for organic farming in Israel, unlike in Europe, it appears that they are not necessary. This is because both revenue and profit from organic groves were the highest in our study, surpassing those recorded in Europe (e.g., Sintori et al., 2023; Rodríguez Sousa et al., 2020). These differences can be attributed to the generally high price levels in Israel, which are the highest among OECD countries (OECD, 2024). Prices of organic olive oil are also high due to the small market and high demand. Additionally, given the small market, many organic olive farmers in Israel employ direct marketing strategies, which eliminates the need for intermediaries and agents who typically charge commissions. However, if high adoption of organic practices will lead to reduce market prices, subsidies for organic production could be considered against alternative approach of promoting agroecological practices in rain-fed traditional or extensive olive farms. A notable drawback of organic groves, when compared to traditional ones, is their irrigation requirement. The high-water usage in these groves, particularly in water-scarce regions, poses a significant sustainability challenge (Guerrero-Casado et al., 2021).

Table 3

Results of the economic models showing effects of intensity level (in NIS; 1 USD = 3.75 NIS). Likelihood-ratio tests with χ^2 values are presented for the main effects, and Tukey-corrected multiple comparisons (t scores) are shown for differences between intensity levels. Marginal-R^2 are presented. Sigificant variables are marked in bold with the following sigificnace levels: (***) p<0.001, (**) p<0.01, (*) p<0.05, (.) p<0.1.

	Yield (kg ha^{-1})		Revenue (NIS ha^{-1})		Profit (NIS ha^{-1})		Total costs (NIS ha^{-1})		Variable costs (NIS kg^{-1})	
	χ^2 / t	df	χ^2 / t	df	χ^2 / t	df	χ^2 / t	df	χ^2 / t	df
Intensity level	**34.25*****	3	**24.91*****	3	**10.1***	3	**22.75*****	3	**26.9*****	3
Traditional - Extensive	−0.20	18	0.45	18	1.56	18	−0.61	11	−0.42	11
Traditional - Organic	**−4.46****	18	**−4.09****	18	−1.85	18	**−3.82***	11	1.16	11
Traditional - Intensive	**−3.85****	18	−2.31	18	−0.98	18	−1.77	11	**3.20***	11
Extensive - Organic	**−4.34****	18	**−4.42****	18	**−2.87***	18	**−4.13****	11	1.43	11
Extensive - Intensive	**−3.77****	18	−2.64$^{(.)}$	18	−2.01	18	−1.49	11	**3.01***	11
Organic - Intensive	−0.77	18	1.53	18	0.69	18	2.14	11	**3.12***	11
R^2	0.84		0.78		0.42		0.59		0.11	

4.2. Balancing the trade-off in olive farming: yield and profit vs. biodiversity and cultural services

Extensive and traditional rain-fed groves, with lower yield and profit than intensive and organic groves, illustrate the trade-off between biodiversity, cultural services and yield. However, they provide a good example of how different trade-offs can be managed. The traditional groves had the highest biodiversity, with species composition resembling to the natural habitats. They also received the highest scores in three social measures used to assess attitudes towards olive groves. Traditional groves are a relic of older times and are scarce in Israel, and they can be compared to traditional abandoned olive groves in Europe, which also show high ecological and social values (Allen et al., 2006; Assandri et al., 2017; Duarte et al., 2008; Loumou and Giourga, 2003; Sánchez-Fernández et al., 2020; Torquati et al., 2019). These grooves are located in marginal areas and are often abandoned, as their economic value and competitive power are very low. The traditional groves in our study area remained profitable despite the costs invested in their management (mainly manpower costs) thanks to good marketing that resulted in very high premium price paid for their olive oil. This marketing is often not feasible for many marginal traditional olive groves and efforts were directed to mitigate this process of abandonment (Duarte et al., 2008; Torquati et al., 2019). An alternative approach could be to develop a scheme that supports a management of such groves that aims to maintain their high potential for ecological and cultural value, even at the cost of production, as previously promoted in Spain (Rodríguez Sousa et al., 2020). Thus, subsidizing traditional groves where a premium price is not reached to conserve these valuable habitats and landscapes.

Extensive groves demonstrated intermediate social and ecological benefits and the lowest yield and profit in our study. In Israel, extensive farming (mostly by Arab minority) is mostly driven by cultural and not economic motivation, to maintain tradition, local heritage and protect the land (Perlberg et al., 2013). In Europe, extensive groves lacking irrigation face economic challenges, relying on family labor or subsidies, and cannot match intensive farms' output. Furthermore, many farmers have also abandoned traditional hard labor practices and adopted practices such as ploughing, and pesticide use instead of grazing management and cover crops, mirroring trends observed in Europe (e.g., Giourga et al., 2008). Altogether these changes reduce the ecological and cultural values of extensive olive groves that participated in our study without improving yield and profit, leading to a 'lose-lose' situation. Some extensive groves in our study even showed a negative profit due to income failing to offset labor costs, but this did not translate to actual financial losses, primarily because most expenses were unpaid family labor. Getting out of this 'lose-lose' situation towards sustainable extensive production holds a great potential, as these groves occupy about 75 % of olive groves in Israel. This can be achieved either by encouraging and guiding farmers that wish to increase their profit to adopt organic farming, or by developing agri-environmental schemes that provide subsidies for implementing environmentally-friendly practices (Kathage et al., 2022; Lombardo et al., 2021). For instance, maintaining natural vegetation cover can restore ecological and cultural values of extensive groves, while providing subsidies that support farmers' livelihood.

Maintaining permanent natural vegetation cover seems to play a major role in the difference we found between traditional, extensive and organic farming. Vegetation was traditionally removed from groves due to concerns about nutrient and water competition, weed dispersal, and pests (Kathage et al., 2022; Teff-Seker et al., 2022). This is changing as evidence shows that permanent cover improves soil structure, fertility, carbon sequestration, and biodiversity (Carpio et al., 2019; Rey et al., 2019). Management with traditional grazing may have also increased the plant species richness present in the traditional groves (Segre et al., 2016). Nevertheless, some species can benefit from mild ploughing (Pereira et al., 2023), and even red listed species. Extensive plots recorded rare plants like *Silene fuscata* and endangered *Alkanna tinctoria*, typical of heavy soils. These species are declining due to conversion of land from extensive farming to intensive farming, and the extensively managed olives represent an important refuge for those species and protection of the local seed bank, which are often under threat (Carpio et al., 2020). Therefore, recommendations about maintaining permanent cover instead of ploughing may not be suitable everywhere, and combining mild traditional ploughing with grazing can be considered. Additionally, organically managed groves had high vegetation cover, but high proportion of ruderal species (despite their high species diversity). This may be attributed to irrigation and fertilization, but in this study, we could not disentangle the effects of organic and conventional fertilizers, irrigation and ground cover across the different practices. Future research should try to further explore which specific management practices are responsible for the observed changes in biodiversity to accurately design recommendations.

Adopting permanent vegetation cover in groves is increasingly popular in Israel and other European countries (e.g., Spain), where such practices are encouraged through subsidies, although some Israeli farmers perceive it as unaesthetic (Teff-Seker et al., 2022). Contrastingly, in our survey the general public preferred groves with high plant cover, especially in traditional and organic, over bare ground extensive, intensive, and super-intensive groves. The low preference for extensive and intensive landscapes can be attributed to the low green vegetation cover, which is a strong predictor for perceived naturalness (Nekhay and Arriaza, 2016; Tveit et al., 2006). The artificial appearance of groves with high tree density and perfect rows may also impact perceived naturalness, resulting in lower scores. Regardless of the degree of naturalness, low-intensity olive groves are recognized as cultural landscapes that strengthen the sense of connection to the land (Loumou and Giourga, 2003). This recognition of cultural heritage is essential for conservation given that community conservation behavior is enhanced by spiritual place-based identity and a long-term relationship with nature (Kato, 2006). Community visits and participation in the agronomic

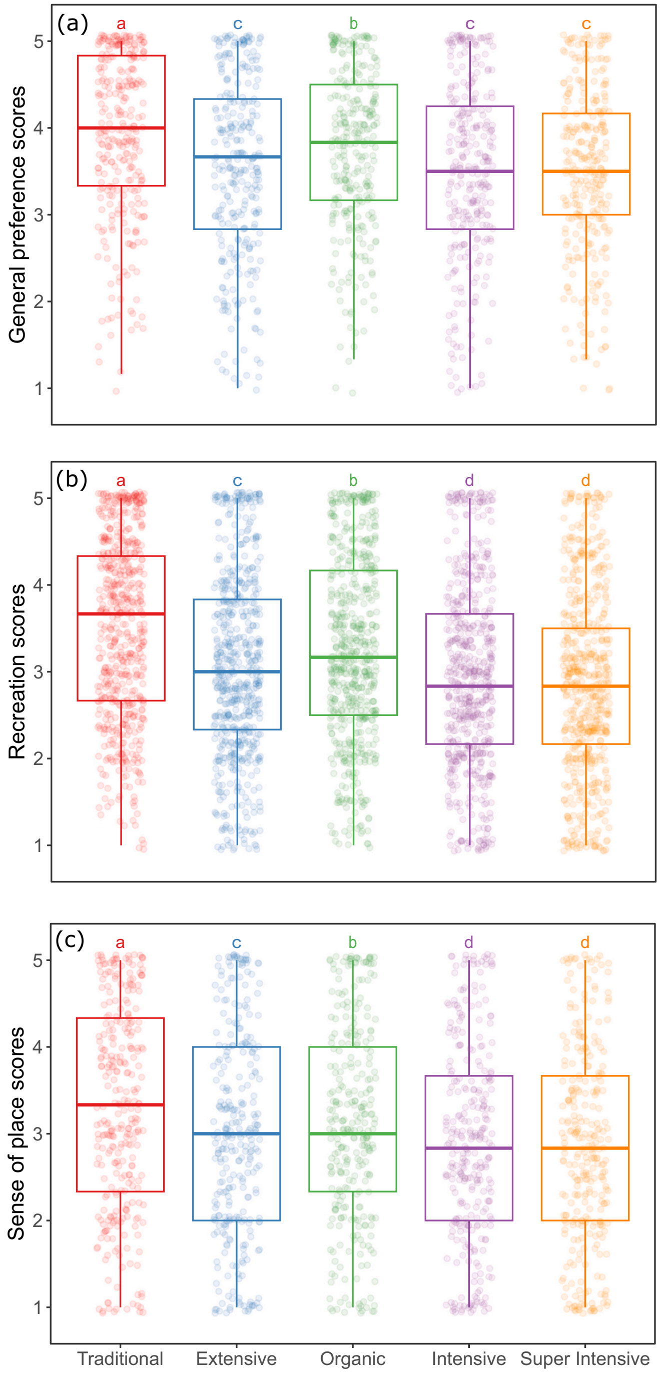

Fig. 6. Boxplot demonstrating the differences in general preference scores (a), recreation scores (b) and sense of place scores (c) between the five intensity levels. Box boundaries indicate the 25th and 75th percentiles, the median is marked by the line inside the box, and whiskers extend to 1.5 times interquartile range. Raw data is presented underneath the boxplot (points). Different letters denote significant differences ($p < 0.05$) between intensity levels.

Table 4

Results of the social survey models showing effects of intensity level on scores of general preference, recreation and sense of place. Likelihood-ratio tests with χ^2 values are presented for the main effects, and Tukey-corrected multiple comparisons (t scores) are shown for differences between intensity levels. Marginal-R^2 are presented. Sigificant variables are marked in bold with the following sigificnace levels: (***) p<0.001, (**) p<0.01, (*) p<0.05.

	General preference		Recreation		Sense of place	
	χ^2 / t	df	χ^2 / t	df	χ^2 / t	df
Intensity level	**168.16*****	4	**356.01*****	4	**173.5*****	4
Traditional - Extensive	**9.13*****	1192	**11.79*****	1192	**7.42*****	1192
Traditional - Organic	**4.89*****	1192	**6.84*****	1192	**4.38*****	1192
Traditional - Intensive	**9.73*****	1192	**14.68*****	1192	**10.18*****	1192
Traditional - SI	**9.44*****	1192	**16.55*****	1192	**10.4*****	1192
Extensive - Organic	**−6.24*****	1192	**−4.95*****	1192	**−4.34*****	1192
Extensive - Intensive	0.71	1192	**2.89***	1192	**2.9***	1192
Extensive - SI	0.45	1192	**4.76*****	1192	**3.92*****	1192
Organic - Intensive	**6.98*****	1192	**7.84*****	1192	**7.8*****	1192
Organic - SI	**6.64*****	1192	**9.71*****	1192	**8.14*****	1192
Intensive - SI	−0.26	1192	1.87	1192	1.41	1192
NRS	**118.82*****	1	**163.45*****	1	**134.28*****	1
Sex	1.46	1	0.13	1	0.41	1
Age	**10.27***	4	1.85	4	3.43	4
Religion	4.86	4	1.86	4	5.39	4
Present residence	0.61	2	2.09	2	3.29	2
Childhood residence	0.3	2	1.26	2	3.01	2
Device	**3.89***	1	**5.38***	1	1.6	1
Income	0.78	1	0.04	1	0.57	1
Education	1.18	3	3.26	3	3.31	3
R^2	0.28		0.38		0.36	

process can create meaningful connections between farmers, the public and nature, contributing to a stronger sense of place and value for these landscapes. Strong sense of identity and cultural values can benefit farmers, as they may contribute to the higher premium prices associated with the non-intensive products and thus support sustainable farming over intensive methods.

Intensive and super-intensive groves boost economic output at the expense of ecological and cultural benefits. The plant diversity and cover in these groves was extremely low and comprised of almost solely ruderal weeds. Similarly, breeding bird diversity showed a decline with increasing management intensity, predominantly of cavity nesting species. The intensive groves are relatively young with smaller trees which cannot support cavity nesters as in the extensive practices (Castro-Caro et al., 2014; Morgado et al., 2020). The lack of herbaceous layer may also significantly reduce insects and seeds as a food source (Castro-Caro et al., 2014; Duarte et al., 2014), and reduce breeding bird communities depending on them. These results largely correspond with previous research showing that bird richness and abundance decline in more intensive olive groves (e.g., Bouam et al., 2017; Rey et al., 2019), with limited focus on super-intensive management (e.g., Morgado et al., 2020, 2021). Despite the low biodiversity in intensive groves, breeding bird richness further declined by 38 % and plant richness by 10 % under super-intensive management. These results, as well as our experience in the field while sampling birds in super-intensive groves, supported that description suggested by Morgado et al. (2020) of a “Mediterranean silent spring”. Our estimates for biodiversity loss under super-intensive management should be considered with caution since we had a small sample size for this practice. Unfortunately, we could not collect economic data to corroborate the economic gain from this transition, but it is considered by farmers to be more efficient and economical and is becoming increasingly common. Further expansion of super-intensive groves can cause increased pressure on biodiversity in ecological-sensitive areas and should be carefully monitored.

4.3. *Limitation and future direction*

While this study provides valuable insights into the economic, ecological, and cultural consequences of olive grove intensification, it is important to acknowledge certain limitations that may affect the interpretation and generalizability of the findings. First, our plant survey, conducted in March, captures the plant community at that time and future studies could benefit from extended sampling periods. However, in our system vegetation already starts to dry in April and since all species and not just flowering species were recorded, we believe this single-time point survey still effectively represents the local vegetation. Second, our social survey utilized springtime pictures featuring abundant greenery, in contrast to the less visually appealing dry summer vegetation. Including images from other seasons could provide a more comprehensive understanding of the cultural services or disservices offered by different types of olive groves. Third, the yield and economic benefits of the rain-fed traditional and extensive olive groves are significantly affected by rainfall. Our survey, spanning two years, was conducted during a period of near-average rainfall in 2017/2018 (522 mm) and above-average in 2018/2019 (734 mm). Considering that most years in this decade had below-average rainfall, our economic results for these groves likely represent higher yields than typically expected. As these groves showed the lowest economic benefits in our study in rainy years, we believe our findings are robust and conservative. However, for a more comprehensive understanding, future research should extend over multiple years to accurately capture economic variations in environmental conditions.

5. Conclusions

Promoting sustainable agriculture is considered one of the major challenges of humanity (Bommarco et al., 2013; Tilman et al., 2017). This interdisciplinary study explored the impact of intensification process of olive cultivation on the three main pillars of sustainability: society, economy and biodiversity. Olive farming represents a unique opportunity to explore the impact of intensification, as it is currently undergoing a rapid intensification process (Morgado et al., 2022). Our results highlight a trade-off between economic benefits, which peak at intensive and super-intensive management regimes, and socio-ecological benefits, which peak at traditionally managed olive groves. Nevertheless, jointly exploring social, economic, and ecological aspects across five levels of intensification has also revealed important opportunities for sustainable management. Organic olive farming provides yields and profit which are similar to intensive farming, while these groves also host rich biodiversity and are highly appreciated by people. Efforts should be made to inform farmers about these socio-economic and ecological benefits and develop policies that remove barriers and encourage farmers to adopt organic production (Teff-Seker et al., 2022). On the other hand, extensive olive farming represents a non-sustainable situation, in which socio-ecological benefits are similar or lower than organic management, while yield and profit are extremely low. Therefore, we argue that it is important to develop policies that conserve the cultural and ecological values of these extensive rain-fed olive groves, as they are considered important cultural landscapes across the Mediterranean basin (Loumou and Giourga, 2003). The traditional ancient olive groves demonstrated extremely high socio-ecological benefits and should be protected and cultivated using traditional methods that conserve the Mediterranean scenery and endangered species that are impacted by intensification. Therefore, the way to resolve the production-sustainability trade-off is to tailor practices to specific needs and targets of each sector while taking into account their strengths and problems.

CRediT authorship contribution statement

Simon Raz: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Segre Hila:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Methodology, Formal analysis, Data curation. **Shwartz Assaf:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Assaf Shwartz reports financial support was provided by Israeli Nature and Park Authority. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2024.171035.

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