



# Community perceptions about mangrove ecosystem services and threats

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## ABSTRACT

The Ecosystem Service Framework discloses the ecosystem's benefits to society and provides support to preserve threatened systems while considering the economic and social dimensions of the communities more dependent on its resources. Mangroves provide important and valuable goods and services to communities, at different spatial and temporal scales. Nevertheless, over-exploitation of these resources can generate poverty traps, where rural households can no longer use the ecosystem as a source of food security or income. This study uses three communities that live in surrounding areas of mangroves from São Tomé Island (Diogo Nunes, Angolares, and Malanza) as a case study. The main aim was to evaluate locals' perspectives about ecosystem use, threats, and conservation. Questionnaires were conducted among local populations and provided valuable information to identify the major beneficiaries of mangrove resources. These results also indicated that the services and threats identified locally are different from those identified in the literature. The importance of considering the impact of local values and traditions in the use of ecosystem resources was also highlighted by the obtained results since São Tomé residents do not acknowledge the existence of services that do not bring a direct benefit. The absence of awareness about mangroves and their threats can cause severe damages to the ecosystem's health, requiring the implementation of specific awareness-raising policies among populations that interact with mangrove ecosystems.

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## 1. Introduction

Social-ecological systems represent independent interactions between different sub-systems, such as biological, social, economic, and cultural, and may vary with temporal and spatial scales (Anderies et al., 2004). Every sub-system is interconnected and can have real impacts on each other. The outcomes provided by Ecosystem Services (ES) are not only a result of the ecosystem alone but a mixture of different sources of capital, *i.e.* natural, manufactured, human, and social (van Reeth, 2013). The concept of ES supports a broader view of the interaction between human society and nature, linking both concepts and addressing environmental degradation (Hicks and Cinner, 2014). The concept of

ES has been also used as a tool to support ecosystem conservation, by emphasizing the benefits that they provide to human populations while integrating the social-ecological system in the decision-making process (Daily et al., 1997).

The valuation of ES requires the quantification of each service, thus, this value will be influenced by cultural constructions and conditioned by preferences and principles that people idealize. Socio-cultural valuations are comprehensive approaches since they encompass not only the quantification of the services but also the social aspects of the cultural context. Moreover, they can assess how human well-being may be affected by the environment (Chan et al., 2012). In theory, this interdisciplinary approach is broader, although it can be hard to apply due to the difficulties in integrating areas with such different philosophies (Solé and Ariza, 2019). The study of perceptions has a higher probability of capturing how ES contributes to human well-being than biophysical assessments (Martín-López et al., 2012).

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To better comprehend measures for ecosystem management and to alleviate poverty in communities dependent on the ecosystem, it is necessary to understand the social-ecological system in which the community is integrated, and the types of stakeholders involved. One way to understand this is with direct observations of how people live and analyze their perceptions about the system under-study (Adams et al., 2018). Social assessments are important to understand the perspectives of the beneficiaries of socio-ecological systems (Potschin-Young and Haines-Young, 2011). Human behavior can be affected directly by the perception of an individual and indirectly by socio-economic variables. This logic has been applied in the study of the impact of demographic indicators on environmental perceptions (Allendorf et al., 2006).

Transitional ecosystems like mangroves are present in the interface between fresh and marine systems and are present in coastal zones from tropical and temperate countries. These systems are considered the third most productive ecosystems in the world, and the mangrove species are the most likely to survive climate change effects due to their rapid growth and reproductive cycles (Mukhopadhyay et al., 2018; Polidoro et al., 2010).

These wetland systems provide various exclusive goods and services, very important to the human communities, such as coastal protection against natural hazards and nursery areas to several species (Badola and Hussain, 2005; Bassett et al., 2013; Mumby et al., 2004). However, a high proportion of mangrove uses and benefits are not marketable, therefore their full value cannot be captured through economic systems. However, these benefits play an important role in supporting communities located in the surrounding area (Glaser, 2003). As an example, Mozumder and Shamsuzzaman (2018) reported 3.5 million individuals in Bangladesh with some level of dependency on mangrove systems. Activities such as fishing and timber harvesting in mangrove areas are commonly used by locals and have been proved to contribute substantially to the economy and food security of local communities (Datta et al., 2012). Consequently, studies seeking to assess the value of mangroves at the regional level are becoming more common in order to facilitate decision-making (Adekola et al., 2015; Bandaranayake, 1998; Glaser, 2003; Iftekhhar and Takama, 2008; Naylor and Drew, 1998; Palacios and Cantera, 2017).

Most ES provided by mangroves are public goods with open-access and poorly defined property rights. These situations can lead easily to over-exploitation, degradation, and the so-called *tragedy of the commons*, which can trap households in poverty (Chaikumbung et al., 2016; Hardin, 1968). When households become poorer, they can turn to mangrove and fish resources as a 'safety net'. This is beneficial when there is a lack of substitutes or alternatives, however, the uncontrolled exploitation of the mangrove system can cause damages to the ecosystem and reduce the provision of services, therefore increasing the risk of poverty traps (Uchida et al., 2019). Traditionally, people prioritize short-term needs above long-term sustainability, this mostly is the result of the lack of safety nets and access to resources and secure income (Poppy et al., 2014). Community-based resource management coupled with the tools provided by the ES framework could improve ecosystem conservation, environmental health, and empower local communities, by enabling them to participate and influence decision-making, while achieving both food security and environmental sustainability (Poppy et al., 2014; Thompson et al., 2017). Moreover, it has been proven that the support of local communities can improve ecosystem conservation (Roy, 2016). This type of management can develop inclusive decision-making processes that ensure the provisioning and equitable distribution of benefits (Orenstein and Groner, 2014).

This study attempts to understand the importance of mangrove ES for local communities from a socio-ecological perspective encompassing local views and dependencies from mangrove systems. Thus, the main aim of this paper is to assess the perceptions of local inhabitants about mangrove ecosystems and their perspective on the threats and mangrove conservation approaches. This assessment will use São Tomé Island as a case study to understand how local inhabitants: (i) perceive mangrove ecosystems and human impacts on ecosystem health; (ii) identify mangrove threats; (iii) envisage strategies to ensure mangrove conservation.

## 2. Methodology

### 2.1. Study area

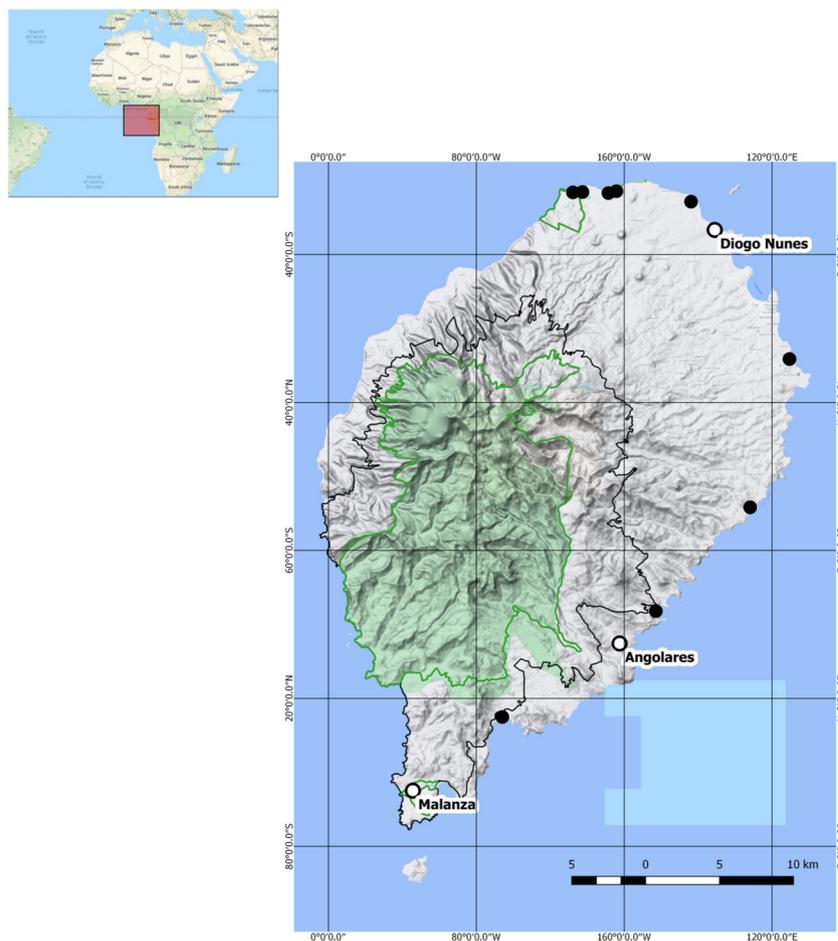
#### 2.1.1. Study site

The Democratic Republic of São Tomé and Príncipe is an island country (Gulf of Guinea; 0°25'N–0°01'S, 6°28'E–6°45'E) known for its richness in endemic species, as well as diverse ecosystems. Three of the 12 mangrove systems located at the largest island, São Tomé (854 km<sup>2</sup>) were selected as study areas: Diogo Nunes, São João dos Angolares and Malanza (Fig. 1). These systems were selected because they represent different environmental conditions and have surrounding communities with different social contexts. The smallest mangrove, Diogo Nunes, has a total area of 0.01 km<sup>2</sup> (Figure S1A–Afonso et al., 2021) and is the most degraded of all case study mangroves. São João dos Angolares (0.13 km<sup>2</sup>, Figure S1B–Afonso et al., 2021). Malanza is the biggest mangrove system on the island, with a total area of 1.52 km<sup>2</sup> (Figure S1C–Afonso et al., 2021). In Malanza there is a local group of guides that is responsible for conducting tours in the mangrove area. This is an activity that has a strong influence on the attitude of locals towards the mangrove systems since it brings profit to the community. A recent study has shown that most mangroves represent a relevant source of ES in São Tomé, providing a total of 27 services to the nearest communities, mostly services with indirect benefits, such as *erosion regulation* and *water cycling* (Afonso et al., 2021). Nevertheless, they have highlighted the difficulties in identifying ES in mangroves.

#### 2.1.2. Population and demography

São Tomé has a population density of 197.5 persons per km<sup>2</sup> with a sex ratio of 1:1 (49.6% males to 50.4% females—(Instituto Nacional de Estatística, 2018)). As a developing country, the population of São Tomé is highly dependent on direct ecosystem products and activities like agriculture of cocoa and banana and livestock farming (i.e. pig and goat farming). Some inhabitants also produce liquors (i.e. palm wine) to sell within the community and obtain an additional income.

The near area adjacent to Diogo Nunes mangrove there is a community of Diogo Nunes with 392 inhabitants (INE São Tomé e Príncipe, 2016). The Angolares mangrove is located in the vicinities of a city with 2037 inhabitants (INE São Tomé e Príncipe, 2014). Two communities are located in the surrounding areas of Malanza mangrove, namely Vila Malanza and Porto Alegre, accounting for a total of 1345 inhabitants (INE São Tomé e Príncipe, 2014). There are several aspects that the three communities have in common, they are dominated by males born in São Tomé, belonging to age class 15–64 years with access to formal education (Table 1). However, in Angolares, there are more people living together or married than in other communities.



**Fig. 1.** São Tomé and Príncipe location in the Gulf of Guinea (left corner). São Tomé island with mangrove systems identified black circles and study areas with white circles. The green and black lines delimitate the Obô Natural Park and its buffer area, respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

**Table 1**  
 Resume of demographic variables (%) from the communities living near the study areas (Diogo Nunes, Angolares, Malanza)  
 Source: INE São Tomé e Príncipe (2016).

Demographic variables		Diogo Nunes	Angolares	Malanza
Gender	<b>Female</b>	46.94	42.58	48.18
	<b>Male</b>	53.06	57.42	51.82
Age	<b>0–14</b>	42.09	32.90	44.24
	<b>15–64</b>	55.10	49.68	51.75
	<b>≥ 65</b>	2.81	17.42	4.01
Country of birth	<b>National</b>	94.13	98.39	98.29
	<b>Foreign</b>	5.87	1.61	1.71
Formal education	<b>No access</b>	11.99	21.83	13.44
	<b>At least primary school</b>	88.01	78.17	86.56
Marital status	<b>Single, Widowed, Divorced</b>	54.66	35.92	41.51
	<b>Living together, Married</b>	45.34	64.08	58.49

2.2. Questionnaires

2.2.1. Structure

A semi-structured questionnaire was used in this study. It consisted of a set of pre-established questions, but also the possibility of approaching other topics during the interview (Longhurst, 2016). This is particularly important when there are language barriers (Barribal and While, 1994), as it happens in São Tomé where Portuguese is the official language but creole, forro and angolares are commonly spoken by most of the population. This

questionnaire was developed and previously applied (for details see Clara et al., 2018; Afonso et al., 2021), after being validated by an appropriate ethics committee. The questionnaires were conducted to inhabitants older than 18 years old during August 2017 during in-person visits to the surrounding areas of the studied mangroves. The present study was focused on the small rural communities that were considered the primary mangrove ES beneficiaries and, thus, the target group (Table 2—Afonso et al., 2021).

**Table 2**

Mangrove Ecosystem Services identified in mangroves on a global scale (Afonso et al., 2021), services identified by local communities (in bold), and associated quantification indicators. In – services not identified by locals. ● data available to quantify the Ecosystem Service; ○ no data available.

	Ecosystem services	Indicators	Data
Provisioning	<b>Capture Fisheries</b>	Yearly market species biomass (kg year <sup>-1</sup> )	●
	Crops cultivation	–	
	Aquaculture	–	
	<b>Wild Foods</b>	Number of wild species used as food	●
	<b>Timber</b>	Yearly consumption of bark mangrove (kg km <sup>-2</sup> year <sup>-1</sup> )	●
	Fibers and ornamental resources	–	
	<b>Biomass fuel</b>	Yearly consumption of fuelwood (kg km <sup>-2</sup> year)	●
	Genetic resources	–	
	Medicine and pharmaceuticals	–	
	<b>Water for non-drinking purposes</b>	Yearly freshwater runoff (m <sup>3</sup> year)	○
Regulating	Air quality regulation	–	
	Global climate regulation	–	
	Regional climate regulation	–	
	Water regulation	–	
	Coastal Erosion regulation	–	
	Groundwater recharge	–	
	Wastewater treatment	–	
	Disease regulation	–	
	Soil quality regulation	–	
	Pest regulation	–	
	Pollination	–	
	Natural hazards regulation	–	
	Nutrient cycle	–	
Cultural	<b>Aesthetic/ethical values</b>	Yearly number of visitors for sightseeing (visitors year <sup>-1</sup> )	○
	<b>Recreational and ecotourism</b>	Guided tours profit (€ pax <sup>-1</sup> year <sup>-1</sup> )	●
	Spiritual and religious values	–	
	Cultural heritage	–	
Supporting	Scientific/education	–	
	Primary production	–	
	Nutrient flow	–	
	Water cycling	–	
	Habitat heterogeneity	–	
	Nursery area	–	

### 2.2.2. Survey design

The respondents were approached in social gatherings, streets, or mangrove surroundings, as well as at the front of their houses, to facilitate communication during the survey. Furthermore, to guarantee the easy communication and fluidity of the interviews, the questionnaire was designed in Portuguese (São Tomé's official language) and performed accompanied by a local. Similar approaches have been helpful in ethnographic studies (Bryman, 2015).

Only one member *per* household was interviewed to avoid duplication since each questionnaire was designed to integrate information about one household as a unit of measure. No ES lists were provided when the respondent was asked to identify mangrove ES, in order to assess the perception of the local community avoiding external influences. Each ES identified was compared with a list of ES provided by mangroves (Afonso et al., 2021) and quantified, based on indicators previously selected (Afonso et al., 2021–Table 2). The data obtained with the questionnaires allowed not only to quantify the services provided to those communities but also to predict the number of households that benefited from the mangrove presence. To qualitatively estimate ES beneficiaries while accounting for differences in the ES use by different households and knowing that in each household can benefit from the ES by just one person or everyone, it was defined that the minimum value was 1 and the maximum was the total of household members. The maximum value was defined, for each community, by calculating the mean value of the number of persons per household.

### 2.3. Socio-demographic and economic characterization of respondents

During fieldwork, 202 individuals were interviewed, with the male gender showing a bigger interest in answering the questionnaire in all the study areas (69.9–80.0%, Table 3). Respondents had an average age of 41–42 years. The best-represented community, i.e. total of members from all households inquired comparatively to the total number of people inhabiting the community, was Malanza (74.33%), followed by Diogo Nunes (52.05%). Although a minority of respondents had access to a high school level (8%), most of them attended primary school at least for one year (Malanza: 93.5%, Table 3). Most households are dominated by adults between 15 and 64 years old (Table 3). In general, São Tomé inhabitants that live in the rural communities do not earn a fixed salary (78.2%) and most of them have multiple sources of income (93.1%), mainly from livestock farming, and/or agriculture. The average monthly income of each household is 82 €. Considering an average of 5 people *per* household (Table 3), this indicates a daily income of 0,55 € per capita, which is below the poverty threshold of 1.9 \$USD person<sup>-1</sup> day<sup>-1</sup> (1.7 € using conversion rates consulted on 20th August 2019).

A stakeholder characterization was conducted to understand the social dynamics at São Tomé mangroves, based on Vallet et al. (2019) approach, in which every stakeholder is categorized based on three attributes: power, legitimacy, and urgency (Figure 2, adapted from Mitchell et al., 1997). Each category is defined by these attributes, even if some attribute is absent, for instance, a non-profit organization has legitimacy, however, does not have the power or the urgency. The categories represented in the mangrove areas of São Tomé are: (i) the *civil*

**Table 3**  
Resume of demographic variables about person interviewed and their households from the study areas (Diogo Nunes, Angolares, Malanza).

Demographic variables		Diogo Nunes	Angolares	Malanza	
<b>Number of questionnaires applied</b>		10	73	119	
Interviewed	<b>Male (%)</b>	80.00	69.90	73.10	
	<b>Average age</b>	42	41	41	
	<b>Born in São Tomé (%)</b>	80.00	98.60	97.50	
	<b>Access to formal education (%)</b>	10.00	86.30	93.50	
	<b>Living together or married (%)</b>	60.00	73.97	81.61	
Household	<b>No. persons per household</b>	4.8	5.1	5.1	
	<b>Total no. of persons sampled</b>	203	882	1022	
	<b>Representativity of the community (%)</b>	52.05	43.30	74.33	
	<b>Age</b>	<b>0–14</b>	68	253	397
		<b>15–64</b>	135	604	600
		<b>≥ 65</b>	0	25	25

**Table 4**  
Classification of Demographic and Conservation variables. Each class indicates the minimum and maximum value based on individuals' answers. \* Quantitative continuous variable.

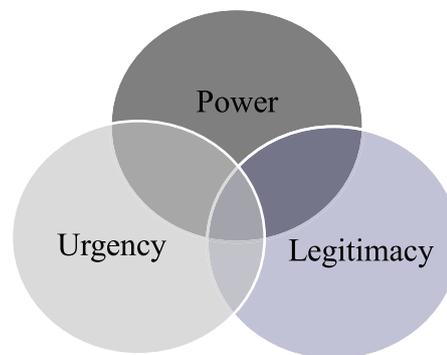
Variables	Number of classes	Class	
		Minimum	Maximum
Demographic	Gender	Female	Male
	Age	Young	Elderly
	Country	Foreign	National
	Formal educational	No access	At least primary school
	Level of financial resources	Fewer goods	More goods
	Children in the household	None	At least one kid
	Household size	1 or 2 individuals	10–14 individuals
	Marital status	Single, divorced or widower	Living together or married
Mangrove conservation	Differences identified over the years	No differences	Identified differences
	Threats	None	At least identify one
	Changes in the number of tourists	No changes	Some changes
	ES importance	Low importance	High importance
	Monetary contribution for conservation	No contribution	Monetary Contribution of 2 €
	Contribution in free time for conservation	No contribution	Contribution of 6–10h weekly
	ES chosen to preserve in the future	No ES preserve	Extraction ES (i.e. wild foods, biomass fuel)

society, i.e. government, Obô National Park and Fisheries and Environment Departments, (ii) the *non-governmental organizations*, e.g. Oikos and MARAPA, (iii) the *public sector*, i.e. common beneficiaries, (iv) the *business sector*, i.e. fishermen, fishermen-wives and Mangrove tours, and (v) the *scientific research* (e.g. MARE, CE3C). Based on Mitchell et al. (1997) *civil society* has both power the legitimacy (Fig. 2), being defined as a dominant stakeholder. *Non-governmental organization* and *scientific researchers* only have the legitimacy attribute, social responsibility but no obligation (Fig. 2), thus are considered discretionary stakeholders.

*Public* and *business sectors* have the urgency and legitimacy (Fig. 2), so are dependent stakeholders, they have needs but no power to solve them. The questionnaire respondents were mostly part of the *business* and *public sectors*, and some belonged to the *civil society*, none of the respondents belonged to the *non-governmental organizations* and *scientific research* category. Additionally, some stakeholders accumulated categories, for example, some members of the *civil society* were workers in the Mangrove tours. This class was designated as *civil society with business*.

2.4. Data analysis

Data obtained with the questionnaires was divided into three variable groups: **demographic** (numerical), **ES-related** (categorical: presence or absence), and **conservation opinions** (categorical). The categories were defined based exclusively on the questionnaire results (Table 4). The demographic variables were chosen based on other studies using the same social approach



**Fig. 2.** Attributes used to categorize stakeholders' groups. Source: Adapted from Mitchell et al. (1997).

(Frank et al., 2017; Lau et al., 2019; Oteros-Rozas et al., 2014; Owuor et al., 2019). The *monetary contribution for conservation* variable had 5 defined categories, based on the willingness of locals to pay for conservation and the value they were able to give (< 0.4 €; 0.4–1 €; 1–2 €; > 2 €). The *contribution in free time for conservation* variable had also 5 defined categories, based on the willingness of locals to participate and the number of weekly hours they were able to spend (< 2 h; 2–4 h; 4–6 h; 6–10 h). The *ES chosen to preserve in the future* variable was categorized based on the willingness of people to preserve or not the ES, and if they wanted to preserve them if they prefer non-extractive

**Table 5**

Percentage (%) of questionnaire respondents from each mangrove community (DN - Diogo Nunes; A - Angolares; M - Malanza) that identified each category of Ecosystem Services (ES).

Ecosystem services identified		Inquired inhabitants' percentage by ES user household			
		DN (%)	A (%)	M (%)	Total (%)
Provisioning	Fisheries	0.0	4.1	0.8	1.9
	Wild food <sup>a</sup>	20.0	39.7	15.1	24.3
	Timber (mangrove bark) <sup>b</sup>	0.0	1.4	2.5	1.9
	Biomass fuel	0.0	1.4	0.8	0.9
	Water for non-drinking purposes	0.0	5.5	0.0	3.5
Cultural	Aesthetic values	20.0	20.5	11.8	15.3
	Recreation and ecotourism	0.0	0.0	16.8	9.9
Total number of questionnaires performed (one per household)		10	73	119	202
Total number of individuals who consider themselves as mangrove ES beneficiaries		4	46	50	100
Average number of individuals per household		4.8	5.1	5.1	5.1
Total ES beneficiaries by community		33–160	252–1284	111–565	9.70–49.47
Total population		392	2037	1345	3774

<sup>a</sup>Only seafood.

<sup>b</sup>Extraction of the mangrove tree bark used for dyeing fishing nets.

(i.e. ecotourism, aesthetic value) or extractive services (i.e. wild foods, biomass fuel).

Different demographic variables were available to translate the level of households' financial resources, which were: (i) power and water in the home; (ii) own house and/or car; (iii) the presence of bathroom division in the house; (iv) the number of bedrooms. These variables were correlated in a factorial analysis and a single variable was extracted using the scores vector as a socioeconomic continuous variable reflecting the economic condition of a household (SPSS, IBM v25). A Kaiser–Meyer–Olkin (KMO) and a Bartlett's test were applied first to assess the suitability of the method and the correlation between variables, which was followed by Principal Components Analysis (PCA) to extract the variable that assessed the economic household condition.

Permutational analyses of variance (PERMANOVA – PRIMER 6 v6.1.13 & PERMANOVA+ v1.0.3) were used to assess differences in **ES** and **conservation** perceptions between communities (Anderson, 2001). Additionally, multifactorial PERMANOVA tested differences for the same ES and conservation variables but considering two fixed factors: 'community' (3 levels: Diogo Nunes, Angolares, Malanza) and a 'stakeholder' factor (4 levels: *business*; *civil society*; *civil society with business*; *public*). Data were log-transformed ( $\log(x+1)$ ) and the Bray–Curtis similarity coefficient was used as a resemblance measure. In case of significant differences, a Simper test was applied to assess which independent variables were responsible for the differences (cut-off of cumulative percentage: 90%).

Lastly, when the PERMANOVA and Simper tests revealed significant differences between the communities, a Canonical Correspondence Analysis (CCA - CANOCO version 4.5.) was used to identify patterns in the individual's perceptions about **ES** and **conservation**, and relate them to socio-economic parameters mentioned in Table 4 and to the social-groups mentioned in Section 2.3 (Ter Braak, 1988). Every social variable was included. In the CCA the first and second ordination axis was extracted from the socio-economic parameters that maximized the separation between the groups of individual's perception.

### 3. Results

#### 3.1. Ecosystem services provided by mangroves to São Tomé communities

Only 50% of questionnaire respondents considered themselves as beneficiaries of mangrove ES and none of them mentioned

restrictions on the use of mangroves, even when mangroves are part of São Tomé Obô National Park. Relatively to mangrove benefits, two aspects were evaluated: services indicated by locals; and the quantification of those services based on the actual quantities expressed by their answers.

The respondents acknowledge the use of 7 provisioning and cultural services (Table 2), out of 27 previously identified in São Tomé mangroves (Afonso et al., 2021). The most mentioned services were *wild food* and *aesthetic values* (24.3% and 15.3%, respectively—Table 5) and these were also the only ES mentioned by all communities. In Angolares and Malanza were identified more ES than in Diogo Nunes (Table 5). Since most households' habitations did not contain sanitation areas (e.g. bathroom, restroom), households from Diogo Nunes and Angolares used the mangroves for hygienic purposes, included in *water for non-drinking purposes*. The *Recreation and ecotourism* service was exclusively identified for the Malanza community and it consisted of four types of beneficiaries ( $N = 20$ , 16.8%—Table 5): (i) the Mangrove tours guides (60.0%); (ii) Santomeans who primarily work as tourist guides and are responsible for transporting people to and from the mangrove location (25.0%); (iii) the participants on the process of mangrove cut and preparation for the tours (10.0%); (iv) harvesters of macrobenthos captured on mangrove systems (e.g. *Bivalvia - Senilia senilis*, crabs 5.0%). Moreover, the only services that generated revenue were *fisheries* and *recreation and ecotourism*, although the last one only occurred in Malanza.

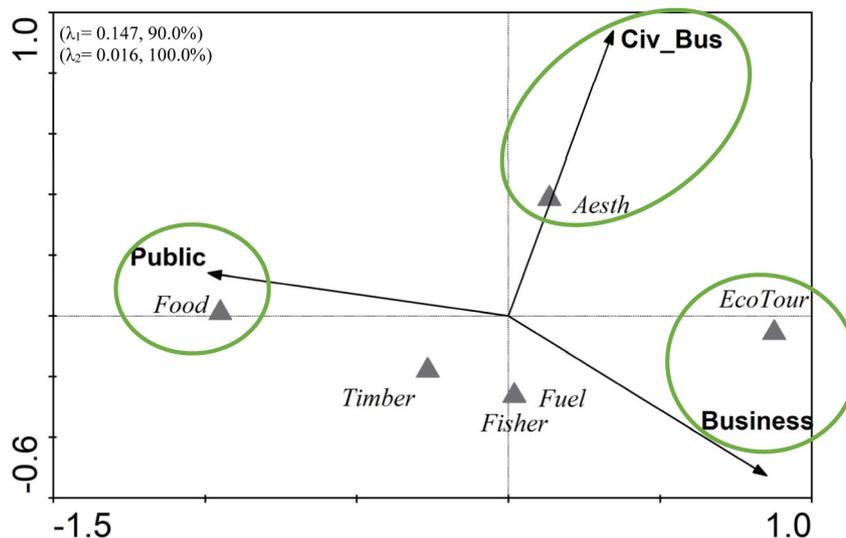
It was possible to quantify 5 of the 7 identified ES based on the questionnaires, mostly provisioning services (Table 6). *Wild foods* was the only quantifiable service identified by the Diogo Nunes community.

#### 3.2. Social groups and ES use

The results of the PERMANOVA test on the differential use of ES by stakeholders indicated that ES were used in different ways per social group and community ( $p$ -value = 0.0077—Table S2). The PERMANOVA pairwise tests used to evaluate if social groups use ES in each community showed that in Angolares and Diogo Nunes ES uses were not influenced by social groups ( $p$ -value > 0.05). However, in Malanza differences were identified, especially between *civil society with business* & *public sector* and *business* & *public sector* ( $p$ -value = 0.0191 and 0.0001 respectively—Table S4). The SIMPER procedure was used to identify which ES were used differently between the classes of stakeholders. The differences between *civil society with business* & *public sector* were mostly associated with the *recreation and*

**Table 6**  
Quantification of mangrove Ecosystem Services in Diogo Nunes (DN), Angolares (A) and Malanza (M).

Ecosystem services	Indicator	Quantification value			
		DN	A	M	Total
Fisheries	Yearly market species biomass (kg year <sup>-1</sup> )	-	168	12	180
Wild foods	Number of wild species used as food	3	13	15	21
Timber	Yearly consumption of bark mangrove (kg km <sup>-2</sup> year <sup>-1</sup> )	-	1384.6	256.6	1641.2
Biomass fuel	Yearly consumption of fuelwood (kg km <sup>-2</sup> year <sup>-1</sup> )	-	461.5	39.5	501
Recreation and ecotourism	Yearly guided tours profit (€ pax <sup>-1</sup> year <sup>-1</sup> )	-	-	1920	1920



**Fig. 3.** CCA based on variables that characterize mangrove Ecosystem Service (ES) used by local communities of São Tomé. The social groups (in bold) of the Malanza community are represented as vectors. The ES considered in the CCA were: Aesth (Aesthetic value), EcoTour (Recreation and Ecotourism), Fisher (Fisheries), Food (Wild foods), Fuel (Biomass fuel), Timb (Timber). The social groups considered in the CCA were: Civ\_Bus (Civil Society with Business), Business sector and Public sector. Green circles identify closer relationships between social groups and ES. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

ecotourism service (45.24%—Table S5), while wild foods service contributed mostly to the differences between business & public sector (35.13%—Table S5).

The Canonical Correspondence Analysis (CCA) was only performed for communities that showed significant differences, thus, only for Malanza. The business sector was a user of ES recreation and ecotourism, however, did not benefit from the service wild foods. The civil society with business possibly has a higher tendency to use the ES aesthetic value but did not appreciate the use of timber, fisheries, and biomass fuel services from mangroves. And the public sector benefits from the ES wild foods and did not benefit from the recreation and ecotourism service (Fig. 3).

### 3.3. Assessment of local perceptions about Ecosystem Services

The factorial analysis and single variable extraction were performed after validation with the KMO and Bartlett tests (0.65 and  $\chi^2 = 240.089, df = 28, sig = 0.00$ , respectively). From the PCA, the single economic household condition variable was extracted from the vector scores of the first axis, which explained the most variance (28.9%—Table S1).

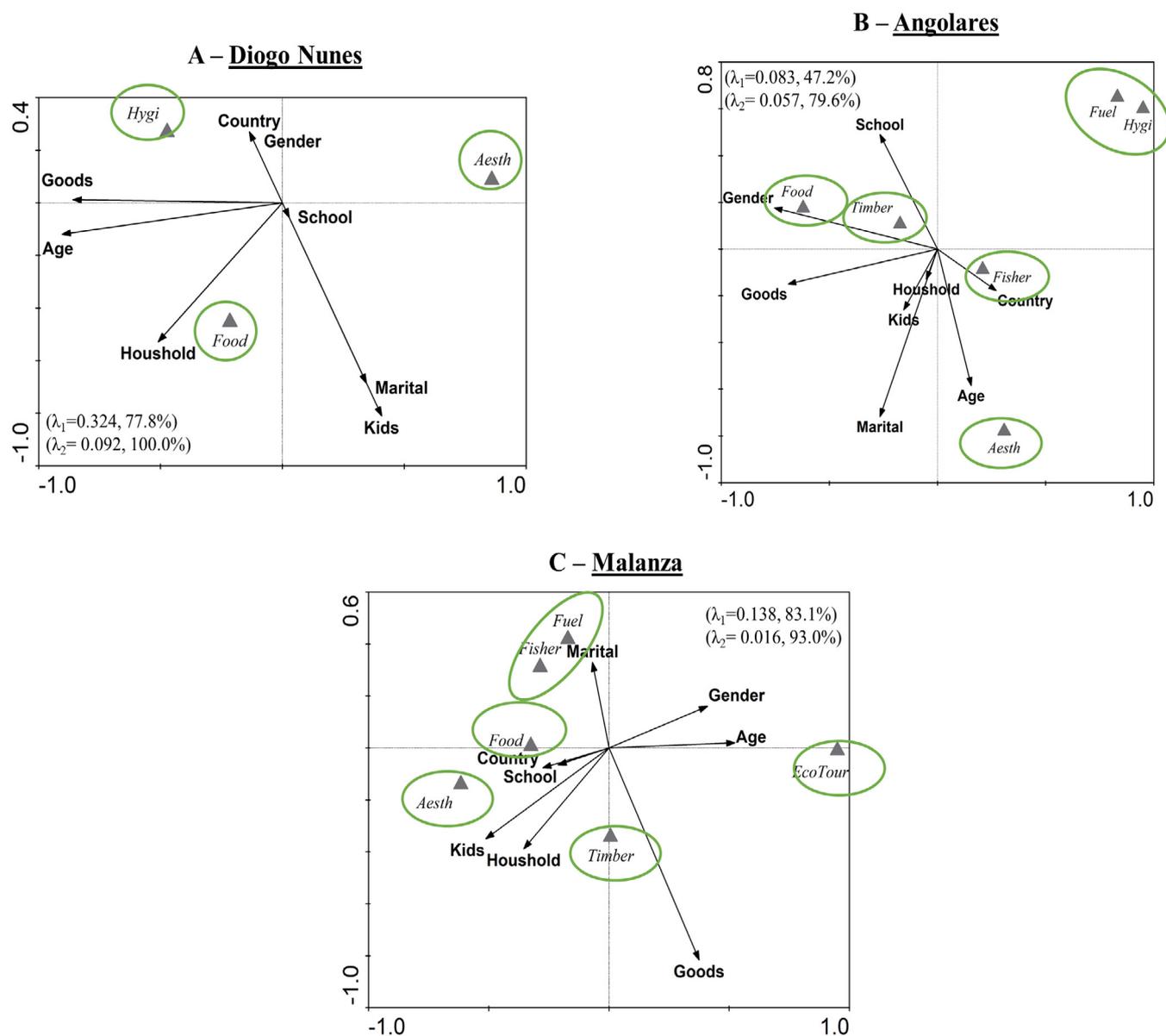
The use of ES differed between communities ( $p$ -value = 0.0001—Table S2), as indicated by the PERMANOVA main test, pairwise comparisons showed that there were differences only between the Malanza & Angolares communities ( $p$ -value = 0.0001) and between the Malanza & Diogo Nunes communities ( $p$ -value = 0.0179—Table S3). The SIMPER analysis showed a major contribution of ES Wild foods for differences found between the Malanza & Angolares communities (42.57%), while ES water for non-drinking purposes contributes most for

differences between the Malanza & Diogo Nunes communities (27.01%—Table S6).

The CCA which characterized the use of ES by the local communities showed that people with less financial resources from Angolares and Malanza benefited more from the ES fisheries service. Respondents from Angolares and Malanza with higher scholar degrees were the beneficiaries of the ES wild foods service, although in Angolares these individuals were also males born in foreign countries, while in Malanza this service was mostly used by females born in the São Tomé Island. The ES biomass fuel in Malanza and Angolares benefited poorer locals, although in Malanza they were also married and in Angolares were single (Figs. 4B, 4C). Inhabitants from Angolares and Diogo Nunes that are single were the principal beneficiaries of water for non-drinking purposes service (Figs. 4A, 4B). The ES aesthetic value benefited younger people from Diogo Nunes and Malanza, and older people from Angolares. This service also benefited small households from Diogo Nunes and bigger households from Malanza (Figs. 4A, 4C). The ES recreation and ecotourism only benefited people from Malanza, especially older males (Fig. 4C). The other ES did not show any significant relationship comparable between communities.

### 3.4. Community's perception of mangrove threats and conservation

Of all 202 inquired locals, only 16.3% recognized the existence of threats to mangrove systems, which included the input of pollutants, direct human impact (i.e. higher human density), fishing, and deforestation (Table 7). The community from Diogo Nunes was only aware of threats in the form of pollutant input (30%). Both Angolares and Malanza communities identified the same



**Fig. 4.** CCA based on variables characterizing Ecosystem Services (ES) used by local communities. Vectors represent the demographic variables in the different communities under study. The ES considered in the CCA were: Aesth (Aesthetic value), EcoTour (Recreation and Ecotourism), Fisher (Fisheries), Food (Wild foods), Fuel (Biomass fuel), Hygi (Water for non-drinking purposes), Timb (Timber). The demographic variables considered in the CCA were: Age, Country (Country of origin), Gender, Goods (Level of financial resources), Houshold (Household size), Kids (Kids in the household), Marital (Marital status), School (Formal education). λ<sub>1</sub> Eigenvalue and percentage extracted for first ordination axis; λ<sub>2</sub> Eigenvalue and percentage extracted for first and second ordination axis. Green circles identify ES variables with closer distances. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

threats, although fishing had a higher expression for the former (5.5%), deforestation was the biggest threat considered by the latter (5.9%—Table 7).

Regarding the availability and perception of respondents to preserve mangrove ecosystems, most locals were willing to protect the system (93.1% of total inquired). The vast majority were willing to contribute with free time and money (71.3%), only a small percentage were willing to contribute solely with money (5.3%). People who preferred to provide their free time (21.8%) tended to offer 2 to 4 h a week for the activity. Those who were willing to pay for preservation were willing to do so in a single payment, an amount greater than 2 € (44.4%). Moreover, this value is independent of the type of ES considered ( $z/\chi^2 = 3.597; p = 0.463$ ). Opinions about conservation did not differ accordingly to the different social groups ( $p$ -value > 0.05).

When asked about changes in mangrove systems in the past 10 years, almost 50% of the respondents did not know or had

no opinion on the subject. Despite the benefits that mangroves bring to communities and the willingness of most of the respondents to protect the mangroves, 34% of the respondents indicated that mangrove trees should be cut, with the main motivation of cleaning the ecosystem to open the canal and improve navigation for canoes. Only 4.5% of respondents considered that tourism has increased in the last years.

In general, the most common opinion was that the ES provided by the mangroves are not relevant in their daily activities (44%). Especially in Diogo Nunes, a large part of the respondents considered that the ES had low relevance (75%).

The most common opinion from all respondents (72%) was that the only ES to be used in the future should be within the non-extractive category, however, the Angolares community showed a higher interest in the use of extractive services (40%

**Table 7**  
Threats identified in São Tomé mangroves by: 1) literature review (Bonfim and Carvalho, 2009; Brito et al., 2017; Félix et al., 2017); 2) expert-knowledge by researchers who did fieldwork in the study area; 3) interviewed inhabitants. And percentage of inhabitants from each community that identified the listed threats. ● Identified Threats, ○ Non-identified threats.

Mangrove threats	São Tomé	Fieldwork	Inhabitants inquired (%) which identified threats		
			Diogo Nunes	Angolares	Malanza
Freshwater input	●	●	○	○	○
Sediment input	●	●	○	○	○
Nutrient input	●	●	○	○	○
Pollutant input	●	●	●	●	●
			30.0	2.7	4.2
Coastal development	●	●	○	○	○
Direct human	●	●	○	●	●
				4.1	1.7
Livestock grazing	○	●	○	○	○
Fishing	●	●	○	●	●
				5.5	2.5
Climate change	●	○	○	○	○
Species invasion	●	●	○	○	○
Ocean-based pollution	●	○	○	○	○
Ecotourism	○	●	○	○	○
Deforestation	●	●	○	●	●
				5.5	5.9
Ecosystem conversion	●	●	○	○	○
Applied Questionnaires			10	73	119
Inhabitants inquired which identified threats			3	13	17
Proxy for community members which identify threats			118	363	192
Community members			392	2037	1345

of interviewed people in Angolares). Regarding mangrove protection, 7 measures were suggested by respondents, highlighting the cleaning and maintenance of the mangrove by cutting it (54.46%—Table S7).

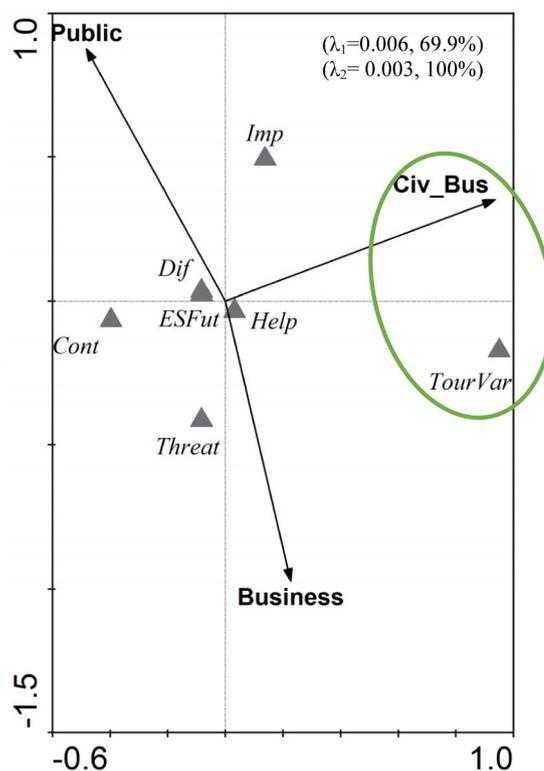
### 3.5. Social groups and opinions about Mangrove Conservation

Opinions about mangrove threats and conservation can differ accordingly to the different social groups included in the study inquired, as indicated by the PERMANOVA test, which demonstrated that opinions were significantly different between groups and per community ( $p$ -value = 0.0279—Table S2). The PERMANOVA pairwise tests used to evaluate how social groups' opinions diverge in each community showed that the differences were more noticeable in Malanza, especially between *business* & *public sector* ( $p$ -value = 0.0427—Table S4). The SIMPER analysis indicated that differences between these two groups were mostly associated with the *monetary contribution* variable (24.89%—Table S7).

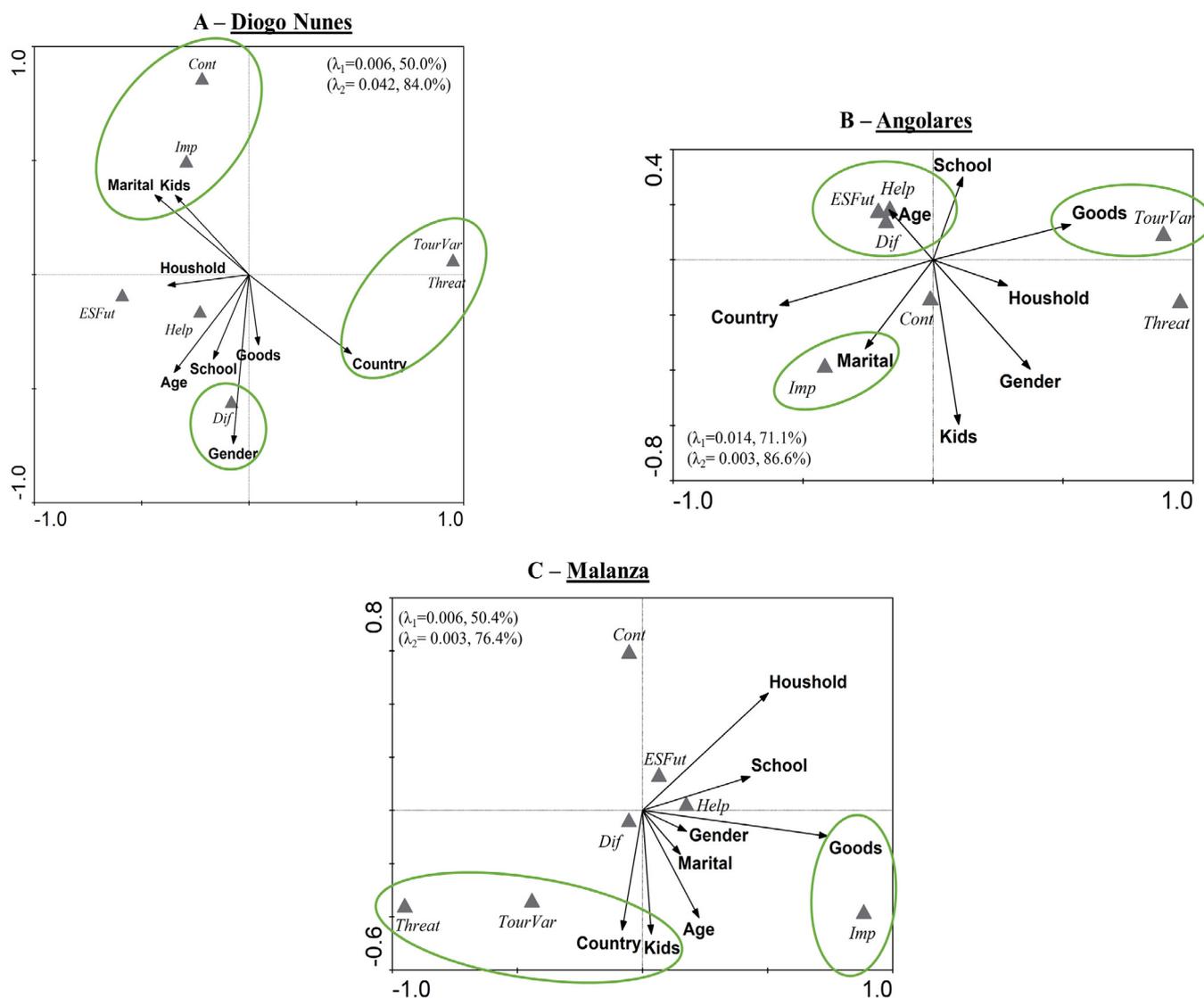
The CCA was only performed for communities that showed significant differences between social groups, namely for Malanza. The *business* sector considers ES provided by mangroves not important. The *civil society with business* identified changes in the tourist number, in the last years, and they were not willing to pay for mangrove conservation. The *public sector* did not identify threats to mangroves (Fig. 5).

### 3.6. Assessment of local perceptions about mangrove conservation

The opinions about mangrove threats and conservation were different in every community ( $p$ -value = 0.002—Table S2), as demonstrated by PERMANOVA main test. Pairwise tests indicated significant differences between the Malanza & Angolares communities ( $p$ -value = 0.0034) and the Malanza & Diogo Nunes communities ( $p$ -value = 0.042—Table S3). The SIMPER analysis identified the variables *ES importance* and *monetary contribution to conservation* contribute most for the differences between Malanza & Angolares (24.61% and 24.13% respectively—Table S9), while *monetary contribution to conservation* and *ES importance*



**Fig. 5.** CCA based on opinions about threats and conservation of mangroves from Malanza, with vectors representing different stakeholders. The conservation variables considered in the CCA were: Cont (*monetary contribution to conservation*), Dif (*differences in the last 10 years in mangroves*), ESFut (*ES preserve in the future*), Help (*free-time contribution to conservation*), Imp (*ES importance*), Threat (*threats identified*), TourVar (*changes in the number of tourists*). The social groups considered in the CCA were: Civ\_Bus (*civil society with business*), Public sector, Business sector. Green circle identifies closer relationships between conservation variables and social groups. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)



**Fig. 6.** CCA based on variables characterizing opinions about threats and conservation of mangroves study areas. The vectors representing the demographic variables and the triangles the conservation variables. The conservation variables considered were: Cont (*monetary contribution to conservation*), Dif (*differences in the last 10 years in mangroves*), ESFut (*ES preserve in the future*), Help (*free-time contribution to conservation*), Imp (*ES importance*), Threat (*threats identified*), TourVar (*changes in the number of tourists*). The demographic variables considered were: Age, Country (Country of origin), Goods (Level of financial resources), Houshold (Household size), Kids (Kids in the household), Marital (Marital status), School (Formal education).  $\lambda_1$  Eigenvalue and percentage extracted for first ordination axis;  $\lambda_2$  Eigenvalue and percentage extracted for first and second ordination axis. Green circles identify Ecosystem Services variables with closer distances. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

contributed most for differences between Malanza & Diogo Nunes (23.82% and 17.52%, respectively—**Table S9**).

The CCA analysis showed the influence of different community attributes on the perception of mangrove threats and conservation. People from the 3 communities who consider that ES provided by mangroves are important had kids in the household, however in Angolares and Diogo Nunes they were also married, and in Angolares and Malanza they were born in São Tomé. People from Diogo Nunes and Malanza who identify threats to mangroves and saw differences in national tourism had Santomean nationality. People from Diogo Nunes and Angolares who agree that mangrove ES extractive must be preserve were older. People from Diogo Nunes and Malanza who were willing to contribute financially towards mangrove conservation had foreign nationality (Fig. 6). The other variables did not show any significant comparable relationship between communities.

#### 4. Discussion

The concept of ES was created to try to solve environmental degradation while continuing to link society to nature. Governance and conservation will enable people to benefit from the environment without damage (Hicks and Cinner, 2014). This study gives information to understand the services provided by Santomean mangroves and the perceptions about the damages that resulted from this intense use. Thus, it listed and quantified the ES identified by locals. Later canonical correlation was used to understand the social aspects that have a bigger influence on the perceptions about mangrove ES. Furthermore, it analyzed the local perception of human impact on the mangrove and the damage caused by it. Once again it used the canonical correlation to assess the social aspects that influence local opinions.

#### 4.1. Locals perceptions about ecosystem services provided by mangroves

Almost 75% of the respondents were male, not because it was purposeful for the design, but because most women did not feel confident enough to answer and most felt that the male's opinion should be the one expressed in the questionnaire. This is a common situation in this type of study in developing countries because of the social barriers resulting from cultural constructions of gender roles (Mwangi et al., 2011; Owuor et al., 2019).

Notably, only half of the inquired (48.5%) realized that mangroves provide services for their household and only 45% of them consider these services important, even though the mangroves and coral reefs are the most valuable ecosystems from African wetlands (Davidson et al., 2019). The literature review about assessments in Santomean mangroves disclosed a higher number of services than the results presented in this study (7 out of 27; Afonso et al., 2021). These results also show a different perspective of the São Tomé communities when compared to other communities from mangrove surrounding areas from Kenya (15 services identified in Rönnbäck et al., 2007) or in pacific islands (13 services identified in Warren-Rhodes et al., 2011). All ES identified by locals were included in two categories: provision and cultural. However, similar studies in wetlands showed that surrounding communities had a preference for provision and regulation services, for instance, *nutrient cycle* (i.e. Naylor and Drew, 1998). This is the opposite of what happens in rural areas, where cultural services and well-being tend to be more important (Martín-López et al., 2012). The questionnaires were applied to households, thus the beneficiaries' demographic features (e.g. gender, age) may not fully represent the ES used by the household.

It has been demonstrated that mangroves are important for food security and the subsistence of households (Adeel and Pomeroy, 2002). The strong role of women as caretakers, and by consequence as main users of these services with a bigger impact on the ecosystem damaging has been mentioned in several studies (e.g. Mwangi et al., 2011). However, this was not so obvious in the communities of São Tomé, most answers came from men. The ES *fisheries* was predominantly used in Angolares and Malanza by individuals with lower financial resources, who use the ecosystem as an income source. Moreover, the collection of fish (service *wild foods*) and benthic macrofauna (e.g. bivalves and crabs) can also be used by adults for subsistence or as bait, and by children for entertainment. In Angolares the beneficiaries of this ES were males with bigger financial resources. Fishing activities usually require a higher physical effort, which makes it more appropriate for males (Juma, 1998). The individuals with bigger financial resources in this case study were characterized as having an average wage of 82 € or more, thus even households with higher wages can use mangroves as a source of products for subsistence or recreational fishing (Naylor and Drew, 1998). In general, active workers are younger and tend to use and value more provisioning services rather than other categories (Oteros-Rozas et al., 2014).

The use of mangrove tree barks (ES *timber*) to dye fishing nets is an old tradition in São Tomé. Likewise, it has been used in other African countries with similar functions and obtained principally by the female caretakers of the household that are generally responsible for these activities (Rönnbäck et al., 2007).

The *water for non-drinking purposes* service includes clothes washing in the freshwater courses and hygiene functions (Warren-Rhodes et al., 2011), and sometimes this service is less visible and disregarded in the literature. In São Tomé specifically, this ES was used by people with diverse socio-economic characteristics, not being exclusive to any group in specific. Thus,

this service provided by the mangrove has been considered a consequence of the lack of substitutes in the house or village for hygiene purposes. The differences between communities for this ES were also related to the distance to the closest residential area. As an example, the Malanza community did not indicate this use since the mangrove is more than 1 km away from the closest places (Malanza and Porto Alegre) and the local communities use the closest rivers for hygiene functions.

The ES *recreation and ecotourism* in São Tomé is only carried out by older men, as observed in Kenya (Owuor et al., 2019), therefore, the perspective about the ES may have been conditioned by the average age of the respondents. The *aesthetic value* is traditionally more appreciated by elders (Oteros-Rozas et al., 2014), but this was only observed in the community of Angolares contrarily to the other two, where the younger tend to appreciate more this mangrove quality. This change of perspective might be related to a higher tendency of young residents to have more access to environmental education at school (Oteros-Rozas et al., 2014).

Each ES can benefit differently social-actors, which can affect the conception of benefits to human well-being. This is translated into a social misrepresentation, that can be even more intensified in coastal research (Butler and Oluoch-Kosura, 2006). The stakeholders from the *Business sector* were predominantly males who had the responsibility to address tourist activities in mangroves, like in many other regions (Frank et al., 2017; Rönnbäck et al., 2007). Representatives of this category only used the mangroves for these activities while the public sector only used them for *wild food*.

#### 4.2. Locals perceptions about mangrove threats and their conservation

The respondents showed a lack of awareness about the mangrove presence in nature, which ends up influencing all their perspectives about mangroves and their level of damage. When asked about the mangrove ecosystem, the locals could not identify the integrated and complex ecosystem, however, they could identify the area and their components, i.e. mangrove trees, river, as well as the benefits provided by them. This is demonstrated by having 84% of respondents consider that mangroves are not threatened when several threats have been identified in São Tomé mangroves (Afonso et al., 2021). This lack of awareness was previously described in other studies (e.g. Palacios and Cantera, 2017) but it is not always the case. Some communities located in the surroundings of large mangrove ecosystems seem to be very aware of changes over the years (Conchedda et al., 2011). Some socio-cultural factors can influence this lack of awareness, such as the gender of the respondent, as women are more associated with domestic activities and do not visit the mangroves regularly (Rönnbäck et al., 2007). This can contribute to a low valorization of ES provided by mangroves. Commonly, one of two conditions are more frequent: (i) communities identify their mangrove dependence (i.e. Rönnbäck et al., 2007) or, like in São Tomé, (ii) communities are not aware of their mangrove dependence (Ghasemi et al., 2010). To work in favor of ecosystem conservation people need to be aware of the importance of the mangrove resources so they can acknowledge how their use can affect the recovery period of resources and their sustainability (Owuor et al., 2019). For instance, it is common for local São Tomé communities to use the surrounding areas of mangroves for agriculture, which is very important for their subsistence. Nevertheless, there is a risk associated with this use in the future, particularly considering the imminent effects of climate change that can result in the salinization of the soils, making them infertile (Reed et al., 2013). Considering the damages to the ecosystem's health and changes

in the perception of the ecosystem (Hartter, 2010), this could have a severe impact on the future of these systems.

Almost half of the inquired Santomean individuals did not notice any change in the mangrove ecosystem during the last 10 years. Commonly the elder individuals can see changes in mangroves ecosystems (Owuor et al., 2019), however, considering the population structure of the case study with a high tendency to have more young individuals and with low life expectancy, this group of people may have not lived enough to see the changes in mangrove structure and forestry.

Afonso et al. (2021) has identified considerably more threats to these mangroves than the respondents (4 out of 14 threats identified). This difference is caused by an inherent viewpoint of each group that influences the way threats are perceived, i.e. scientific experts can identify more easily threats to ecosystems based on their intense study. Diogo Nunes stood out since a bigger percentage of inquired individuals identified more threats and less ES, this can be explained by the excessive damage of the mangrove area, with a more visual impact of threats in the ecosystem.

An interesting point is that respondents considered cleaning the mangrove as one of the most important conservation measures. However, for them, this includes cutting the mangrove trees, in order to enhance navigation and improve access. Additionally, this cleaning is also related to the need to control the occurrence of mosquitoes (Warren-Rhodes et al., 2011), especially in countries like São Tomé where there is a risk of a malaria vector emerging in mangrove areas. This procedure can be considered a threat to mangroves' conservation. Although the mortality due to malaria has dropped in recent years, the country is still under the influence of the disease (Bonfim and Carvalho, 2009), so the concern of the communities is reasonable, which leads them to take protective measures, such as the application of products for the extinction of the mosquito, which may act itself as a pollutant to the ecosystem.

The demographic factors have a stronger role than the economic benefits in the willingness of local communities to participate in conservation strategies (Coulibaly-Lingani et al., 2011). For instance, formal education is considered the main driver for perception and it has been suggested to increase conservation awareness (Roy, 2016; Sinclair et al., 2011) However, the results were not always evident, even though in São Tomé young individuals were those showing a bigger interest in conservation, more precisely to give money for this activity.

#### 4.3. How can local knowledge be used to develop better management strategies?

The ES-framework is cyclical, beginning in the ecosystems and their processes and having the benefits provided to the humans as the next step. The process of decision-making affects the ecosystem and how the ES benefits are shared (van Oudenhoven et al., 2012). Explaining the ES concept is not easy in any context (Riechers et al., 2016), but it can change the way ecosystem conservation is considered and applied. In situations when there is a total dependency of mangrove resources, the economic value required to substitute these service will be higher and consequently the attitude of locals will be more positive towards its preservation (Roy, 2016).

In general terms, it can be concluded that communities from the mangrove surrounding areas of São Tomé have low knowledge about mangrove processes and undervalue the high impact of human activities as a source of threats and stress to the environmental quality of these systems. The best ecosystem governance can be achieved with mangrove conservation while enabling people to benefit from the environment and improve their

well-being. The key to successful conservation is to raise awareness to influence positive attitudes towards the preservation and conservation of marine ecosystems (Rahman and Asmawi, 2016). Assessments like this one have the ability to show the degree of poor understanding of ecosystems value and benefits, and the strong need for the implementation of environmental education programs to all ages, which will motivate the dialogue between stakeholders, and by consequence the development of inclusive decision-making.

## 5. Conclusions

The Santomean communities showed a limited perception of mangrove benefits since they were mostly interested in the services that have direct benefits (e.g. provision of food). However, they can understand the value of mangroves for these benefits, but there is also a lack of awareness about important regulating and supporting services provided by mangroves, especially valuable in communities that live so near to these systems. Therefore, education is the most helpful tool which enables people to better understand the relationship between natural resources conservation and human well-being (Vodouhê et al., 2010). This will be one step forward to understand the impact that humans can have on the environment and how we can recover environmental health and guarantee the sustainable use of ES.

### CRedit authorship contribution statement

**Filipa Afonso:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Writing – original draft, Writing – review & editing. **Pedro M. Félix:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Software, Supervision, Writing – review & editing. **Paula Chainho:** Investigation, Writing – Review & editing. **Joshua A. Heumüller:** Investigation, Writing – Review & editing. **Ricardo F. de Lima:** Investigation, Writing – Review & editing. **Filipe Ribeiro:** Investigation, Writing – Review & editing. **Ana C. Brito:** Conceptualization, Investigation, Methodology, Supervision, Writing – review & editing.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

Supplementary material related to this article can be found online at <https://doi.org/10.1016/j.rsma.2021.102114>.

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