



Sustainability Dimensions Assessment in Four Traditional Agricultural Systems in the Amazon

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Although traditional agriculture carried out by ethnic groups is considered for its high biodiversity and important for food security and sovereignty, few studies have investigated the potential of these systems in the interest of promoting a sustainable agricultural development policy according to United Nations Sustainable Development Goals. Using the FAO's Sustainability Assessment of Food and Agriculture (SAFA) methodology, this study analyzed the sustainability of four traditional agricultural systems, three indigenous (Waorani, Shuar, and Kichwa) and one migrant settler populations in the Yasuní Biosphere Reserve (YBR) and identified synergies and trade-offs among the dimensions of sustainability. The results showed different dynamics in all dimensions of sustainability—specifically, trade-offs in the dimensions of good governance with environmental integrity and social well-being, economic resilience, and social well-being. It was identified that the differences in terms of sustainability are narrowing between the indigenous Shuar people's traditional agricultural systems and those of migrant settlers, which provides policymakers with specific information to design sustainable development policies and rescue traditional agricultural systems in the Amazon region.

Keywords: agriculture, indigenous peoples, migrant settlers, rural development, Yasuni Biosphere Reserve, livelihoods

INTRODUCTION

Traditional production systems have several attributes that contribute to sustainable development, such as high species diversity with strong environmental adaptability (Zhang et al., 2011) and resistance to pests and diseases (Flores-Delgado et al., 2011). They can act as instruments for resilience, mitigation, and adaptation to climate change (McCord et al., 2015; Torres et al., 2015, 2018; Tesfaye and Tirivayi, 2020). Such systems can help manage risk and decrease rural poverty and food insecurity (Michler and Josephson, 2017; Waha et al., 2018; Lovo and Veronesi, 2019; Mustafa et al., 2019; Bellon et al., 2020) through providing income from local markets (Bellon et al., 2020) and nutrition and child health in impoverished rural households. Due to the great diversity of edible and commercial crop species (Perreault, 2005), traditional production systems

have been supporting many indigenous populations who live in voluntary collective isolation. To protect the sustainability of these systems, instruments are needed to reduce the possibility to have these communities becoming or being forced to be in contact with the outside world (Cabodevilla, 2008; Beckerman et al., 2009; United Nations, 2009; Colleoni and Proaño, 2010; Heredia-R and Hernández, 2019), based on these antecedents, Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES; <http://www.ipbes.net/>) and the Convention on Biological Diversity (CBD) recognizes that the diverse social, cultural and environmental knowledge of indigenous peoples and local communities (IPLC) contributes extensively to sustainability across large parts of the globe, and thus has a major role to play in assessments and policy formulation for biodiversity and ecosystem services (IPBES, 2012; Tengö et al., 2017; Hill et al., 2020).

The Ecuadorian Amazon Region (EAR) is home to 11 Indigenous groups who have inhabited the land for thousands of years. Sixty years ago, several populations of migrant settlers arrived after the discovery of significant oil reserves in the northern EAR. Roads were opened by oil companies (Pichón, 1997; Bilsborrow et al., 2004), leading to a change in the demography with populations of heterogeneous life strategies (Torres et al., 2018). The northern EAR has become a multiethnic and multicultural system. Within this region, the Yasuní Biosphere Reserve is populated by Indigenous Waorani, Shuar, and Kichwa people as well as migrant settlers who arrived mainly from rural areas of the Ecuadorian highlands (Santos, 1996; Murphy et al., 1997; Barbieri et al., 2003, 2009; Bilsborrow et al., 2004; Sellers et al., 2017).

These groups manage their own traditional agricultural systems, which are part of each cultural heritage and geographic origin, for their tangible and intangible assets (Rudel et al., 2002; Lu and Bilsborrow, 2011; Ima Omene, 2012; Torres et al., 2015; Zurita-Benavides, 2017). However, climate variability, deforestation, and poor land management practices have led local populations to depend on agrochemicals (Davis et al., 2012) or in the expansion of the agricultural frontier to increase incomes (Mena et al., 2006, 2011; Walsh et al., 2008). Land use changes and degradation have resulted in the decrease in agricultural sustainability as a means of livelihood. Agricultural intensification policies, migration processes, population growth, and low educational levels (Viteri-Salazar and Toledo, 2020) have led to socioeconomic and demographic changes that include alterations in household composition and other family life cycle factors (Bilsborrow et al., 2004). It is necessary to analyze these factors from a sustainability perspective to gradually define potential solution for the future under the 2030 Sustainable Development Goals.

The sustainability of traditional production systems in the Amazon has generally been assessed from an environmental perspective (Galford et al., 2013). Nevertheless, social, economic, and governance dimensions of sustainability are also important, but little studied in this region (SAFA, 2012). Sustainability assessment aims to better understand the conditions of a location (from a community or region to a country) to support future decisions making that support all three pillars, i.e., social,

economic, and environmental, of sustainable development (Bond et al., 2012). Several approaches have been developed including (Belcher et al., 2004) the human well-being index (Kaivo-oja et al., 2014), the environmental performance index (Hsu and Zomer, 2014), and the sustainable development index (Barrera-Roldán and Saldívar-Valdés, 2002). A multicriteria approach is often encouraged to ensure that the social component is not forgotten (Maness and Farrell, 2004). This is especially important when examining sustainability in the context of resource management and therefore agricultural development (Asimeh et al., 2020). For traditional production systems, such assessment provides not only benchmarks but also help reveal the impacts of policy measures adopted at a national level on a region or individual farm (Van Calker et al., 2005).

Sustainability assessments require a combination of methods and models to provide useful information on the impacts of past or proposed changes within systems (Thornton and Herrero, 2001). No single approach can satisfy the multiple purposes of sustainability assessment (Schader et al., 2014). Generally, the results of sustainability assessment are a starting point for discussion, reflection, and learning (De Olde et al., 2016). Within this context, our study seeks to: (a) examine the main agricultural and socio-demographic characteristics at the household level in four social groups (Waorani, Shuar, Kichwa, and migrant settlers) living in the YBR; (b) evaluate the sustainability dimensions of their traditional production systems; and (c) identify the existing interactions (synergies and trade-offs) between the sustainability dimensions of these traditional production systems.

The Traditional Agricultural Context of the Waorani, Shuar, Kichwa, and Migrant Settlers in the Yasuni Biosphere Reserve

The food production system of the Waorani indigenous populations is based on reciprocity or individual production to share with their nuclear families (Rival, 2002), which is complemented by food gathering from the surrounding forests (Tirira et al., 2020). In their language (*Wao-terëro*), the generic name for the Waorani's traditional production system is the *kinkore*. According to Zurita-Benavides (2017), this ethnic group considers that the name of the traditional system depends on the main crop, which is usually accompanied with other crop species. For example, if cassava (*Manihot esculenta* Cranz) is the main crop, it is called *kewenkore* (a traditional system of cassava production), while if it is banana (*Musa paradisiaca*), the system is called *penenkore* (a traditional system of banana production). Likewise, the traditional system based on peanut (*Arachis hypogaea*) takes the name *koromonkore*, the one of corn (*Zea mays*), *kaginkore*, and the system with barbasco (*Lonchocarpus utilis*) (a product used for fishing) is called *kompankore*. These crop systems are generally oriented to subsistence production, with few produces destined for sale. These systems stand out for having a low impact on the landscape and do not use chemical fertilizers or agrochemicals for pest control (Gray and Bilsborrow, 2020). The size of the *kinkore* depends on the composition of the family group. Edible and medicinal plants are sown, as well as other species that allow for the extraction of

natural dyes, seeds, and fiber for handicrafts (Zurita-Benavides, 2017). The *kinkore* are the places where knowledge is transferred to younger generations, commonly managed by Waorani women (Zurita-Benavides, 2017; Paniagua Blanc, 2019).

The Shuar people originate from the southern EAR and migrated to the northern part (Rubenstein, 2001), due to high population growth rate, land scarcity, and low agricultural production (Vasco et al., 2018). Their food supply is obtained through fishing, hunting, gathering forest products (Caballero-Serrano et al., 2017), and growing crops in a traditional system called *aja*. For the Shuar, the *aja* is a sacred space and is managed by women (González de Lema and Herrera, 2017). To establish an *aja*, first the man does the initial clearing of the forest (Karsten et al., 2000), then the woman has the main role of establishing (Pérez-Robalino et al., 2019) and maintaining the *aja* for life (Pohle and Gerique, 2008), since the *aja* for this culture constitutes the woman's identity (Carvajal and Shacay, 2004; González de Lema and Herrera, 2017). The transmission of knowledge about the ecology of planting and harvesting is only taught to the daughters (Cañadas and Sandoval, 2019). As the Shuar people have moved into the market economy, they have created an agricultural landscape that is more biodiverse than the mestizo (mixed-race) migrant settler system (Lu and Bilsborrow, 2011), although biodiversity is not as high as the primary forest (Vasco et al., 2017). Therefore, the agricultural practices carried out in an *aja* are considered compatible with the conservation of biodiversity (Rudel et al., 2002).

The Kichwa population living in the YBR comes from a complex process of multi-ethnic relations between the Quijos, Kichwa from the highlands, Zaparos, Omaguas, Tucanos Shuar, Achuar, Siona, and Secoya (Almeida and Proaño, 2008). This group migrated from Tena and Archidona (Napo, Ecuador) with the opening of roads to the YBR (MAE, 2013). Their predominant traditional production system is the *chakra*, which today has been widely studied (Torres et al., 2015, 2018; Vera et al., 2017; Coq-Huelva et al., 2018; Vera-Vélez et al., 2019) and is considered a combination of culturally specific means of bio-social construction (Coq-Huelva et al., 2017). It is characterized by its high level of biodiversity (Vera et al., 2017; Vera-Vélez et al., 2019) and a high number of fruit and timber trees (Jadán et al., 2015; Torres et al., 2015; Coq-Huelva et al., 2017, 2018; Luzuriaga-Quichimbo et al., 2019), with the predominant crops being cocoa (*Theobroma cacao* L.), coffee (*Coffea canephora* Pierre ex A. Froehner), and to a lesser extent guayusa (*Ilex guayusa* Loes.) (Krause and Ness, 2017), alongside medicinal plants for healing purposes, spiritual rituals, handicrafts, and consumption (Coq-Huelva et al., 2017).

The traditional production systems of the migrant settlers are more market-oriented and, according to several authors, are less sustainable compared to traditional indigenous systems (Heredia-R et al., 2020a,b,c,d,e; Viteri-Salazar and Toledo, 2020). They include pastures, annual crops (rice, corn, and cassava), and perennial crops (coffee and cacao) to generate income (Mena, 2007; Monteros, 2011), resulting in intense deforestation (Pan and Bilsborrow, 2005; Sellers et al., 2017; Mullan et al., 2018). The dynamics of migrant settlers have forced neighboring indigenous communities to join the market economy and change some of

their ancestral traditions of coexistence with the forest (Orta-Martínez and Finer, 2010). Northeastern Ecuador is one of the places where the cattle frontier in Ecuador is rapidly expanding (Sierra, 2000; Suárez et al., 2009), and is one of the main promoters of land-use change and deforestation in the EAR (Sierra, 2013). In this region, as of 2014, it was estimated that around one million hectares of pastureland, which represented 38% of the total agricultural area in the EAR (MAGAP, 2014), were dedicated to extensive cattle ranching (Lerner et al., 2014). Cattle production is for meat and milk to satisfy both the local demand and national markets (Knoke et al., 2014).

MATERIALS AND METHODS

Geographical Location

This study was conducted in the Diversity and Life Zone (DLZ) in the Yasuni Biosphere Reserve (YBR). The YBR was established in 1989 by the Ecuadorian government and has a surface area of 1.68 million hectares. The core conservation area is the Yasuni National Park (YNP), which consists of 9.82 thousand hectares (Taco, 2001; Finer et al., 2009). The DLZ was created in 2007 with the objective of managing in a special way the production systems and livelihoods of indigenous households and migrant settlers established there (Herrera et al., 2017). Through two presidential decrees, the national government declared (1999) and mapped out (2007) a “Forbidden Zone,” also called the Intangible Zone or Tagaeri-Taromenane Intangible Zone (ZITT for its Spanish acronym) (Presidencia de la República de Ecuador, 1999, 2007; Pappalardo et al., 2013). The YBR is in the northern part of the Ecuadorian Amazon Region (RAE) and extends between the provinces of Orellana (50.51%), Pastaza (39.40%), Napo (8.64%), Sucumbíos (1.45%) and it borders two areas of natural and cultural importance: the Sumaco Biosphere Reserve and the Cuyabeno Wildlife Production Reserve (Figure 1).

The YBR is part of an important mosaic of ecosystems. The climate is within the “Amazonian core” (Killeen and Solórzano, 2008), which is characterized by warm temperatures (annual average of 24–27°C), high precipitation (annual average 3,200 mm), and high relative humidity (annual average 80–94%) (Pitman, 2000). The soils are geologically young, fluvial sediments coming from the erosion of the Andes (Pitman et al., 2002; Valencia et al., 2004). The area is part of the hotspot called the “Western Amazon Highlands” (Myers, 1988; Myers et al., 2000). However, like many other areas of high biodiversity, it is threatened by habitat destruction and cultural alterations (Mittermeier et al., 1998; Beristain et al., 2009). The YBR faces high rates of deforestation and land-use change, with one of the main drivers being the opening of roads because of oil concessions (Jorgenson and Coppolillo, 2001; Mena et al., 2006; De la Torre and Cornejo, 2008; Suárez et al., 2009; Bonilla-Bedoya et al., 2018). New roads have facilitated colonization and subsequent deforestation by small-scale migrant farmers engaged in agriculture and cattle ranching (Wunder, 2003; Sierra, 2004). Indigenous peoples also migrated into the Diversity and Life Zone (DLZ) for cash-crop agriculture by indigenous peoples (Sierra, 2004; Lu et al., 2012; Davis et al., 2016).

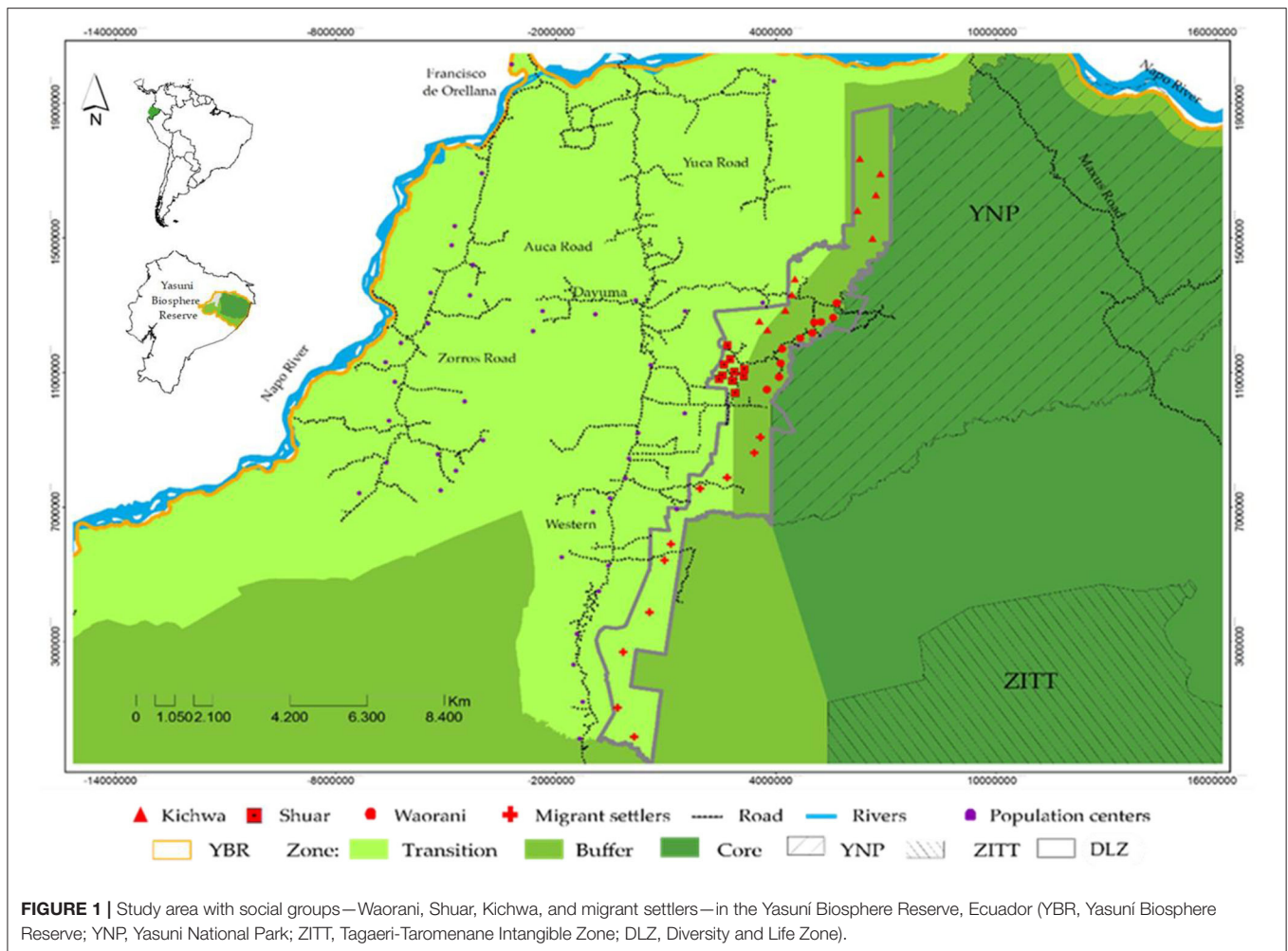


FIGURE 1 | Study area with social groups—Waorani, Shuar, Kichwa, and migrant settlers—in the Yasuni Biosphere Reserve, Ecuador (YBR, Yasuni Biosphere Reserve; YNP, Yasuni National Park; ZITT, Tagaeri-Taromenane Intangible Zone; DLZ, Diversity and Life Zone).

Sample Design and Data Collection

The data come from a household survey conducted between August and November 2019 in the DLZ. A template of the Poverty and Environment Network (PEN) questionnaire (Cavendish, 2003) was adopted to obtain information on the demographic characteristics of the households, the population structure by social group, and their distributions by sex and age. The following indices were calculated: (1) proportions of young population (<14 years, $P_{youngpop}$); (2) adult population (between 15 and 64 years, P_{adults}); (3) ratio of children/women, defined as: the number of children under 5 years of age for every woman of reproductive age (R); (4) masculinity rate, consisting of the ratio of males for every 100 females in a given population, which is the first indicator to analyze the population’s distribution by sex (MR); (5) the youth dependency index—the ratio between those (<15 years) who are potentially dependent and those of a potentially active age (between 15 and 64 years, I_{dy}^t); (6) the working age population structure index—the ratio between those aged 40–64 years and those aged 15–39 years (I_r); and (7) the working age population replacement index- the ratio between those aged 60–64 years and those aged 15–19 years (I_r^t); (Hinde,

2001; Rowland, 2004; Holdsworth et al., 2013; Wilson, 2016). Moreover, we determined the time needed to travel to: (a) the road and river, (b) traditional production systems for indigenous people, and (c) production systems for migrant settlers.

$$P_{young\ pop.} = \frac{P_{0-14}}{P} \times 100 \tag{1}$$

$$P_{adults} = \frac{P_{15-64}}{P} \times 100 \tag{2}$$

$$R = \frac{P_{0-4}}{P_{w. 15-49}} \text{ children per woman} \tag{3}$$

$$MR = \frac{male\ P}{P} \times 100 \tag{4}$$

$$I_{dy}^t = \frac{P_{0-14}^t}{P_{15-64}^t} \times 100 \tag{5}$$

$$I_r = \frac{P_{40-64}^t}{P_{15-39}^t} \times 100 \tag{6}$$

$$I_r^t = \frac{P_{60-64}^t}{P_{15-19}^t} \times 100 \tag{7}$$

The cluster sampling technique was used with a two-stage approach. During the first stage, two to five communities were selected per social groups, based on criteria of ethnicity and ownership of traditional production systems. To this end, 14 communities were identified (Table 1). The variation in conditions between communities ensured a fair representation of the communities' diversity, which influences the robustness of the study (Cavendish, 2003).

During the second stage, with the support of a key informant per social group, 10 households per social group were randomly selected for a total of 40 households (10 households per social group) for the interviews. The survey was translated from English to Spanish, *Kichwa*, *Shuar*, and *Wao-terero*. The 40 households (10 households per social group) housed between 3 and 13 members per household (Table 1). The survey was administered to the husband and wife of each household. Although the sample is not strictly called a probability sampling of communities and households, the 14 communities and 40 households provided a good representation of diverse ethnic or social groupings, geographies, and livelihood diversity, considering the complexity of conducting interviews in indigenous communities (Vasco et al., 2018). The process of obtaining free and informed consent was carried out with the support of indigenous leaders and settlers, through whom all approaches to households were made. Surveys were conducted according to the principles of ethical research (Vanclay et al., 2013) where the objectives, methodology, and timetable of the study were a priori explained to members of each community.

Assessment of Agricultural Sustainability

The program SAFA version 3.0 (SAFA, 2012), developed in 2012 by the FAO, was used to obtain a set of useful indicators that highlighted problems and identified solutions regarding the sustainability evaluation of the production systems, used in this case at the household level. The surveys consisted of questions based on the SAFA indicators (Food Agriculture Organization, 2014) related to agricultural systems and livelihoods. The SAFA has hierarchical levels: dimensions, themes, sub-themes, and indicators (Food Agriculture Organization, 2013). The dimensions include good governance (GG), environmental integrity (EI), economic resilience (ER), and social well-being (WB). One dimension is the pillar of sustainability, which is the highest and most general level in the SAFA structure (Food Agriculture Organization, 2014).

The SAFA usually consists of 21 themes, 58 sub-themes and 116 indicators (Food Agriculture Organization, 2013, 2014). In this research, however, the theme product quality and information (with its 3 sub-themes and 7 indicators) was not considered since none of the products produced and sold was labeled or had any traceability standards. Therefore, to assess the four dimensions of sustainability, the 20 SAFA sustainability themes, 55 sub-themes and 109 indicators (Table 2) were targeted. They were measured on a scale of 1–5 (Food Agriculture Organization, 2013) with the following sustainability levels: insufficient (red, <1.0), moderate (orange, 1.1–2), fair (yellow, 2.1–3), superior (light green, 3.1–4) and best (dark green,

>4.1) sustainability practices (Food Agriculture Organization, 2014).

The development of the SAFA included four stages: (1) mapping: description of the system to be evaluated; (2) contextualization: review of sub-themes and dynamic contexts; (3) indicators: selection of indicators and individual assessment; and (4) reporting of the information obtained at each stage, and presented in a sustainability polygon, using the SAFA version 3.0 and Excel version 2110 programs (Food Agriculture Organization, 2014). The SAFA program lists the metric tools and standards for data collection, which determine the level of data quality by attributing a variable score from 1 to 3, where 1 corresponds to low-quality data; 2 to moderate quality data; and 3 to high-quality data (Food Agriculture Organization, 2013). The survey had a duration of 60–85 min per household.

For the definition of the evaluated topics (Annex 1 in the **Supplementary Material**), three field visits were made to the study area between the months of May and June 2019. The direct observation technique was used because it helped data collection and information, allowed for a more detailed analysis of the facts and realities that made up each case within the study (Campos and Martínez, 2012) and was the best method for an *in-situ* evaluation (Sutton and Austin, 2015).

Statistical Method for Identifying Interactions Within the Dimensions of Sustainability

An analysis of variance (ANOVA) was used to compare the traditional production systems among the four social groups. A heteroscedastic model was fitted in the case of heterogeneous variances between social groupings. When normality was not met, we utilized the non-parametric Kruskal-Wallis test (Kruskal and Wallis, 1952). For significant differences at 5%, a Fisher's multiple comparison test was performed. For nominal variables (0, 1), Chi-square distribution tests were used.

A linear discriminant analysis was performed with the variables (sustainability issues) and social groupings with the aim of adjusting discriminant axes—a linear combination of the original variables—to maximize the differences between populations. The results were visualized in a biplot (variables and social groupings) in which the projection vector of the variables on the axes allows one to identify the relative contribution of the variables to the separation of the populations. Finally, synergies and trade-offs were evaluated using the non-parametric Spearman's correlation test (Spearman, 1904). Positive correlation coefficients ($0 < r_s \leq +1$) represent synergies, while negative correlation coefficients ($0 > r_s \geq -1$) represent trade-offs. Analyses were performed with IBM SPSS Statistics version 21 (SPSS, 2012) and the statistical program Infostat (Di Rienzo et al., 2011).

RESULTS

This section details the sociodemographic characteristics and sustainability scores for traditional production systems; certain

TABLE 1 | Communities in the study sample, with social groups—Waoarani, Shuar, Kichwa, and migrant settlers—in the Yasuni Biosphere Reserve, Ecuador.

Community	Social group	Households	Elevation (m.a.s.l.)	Access via	Main production activity	Traditional production system
Tobeta	Waoarani	2	286	Dirt road	Cassava	<i>Kinkore</i>
Miwaguno	Waoarani	3	248	Dirt road	Cassava, sugar cane	<i>Kewenkore</i>
Nampaweno	Waoarani	2	271	Gravel road	Corn, cassava	<i>Penenkore</i>
Yawepare	Waoarani	3	308	Dirt road	Peanut, cassava	<i>Koromonkore</i> <i>Kaginkore</i> <i>Kompankore</i>
Tzakimp	Shuar	7	303	Trail	Peanut, corn, cassava	<i>Aja</i>
Tiguano Shuar	Shuar	3	207	Dirt road	Cassava, corn	
Mandaripanga	Kichwa	5	343	River	Cacao, cassava, corn	<i>Chakra</i>
Rio Titupini	Kichwa	2	254	Dirt road	Cacao, banana, cassava	
Bay Enomenga	Kichwa	3	255	Dirt road	Cacao, cassava	
Los Alpes	Migrant settlers	2	370	Dirt road	Cacao, coffee, corn, beef cattle	Agroforestry
Perla de la Amazonia	Migrant settlers	2	346	Dirt road	Cacao, cassava, cattle for beef & milk	
Nueva Esperanza	Migrant settlers	2	322	Dirt road	Cacao, coffee, corn	
La Forestal	Migrant settlers	2	283	Trail	Coffee	
El Futuro	Migrant settlers	2	328	Dirt road	Cacao	

TABLE 2 | Structure of the Sustainability Assessment of Food and Agriculture (SAFA).

Dimension	Themes	Sub-themes	Indicators
Good governance	5	14	19
Environmental integrity	6	14	52
Economic resilience	4	11	19
Social well-being	6	16	19
Total	20	55	109

Source: Food and Agriculture Organization (2015).

significant differences are evidenced in demographic terms and a narrowing between the sustainability dynamics evaluated.

Sociodemographic and Agricultural Characteristics

The population for the entire study area was composed of men 55.7% and women 44.3% (262 total), and the average age of both men and women was 27 years old. Household composition did not significantly differ among the social groups. Among the Waoarani, the number of members per household varied between 4 and 13 people, while the Kichwa household had the lowest number of individuals i.e., 3 people. In the Shuar, Kichwa, and migrant settler households, the maximum number of individuals was 9 (Table 3).

The age of male heads of household differed significantly between the Shuar groups at 29 years and the other three social groups (average of 49). In terms of education, there are no significant differences among the Shuar, Kichwa, and migrant settler heads of household. However, four of Waoarani heads of household no formal education, bring the level of education significantly lower at 60% than the three other groups.

The results showed no significant to marginal differences among the four groups in terms of aid for sustainable development from national or international organizations (Table 3). The Shuar and Kichwa tended to have received more help than the Waoarani and migrant settlers. Access to financial credit appeared to be limited to all the four groups with only 10% of migrant settlers having some access. Access to mobile phones did not vary among the four groups but, migrant settlers tended to have highest number of mobile phones (80%), while the Kichwa the lowest. The distance from the household (in minutes) to the main road or to the river port significantly varied, with the longest time to reach the river port (72 min) was for the Kichwa group (specifically the Mandaripanga community). The Waoarani households had the lowest times, with some only having a 2 min distance to reach the main road. For the Shuar and migrant settlers, the average time varied between 12 and 19 min.

Demographic indices, such as percentages of young and adult in the populations, were not significantly different among the four social groups (Table 4). Nonetheless, the Shuar appeared to have the lowest young population, comprised of 18.9% men and 8.1% women, and the highest adult population, made up of 37.8% men and 35.2% women. As expected, this led to having the lowest rate of youth dependency and the highest percent of working-age people, meaning that their replacement rate for future work was the lowest. The other three groups tended to have similar trends with more youth and less working-age population.

The average agricultural land size per household varied from 1.75 ha for the Shuar group to 3.9 ha for the migrant settlers, and these results were significant (Table 5). The Shuar had the largest forested area followed by Waoarani and Kichwa and finally the migrant settlers, which was significantly the lowest in surface area. While the number of staple crops remained similar for the four social groups, the Kichwa and migrant settlers tended to cultivate at least one more cash crop than the Waoarani and Shuar (Table 5). While the Kichwa tended to be closer to their

TABLE 3 | Sociodemographic characteristics of the four social groups evaluated in the Yasuní Biosphere Reserve, Amazon region of Ecuador.

Variable	Average per social group				Significance [†]
	Waoarani	Shuar	Kichwa	Migrant settlers	
Household size (number of members)	7.3 (2.59)	6.2 (1.63)	6.4 (1.78)	6.5 (1.45)	0.8702
Age of head of household (years)	48 ^a (19.51)	29 ^b (5.21)	48 ^a (19.51)	51 ^a (11.27)	***<0.0001
Education level of head of household (% with at least basic education)	60 ^a	100 ^b	100 ^b	100 ^b	***0.0039
Heads of household with no education (%)	40 ^a	0 ^b	0 ^b	0 ^b	***0.0027
National or international help received (%)	10.00	60.00	60.00	30.00	0.057
Access to credit (%)	0.00	0.00	0.00	10.00	0.379
Mobile phones (%)	60.00	60.00	40.00	80.00	0.343
Distance from house to main road or river port (minutes)	7 ^a (3.71)	12 ^b (5.74)	30 ^c (25.36)	19 ^{bc} (11.22)	***0.0009

[†]ANOVA was performed for the means of continuous variables; and χ^2 for dummy/categorical variables. Levels of significance: *** 99%. Values in parenthesis are standard deviations of the means. Letters in superscript denote significant differences based on the ANOVA and χ^2 -tests.

TABLE 4 | Demographic indices according to social grouping (Waoarani, Shuar, Kichwa, and migrant settlers) in the Yasuní Biosphere Reserve of the Amazon region of Ecuador.

Variable	Average per social group				p-value
	Waoarani	Shuar	Kichwa	Migrant settlers	
Young population: 0–14 (%)	43.1	27.0	39.1	32.2	0.2043
Adult population: 15–64 (%)	56.9	73.0	60.9	67.8	0.2043
Ratio of children per woman	1.1	0.5	0.2	1.2	0.0500**
Percent of men (%)	56.9	56.8	50.0	59.3	0.7469
Youth dependency ratio (%)	75.7	37.0	64.1	47.5	0.2043
Working-age population (%)	68.2	80.0	50.0	73.9	0.7422
Replacement rate of the working-age population (%)	83.3	16.7	27.3	50.0	0.3278

χ^2 for dummy/categorical variables. Significance levels: ** 95%.

agricultural system, the results were not significant due to high variation in distances for both migrant settlers and Waoarani. The distance to the forest, however, significant differed among groups with the Shuar being closer to the firested areas than the other groups.

Sustainability Dimensions Assessment

The four dimensions of sustainability were analyzed using the 55 from the 58 SAFA sub-themes for the four traditional production systems. We found that 20 of the 55 (36.4%) of the evaluated sub-themes had significant differences among the four social groups (Table 6) and the sustainability polygons displayed in Figure 2.

Good Governance Dimension

The mean performance scores for the social groups were as follows: Waoarani (1.92), followed by the Shuar group (2.59), the Migrant settler group (2.65), and the highest mean for the Kichwa (2.71). Of the 14 sub-themes evaluated, six showed significant differences among the four social groups. Mission statement, and legitimacy resource appropriation subthemes were always significantly lower for the Waoarani group than the others. It was similar for the subthemes, stakeholder dialogue, and

sustainability management plan. However, the Migrant settler group was not significantly different from the Waoarani. In terms of overall scores, full cost accounting was the lowest followed by sustainability management plan, grievance procedures, and conflict resolutions.

Environmental Integrity Dimension

The average performance scores for the social groups were as follows: Kichwa (2.69), migrant settlers (2.78), Waoarani (2.95), and the highest mean for the Shuar (3.33). Of the 14 sub-themes evaluated, four showed significant differences among the four social groups. Greenhouse gases were similar for the Waoarani and Shuar but different for the Kichwa and migrant settlers, while ecosystem diversity, animal health and freedom from stress were significantly lower for the Waoarani group than the others. In terms of overall scores, freedom from stress was the lowest, followed by animal health, air quality, and material use.

Economic Resilience Dimension

The mean performance scores for the social groups were as follows: the lowest mean for the Waoarani (1.40), Kichwa (1.48), migrant settlers (2.48), and Shuar (2.50). Of the 11 sub-themes

TABLE 5 | Agricultural variables (mean and standard deviation in parentheses) of the traditional productive systems of the Waorani, Shuar, Kichwa indigenous peoples and migrant settlers in the Yasuni Biosphere Reserve, Amazon Region of Ecuador.

Variable	Average per social group				Significance [†]
	Waorani	Shuar	Kichwa	Migrant settlers	
Total agricultural area (ha)/household	1.85 ^a (1.16)	1.75 ^a (0.98)	3.50 ^b (1.90)	3.90 ^b (1.79)	0.0036
Total forest area (ha)	47.85 ^{ab} (1.53)	48.25 ^b (0.98)	46.40 ^{ab} (1.90)	46.30 ^a (1.64)	0.0127
Number of staple crops	3.00 (1.05)	3.22 (0.97)	3.20 (0.92)	2.30 (0.95)	0.1668
Number of cash crops	1.70 ^a (0.67)	1.70 ^a (0.82)	2.60 ^b (0.97)	2.70 ^b (0.82)	0.0147
Distance from dwelling to agricultural system (min)	15.90 (22.76)	10.60 (9.88)	6.70 (4.16)	16.90 (21.89)	0.7171
Distance from dwelling to forest (min)	13.60 ^c (2.46)	4.70 ^a (1.57)	10.00 ^b (4.14)	23.50 ^d (4.88)	<0.0001

[†]ANOVA was performed for the means of continuous variables. Significance levels: *, **, *** are 90, 95, and 99%, respectively. Values in parenthesis are standard deviations. Letters in superscript denote significant differences based on the post-hoc multiple range tests.

evaluated, six showed significant differences among the four social groups. The internal investment, community investment, long-ranging investment, and profitability were significantly lower for the Waorani and Kichwa groups while, the stability of market for the migrant settlers was slightly higher for the others and local procurement for the Kichwa was slightly lower than the other groups. In terms of overall scores, the stability of market was the lowest, followed by the stability of supply, liquidity, and risk management.

Social Welfare Dimension

The average performance scores for the social groups were as follows: the lowest average for the Shuar (2.41), Kichwa (2.44), Waorani (2.54), and the highest average for the Migrant settlers (2.47). Of the 16 sub-themes evaluated, six showed significant differences among the four social groups: the quality of life for the Waorani group; the indigenous knowledge and food sovereignty for the Shuar; the gender equality, support for vulnerable people and public health for the Kichwa were significantly lower than the others. The public health was significantly higher in Kichwa than the others; the indigenous knowledge is the main difference between the Shuar and Kichwa groups; the food sovereignty in the Kichwa group is significantly different from the others. In terms of overall scores, responsible buyers were the lowest, followed by the rights of suppliers, child labor, forced labor, freedom of association, and rights to bargaining.

Interactions Within Sustainability Dimensions and Themes

Before evaluating the sustainability interactions within the four dimensions and 20 themes according to SAFA, it was necessary to quantify their results (Table 7). The results showed that the sustainability indices had a performance level of “moderate.” In general, the traditional aja system (2.84) had the best score, followed by the migrant settlers’ agroforestry system (2.65), considering that the themes with lower performance scores are:

fair trading practices, labor rights, animal welfare and holistic management. They were followed by the Kichwa’s chakra system, influenced by its lowest scoring themes: fair trading practices, investment, vulnerability, and labor rights. In last place was the Waorani’s kewenkore whose lowest scores were in the themes: fair trading practices, investment, animal welfare, and holistic management.

From the scores of the four dimensions and the 20 sustainability themes (Table 7), interactions within the sustainability themes were analyzed using a Spearman’s correlation test. In general terms, trade-offs and synergies were found (50%) (Table 8). There were trade-offs between good governance and environment integrity (15%), followed by social issues (11%), and synergies (25%) with respect to economic resilience. In addition, significant synergies were observed within environmental integrity with economic and social issues, and trade-offs between economic resilience and social well-being.

Multivariate Discriminant Analysis by Social Groups

Similarities and antagonisms in terms of sustainability among the social groups were identified with a multivariate discriminant analysis, using the averages of the 116 sustainability indicators of the four dimensions of the SAFA methodology (Figure 3). The results showed that in the horizontal component (60% of the variation between groups), the social groups were ordered by placing the traditional systems of the Shuar population on the extreme right together with those of migrant settlers because they showed similarities. On the far left were the Waorani and Kichwa cases, which differed in certain aspects to the two aforementioned groups. These differences between the social groups were mainly explained by a contrast or negative correlation between the investment, atmosphere, and materials themes vs. the participation. In this sense, the Shuar and migrant settler populations were characterized by high levels of investment, atmosphere, and materials (although also in biodiversity, animal

TABLE 6 | Sub-themes evaluated in the four traditional production systems evaluated by social groups in the Yasuní Biosphere Reserve's Diversity and Life Zone, Amazon region of Ecuador.

Dimensions	Sub-theme	Worani average (SD)	Shuar average (SD)	Kichwa average (SD)	Migrant settler average (SD)	Significance [†]
Good governance	Mission statement	2.68 ^a (0.59)	3.37 ^b (0.59)	3.36 ^b (0.74)	3.38 ^b (0.46)	0.031
	Due diligence	2.50 (0.63)	3.26 (0.66)	3.09 (1.07)	3.17 (1.06)	0.224
	Holistic audits	2.49 (0.72)	2.99 (0.96)	2.38 (1.10)	2.81 (1.59)	0.611
	Responsibility	2.23 (0.74)	2.41 (0.65)	2.55 (0.50)	2.66 (0.91)	0.574
	Transparency	2.43 (0.57)	2.56 (0.63)	2.47 (0.93)	3.01 (0.79)	0.290
	Stakeholder dialogue	2.04 ^a (0.79)	2.85 ^b (1.20)	3.30 ^b (0.51)	2.30 ^a (0.85)	0.012
	Grievance procedures	1.83 (0.45)	2.12 (0.98)	2.78 (1.16)	2.12 (0.43)	0.089
	Conflict resolution	2.04 (0.65)	2.00 (0.79)	2.57 (1.05)	2.1 (0.76)	0.397
	Legitimacy	1.24 ^a (0.47)	2.68 ^b (1.40)	3.01 ^b (0.95)	3.26 ^b (0.78)	<0.001
	Remedy restoration and prevention	1.92 (0.73)	2.95 (0.67)	2.87 (1.1)	2.78 (1.14)	0.066
	Civic responsibility	1.24 ^a (0.66)	2.57 ^b (0.85)	2.74 ^b (0.89)	3.00 ^b (1.18)	0.001
	Resource appropriation	1.73 ^a (0.34)	2.89 ^b (0.95)	2.98 ^b (1.30)	2.87 ^b (0.98)	0.017
	Sustainability management plan	1.44 ^a (0.68)	2.52 ^b (0.97)	2.33 ^b (1.02)	2.03 ^b (0.73)	0.043
	Full cost accounting	1.03 (0.37)	0.98 (0.78)	1.50 (0.87)	1.50 (1.00)	0.272
	Mean	1.92 ^a (0.53)	2.59 ^b (0.60)	2.71 ^b (0.47)	2.65 ^b (0.54)	0.007
Environmental integrity	Greenhouse gases	3.40 ^a (0.77)	2.96 ^a (0.78)	2.38 ^b (0.63)	2.40 ^b (1.17)	0.034
	Air quality	2.96 (0.61)	3.05 (0.96)	2.11 (0.93)	2.47 (1.16)	0.106
	Water withdrawal	3.63 (0.83)	3.95 (0.41)	3.46 (0.42)	3.48 (0.72)	0.279
	Water quality	3.90 (0.70)	3.94 (0.45)	3.21 (1.10)	3.30 (0.84)	0.398
	Soil quality	3.47 (0.64)	3.54 (0.67)	3.34 (1.06)	3.04 (0.63)	0.286
	Land degradation	3.17 (0.59)	3.46 (0.58)	2.77 (1.23)	3.46 (0.53)	0.207
	Ecosystem diversity	3.04 ^a (0.77)	3.98 ^b (0.46)	3.79 ^b (0.12)	3.26 ^a (0.57)	0.014
	Species diversity	3.32 (1.07)	3.49 (0.76)	3.45 (0.60)	3.14 (0.87)	0.791
	Genetic diversity	3.05 (0.42)	3.67 (0.71)	3.15 (1.89)	2.71 (0.88)	0.303
	Material use	2.73 (0.99)	2.96 (0.56)	2.45 (0.95)	2.67 (0.98)	0.647
Energy use	3.26 (0.61)	2.93 (0.84)	2.38 (1.03)	2.98 (0.65)	0.114	

(Continued)

TABLE 6 | Continued

Dimensions	Sub-theme	Worani average (SD)	Shuar average (SD)	Kichwa average (SD)	Migrant settler average (SD)	Significance [†]	
Economic resilience*	Waste reduction and disposal	3.17 (0.75)	3.07 (0.91)	2.26 (1.42)	2.55 (1.06)	0.318	
	Animal health	1.15 ^a (0.56)	3.05 ^c (1.06)	1.40 ^a (0.98)	1.98 ^b (0.63)	<0.001	
	Freedom from stress	1.09 ^a (0.50)	2.60 ^c (0.63)	1.50 ^b (0.93)	1.51 ^b (1.06)	0.004	
	Mean	2.95 (0.83)	3.33 (0.44)	2.69 (0.74)	2.78 (0.57)	0.064	
	Internal investment	0.96 ^a (0.46)	2.66 ^b (1.17)	1.46 ^a (0.87)	3.07 ^c (0.59)	<0.001	
	Community investment	1.22 ^a (0.55)	3.10 ^c (1.05)	1.51 ^b (1.45)	3.13 ^c (1.41)	0.002	
	Long-ranging investment	1.05 ^a (0.51)	2.93 ^b (1.04)	1.19 ^a (0.56)	2.67 ^b (1.45)	0.003	
	Profitability	0.99 ^a (0.45)	3.19 ^b (1.22)	1.42 ^b (0.54)	3.03 ^b (0.95)	<0.001	
	Stability of production	1.53 (1.64)	2.02 (1.34)	1.51 (0.78)	2.30 (0.61)	0.103	
	Supply of stability	1.39 (1.41)	1.77 (1.55)	1.28 (0.50)	2.09 (1.24)	0.450	
	Stability of market	1.19 ^a (1.04)	1.70 ^{ab} (1.06)	1.16 ^a (0.92)	2.09 ^b (0.69)	0.035	
	Liquidity	1.26 (1.07)	2.03 (1.33)	1.62 (1.12)	1.79 (1.03)	0.472	
	Risk management	1.64 (1.08)	2.54 (0.95)	1.36 (0.93)	1.58 (1.47)	0.146	
	Value creation	2.00 (1.41)	2.80 (0.90)	2.01 (1.55)	2.68 (1.26)	0.272	
	Local procurement	2.18 ^a (0.96)	2.71 ^b (0.90)	1.75 ^a (1.22)	2.94 ^b (0.80)	0.038	
	Mean	1.40 ^a (0.40)	2.50 ^b (0.53)	1.48 ^a (0.25)	2.48 ^b (0.56)	<0.001	
	Quality of life	2.28 ^a (0.98)	2.65 ^a (0.67)	3.02 ^b (0.65)	3.25 ^b (0.46)	0.024	
	Capacity development	2.40 (0.91)	2.57 (0.96)	3.20 (0.92)	3.08 ^b (0.87)	0.167	
	Social well-being	Fair access to means of production	2.45 (0.93)	2.77 (0.28)	3.06 (0.52)	3.22 (0.97)	0.115
		Responsible buyers	1.02 (0.66)	0.99 (0.74)	0.96 (0.46)	0.98 (0.58)	0.768
Rights of suppliers		1.04 (0.46)	0.95 (0.57)	0.98 (0.49)	0.98 (0.54)	0.984	
Employee relations		1.96 (0.87)	1.85 (0.93)	1.50 (0.51)	1.59 (0.75)	0.523	
Forced labor		1.67 (0.99)	1.95 (0.94)	1.62 (0.21)	1.61 (0.46)	0.693	
Child labor		1.05 (0.53)	1.73 (0.94)	1.62 (0.21)	1.69 (0.54)	0.06	
Freedom of association and rights to bargaining		2.07 (0.93)	1.97 (0.89)	1.33 (0.78)	1.51 (0.77)	0.168	
Non-discrimination		3.43 (0.44)	3.16 (0.73)	2.87 (0.64)	3.38 (0.44)	0.137	
Gender equality		3.68 ^c (0.66)	3.33 ^b (0.75)	2.74 ^a (0.69)	3.32 ^b (0.77)	0.046	

(Continued)

TABLE 6 | Continued

Dimensions	Sub-theme	Waorani average (SD)	Shuar average (SD)	Kichwa average (SD)	Migrant settler average (SD)	Significance [†]
	Support for vulnerable people	3.82 ^c (0.79)	3.05 ^a (0.35)	2.90 ^a (0.66)	3.45 ^b (0.35)	0.004
	Workplace safety and health provisions	2.98 (0.66)	2.69 (0.87)	2.26 (0.63)	2.57 (0.71)	0.183
	Public health	3.39 ^c (0.79)	2.60 ^b (0.75)	2.12 ^a (0.84)	2.45 ^b (0.56)	0.004
	Indigenous knowledge	3.82 ^b (0.47)	3.15 ^a (0.82)	4.40 ^b (0.21)	3.26 ^a (0.91)	0.001
	Food sovereignty	3.65 ^b (0.75)	3.07 ^a (0.66)	4.45 ^b (0.16)	3.19 ^a (0.81)	<0.001
	Mean	2.54 (1.02)	2.41 (0.75)	2.44 (1.08)	2.47 (0.98)	0.979

[†]ANOVA or *Kruskal-Wallis as appropriate. Different letters indicate significant differences between social groups at 5%.

welfare, and vulnerability) and low levels of participation. The opposite occurred with the Kichwa and Waorani populations. The vertical component (30% of the variation between groups) separated the Waorani indigenous populations from the Kichwa. This indicated that the Kichwa population was characterized by high values of good governance: participation, holistic audits, and social well-being: decent livelihood (we can add equity and cultural diversity), in contrast to the Waorani population, which was related to high values for labor rights, human, and equity.

DISCUSSION

Assessment of Sustainability Dimensions

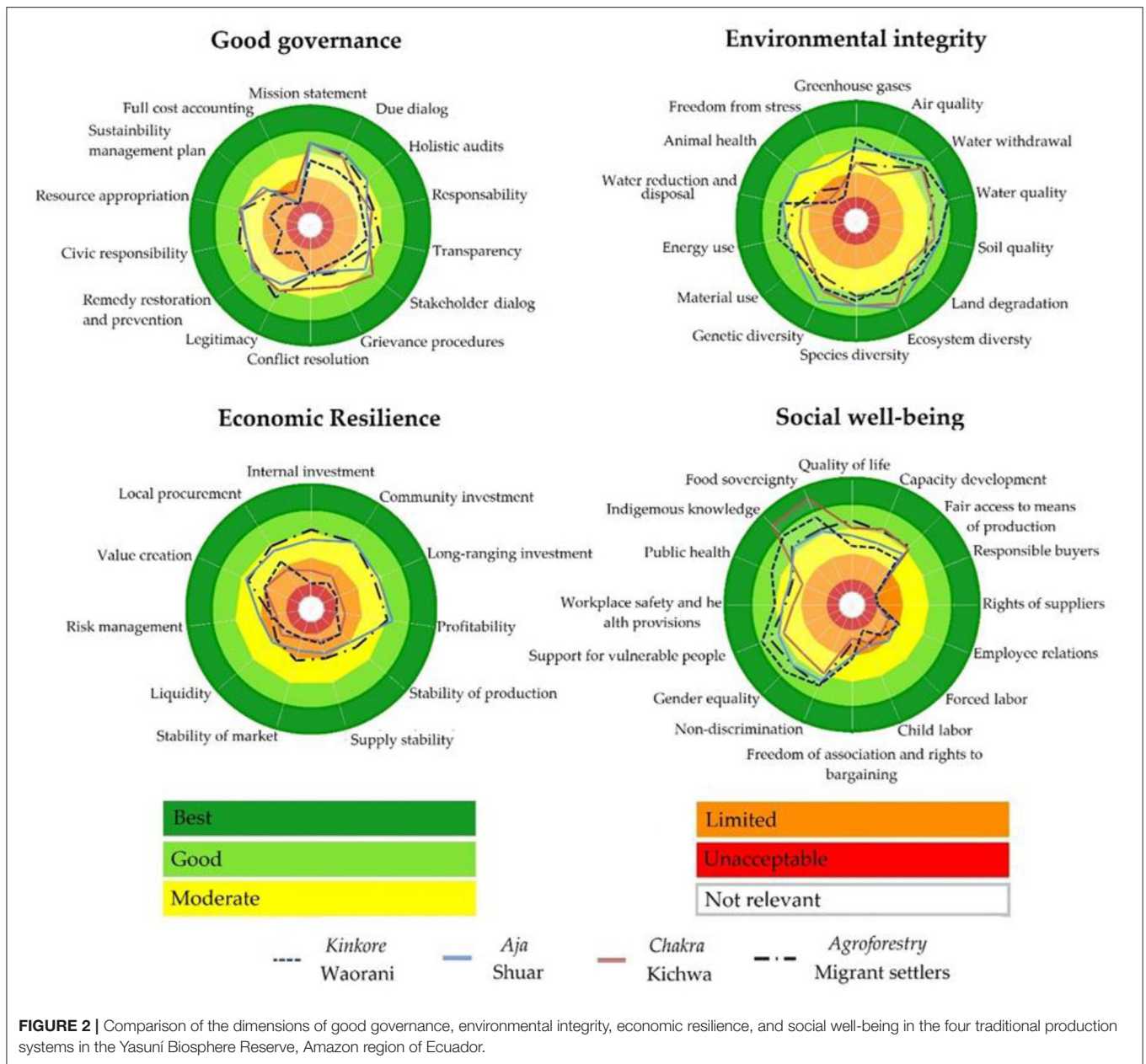
When comparing the four dimensions of sustainability between the traditional production systems (Waorani, Shuar, Kichwa, and migrant settlers), we found that the sustainability profiles by sub-themes are more statistically different in the dimensions of good governance and social well-being in contrast to the dimensions of environmental integrity and economic resilience (Table 7). This is consistent with the dynamics of management in traditional production systems among the Waorani (Zurita-Benavides, 2017), Shuar (Karsten et al., 2000), Kichwa (Coq-Huelva et al., 2017; Luzuriaga-Quichimbo et al., 2019), and migrant settlers (Sellers et al., 2017; Heredia-R et al., 2020a,b,c; Viteri-Salazar and Toledo, 2020). It is related to different cultural and migratory dynamics (Barbieri et al., 2009), such as, mining and land redistribution in favor of settlers. Some Shuar populations had to migrate to the province of Orellana and other provinces of the Ecuadorian Amazon (Holt et al., 2004), when the migrant settlers arrived mainly from the highlands and coast (Barbieri and Carr, 2005; Wasserstrom, 2010; Viteri-Salazar and Toledo, 2020).

None of the traditional production systems works uniformly for all themes (Table 3) and sub-themes (Figure 2) of sustainability. This may be related to social or environmental conflicts (Scheidel et al., 2020) and market access, as has been demonstrated in other indigenous populations, for instance the Baka of Cameroon (Africa), the Punan Tubu of Indonesia

(Asia), and the Tsimane' of Bolivia (South America), where three relatively isolated societies, largely dependent on traditional subsistence systems (Joiris, 2003; Levang et al., 2007; Leclerc, 2012; Reyes-García et al., 2014; Díaz-Reviriego et al., 2016), saw their diets alter when living closer to markets. This shifted their consumption habits from nutritional food (i.e., fruit, vegetables, and food of animal origin) to an increased consumption of fats and sweet products due to market integration, thus decreasing work in traditional production systems (Reyes-García et al., 2019).

The low scores of the Waorani (kinkore) traditional production systems for good governance (Table 7) are influenced by the holistic management theme and correlated with the sub-themes of sustainability management plan and full cost accounting (Figure 2 and Table 6). This contrasts with the common belief that indigenous populations are associated with a holistic management of their traditional systems (long fallows, according to Boserup, 1965), with collective responsibility, participation and, therefore, compatibility with resource conservation (Dufour, 1990; Schwartzman et al., 2000). However, several studies (Henrich, 1997; Zimmerman et al., 2001; Rudel et al., 2002; Godoy et al., 2005; Gray et al., 2008; Porro et al., 2014) indicate that indigenous peoples sometimes also engage in unsustainable practices (Food Agriculture Organization, 2005), driven by the presence of oil activity (Rivera-Parra et al., 2020), which has negative implications (Diantini et al., 2020). The Waorani stand in contrast to the Shuar's aja, which had the highest scores, thus complying with Boserup's assertion (Boserup, 1965) regarding systems with more sustainable levels of governance (Rudel et al., 2002).

In the environmental integrity dimension, the low scores obtained by the migrant settlers are related to the themes of animal welfare (driven by the sub-themes of animal health and freedom from stress) and atmosphere (driven by the sub-themes of greenhouse gases and air quality). An explanation for this finding is that pastoral systems in the EAR are associated with extensive operations (Lerner et al., 2014; MAGAP, 2014). Therefore, they require larger areas



of land. In tropical regions, livestock development is being promoted with an economically, socially, and environmentally sustainable approach (Ness et al., 2007). Cattle ranching offers an alternative source of capital that the rural poor can accumulate as a “savings account” to protect themselves against income fluctuations (Broom et al., 2013; Lemaire et al., 2014). Therefore, raising cattle in rural households is considered an alternative form of insurance, allowing them to earn income from the sale of animals in times of crisis (Hoddinott, 2006; Mogue, 2011). The welfare of ethnic minority households with livestock production tends to be higher than those without livestock production (Truong et al., 2020), and sustainability depends on the availability

of resources for transformation to agrosilvopastoral systems (Lopera-Marín et al., 2020).

In relation to economic resilience, the low scores of the Waorani (kinkore) traditional production systems are related to the theme of investment and the sub-themes internal investment, community investment, long-term investment, and profitability. First, the Waorani have recently become integrated into the markets (Sierra et al., 1999; Franzen and James, 2007; Lu, 2007), driven by certain factors: accessibility, monetary income, trade of agricultural products, and wild meat, and a cultural erosion of exchange (Donders and Barriocanal, 2020). Oil exploitation in the Amazon basin is an additional factor, whereby some Waorani are economically dependent on salaried jobs in the oil industry

TABLE 7 | Means and standard deviations of the themes of the sustainability evaluation in four production systems (Waorani, Shuar, Kichwa, and migrant settlers) in the Yasuni Biosphere Reserve, Amazon region of Ecuador.

Dimension/Theme		Waorani (Kinkore)		Shuar (Aja)		Kichwa (Chakra)		Migrant settlers (agroforestry)		Overall mean	Significance [†]
		Mean	SD	Mean	SD	Mean	SD	Mean	SD		
Good governance	GG1. Corporate ethics	2.75	0.93	3.35	0.18	3.42	0.50	3.41	0.28	3.23	–
	GG2. Accountability	2.53 ^{ab}	0.68	3.20 ^c	0.49	2.06 ^a	0.76	3.00 ^{bc}	0.78	2.70	**
	GG3. Participation	2.05 ^a	0.52	2.97 ^b	0.71	3.41 ^b	0.52	2.36 ^a	0.59	2.70	***
	GG4. Rule of law	2.00 ^a	0.74	3.03 ^b	0.46	3.06 ^{bc}	0.60	3.43 ^c	0.19	2.88	***
	GG5. Holistic management	1.50 ^a	0.22	2.61 ^b	0.40	2.42 ^b	0.30	2.19 ^b	0.72	2.18	***
Environment integrity	EI1. Atmosphere	3.42 ^a	0.25	3.19 ^a	0.56	2.60 ^b	0.27	2.56 ^b	0.57	2.94	***
	EI2. Water	3.91	0.71	4.09	0.57	3.51	0.53	3.59	0.61	3.78	–
	EI3. Land	3.60	0.37	3.53	0.49	3.31	0.50	3.16	0.98	3.40	–
	EI4. Biodiversity	3.55 ^{ab}	0.69	4.07 ^b	0.56	3.92 ^b	0.70	3.31 ^a	0.40	3.71	**
	EI5. Materials and energy	3.45 ^c	0.14	3.33 ^{bc}	0.27	2.73 ^a	0.16	3.08 ^{ab}	0.70	3.15	***
	EI6. Animal welfare	1.50 ^a	0.53	3.33 ^c	0.48	1.69 ^{ab}	0.58	2.07 ^b	0.64	2.15	***
Economic resilience	ER1. Investment	1.20 ^a	0.62	3.29 ^b	0.43	1.51 ^a	0.57	3.21 ^b	0.93	2.30	***
	ER2. Vulnerability	1.60 ^a	0.37	2.05 ^{ab}	0.54	1.55 ^a	0.62	2.30 ^b	0.81	1.88	**
	ER3. Local economy	2.21 ^a	0.46	2.92 ^b	0.71	2.20 ^a	0.73	2.97 ^b	0.57	2.58	**
Social well-being	SW1. Decent livelihood	2.58 ^a	0.47	2.85 ^{ab}	0.54	3.23 ^b	0.71	3.36 ^b	0.61	3.01	**
	SW2. Fair trading practices	0.50	0.38	0.52	0.07	0.52	0.17	0.51	0.14	0.51	–
	SW3. Labor rights	2.13	0.54	2.00	0.80	1.60	0.41	1.65	0.49	1.85	*
	SW4. Equity	3.80	0.74	3.38	1.03	2.97	0.75	3.48	0.69	3.41	–
	SW5. Human safety health	3.64 ^a	0.51	2.74 ^b	0.46	2.38 ^b	0.87	2.67 ^b	0.36	2.86	***
	SW6. Cultural diversity	3.91	0.80	3.27	0.40	4.49	0.75	3.34	0.75	3.75	–
	Global sustainability indicator	2.47		2.84		2.50		2.65		2.62	–

[†]ANOVA or Kruskal-Wallis as appropriate. Different letters indicate significant differences between social groups at 5%. Significance levels: *, **, *** are 1105 90%, 95%, and 99%, respectively.

(Rivera-Parra et al., 2020), which has caused time constraints for interaction with traditional production systems (Diantini et al., 2020). The following factors have also been registered: water contamination (Balseiro-Romero et al., 2018; Maurice et al., 2019), the presence of heavy metals in the food chain (Adzigbli and Yuewen, 2018; Maletić et al., 2019), including crops (Veil et al., 2004; Barraza et al., 2018) health risks for indigenous people and migrant settlers (Barraza et al., 2017; Merchán-Rivera and Chiogna, 2017), a loss of biodiversity (Durango-Cordero et al., 2018) and acculturation processes (Swing et al., 2012). The social and environmental history of the oil industries and state-owned companies in the Amazon basin (Becerra et al., 2018) have not been detrimental for the indigenous and migrant settler populations (Valdivia, 2007; Swing et al., 2012; Bebbington and Bury, 2013) due to the resulting economic dependence (Rival, 1992). This is similar to the scenario in Central Africa, where the Chad-Cameroon pipeline project did not improve the living conditions of the local indigenous community of Bagyeli, poverty increased and the quality of life decreased (Horta, 2007; Husar and Finka, 2016).

Although the production systems evaluated had high scores in most of the social issues, the lowest scores were in the Shuar's aja, mostly determined by fair trading practices and the sub-themes of responsible buyers, rights of suppliers, employee relations,

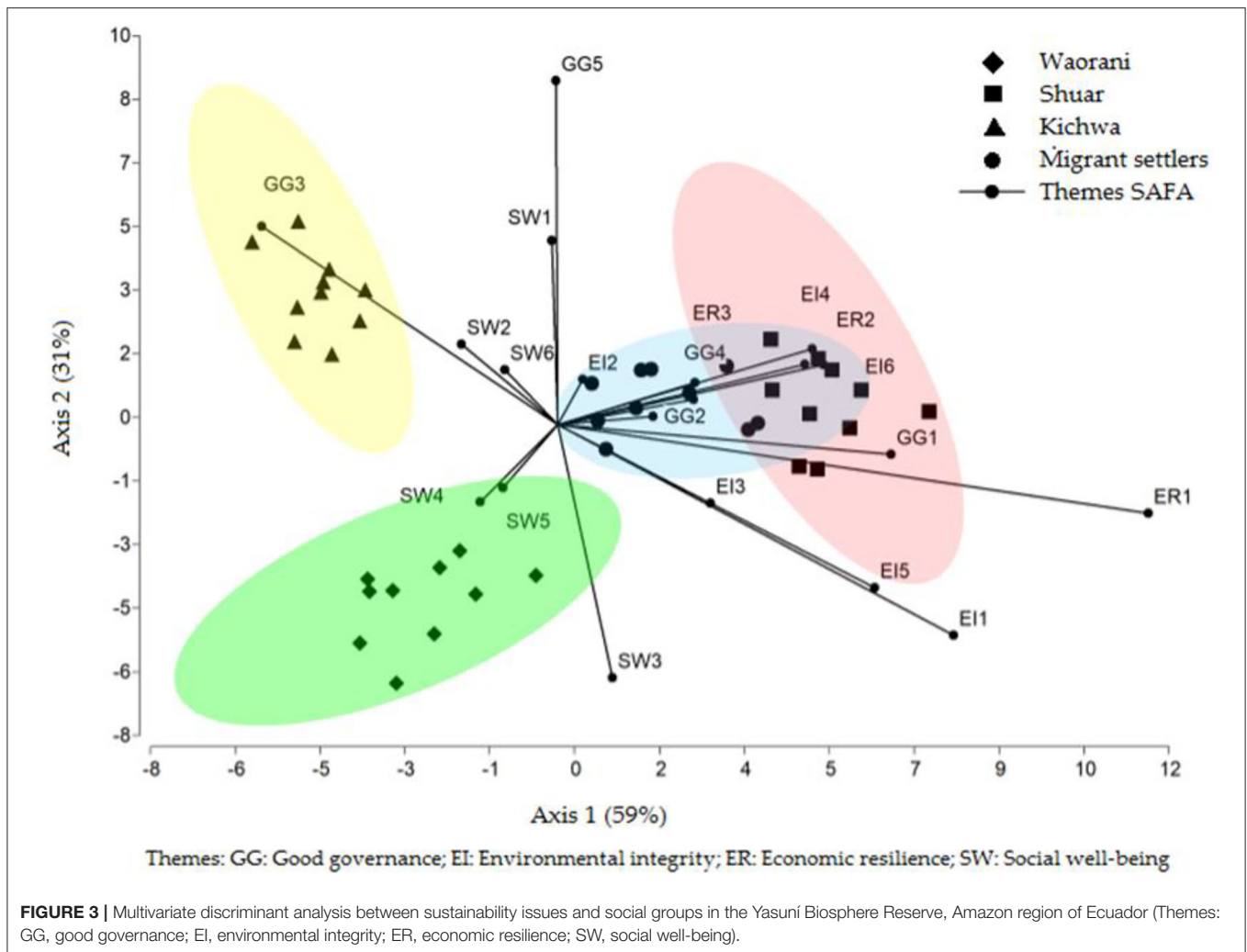
forced labor, and child labor. This is not related to indigenous cultural dynamics, because the management of production systems, from a social perspective, is the result of a set of values, deeply rooted in the indigenous worldview (Goyes et al., 2021; Santafe-Troncoso and Loring, 2021; Varese, 2021), and ancestral knowledge is transmitted from generation to generation through harmonious relationships, based on solidarity and reciprocity (Sierra, 2000). These dynamics can also be identified in traditional production systems along the Napo riverbank, located to the north of the YBR (Heredia-R et al., 2020d,e). It is important to highlight that the contributions of indigenous and local knowledge in research are increasingly being considered in the science of sustainability (Mistry and Berardi, 2016; Tengö et al., 2017).

The discriminant analysis showed attributes of similarity (sustainability issues) between migrant settlers and the Shuar, corroborating the results of other researchers, who suggest that the Shuar are increasingly integrating into the market economy, participating in extensive cattle raising and commercial agriculture, and have similarly to migrant settlers (Rubenstein, 2001; Zimmerman et al., 2001; Rudel et al., 2002; Godoy et al., 2005; Gray et al., 2008). Meanwhile, greater divergence is evident among the Waorani and Kichwa in terms of sustainability, probably influenced by the following factors: (1)

TABLE 8 | Spearman's correlation values between sustainability themes and social groups (Worani, Shuar, Kichwa, and migrant settlers) in the Yasuni Biosphere Reserve, Amazon region of Ecuador.

Dimension	Good governance					Environment integrity						Economic resilience			Social well-being					
	GG1	GG2	GG3	GG4	GG5	EI1	EI2	EI3	EI4	EI5	EI6	ER1	ER2	ER3	SW1	SW2	SW13	SW4	SW5	SW16
Good governance	GG1. Corporate ethics	1.00							-0.15				+0.25							-0.11
	GG2. Accountability	-0.40	1.00																	
	GG3. Participation	0.80	-0.20	1.00																
	GG4. Rule of law	0.80	0.00	0.40	1.00															
	GG5. Holistic management	0.40	0.40	0.80	0.20	1.00														
Environment integrity	EI1. Atmosphere	-0.80	0.00	-0.40	-1.00**	-0.20	1.00						+0.05							+0.13
	EI2. Water	-0.80	0.80	-0.40	-0.60	0.20	0.60	1.00												
	EI3. Land	-0.80	0.00	-0.40	-1.00**	-0.20	1.00**	0.60	1.00											
	EI4. Biodiversity	0.00	0.20	0.60	-0.40	0.80	0.40	0.40	0.40	1.00										
	EI5. Materials and energy	-1.00**	0.40	-0.80	-0.80	-0.40	0.80	0.80	0.80	0.00	1.00									
	EI6. Animal welfare	0.20	0.80	0.40	0.40	0.80	-0.40	0.40	-0.40	0.40	-0.20	1.00								
Economic resilience	ER1. Investment	0.20	0.80	0.40	0.40	0.80	-0.40	0.40	-0.40	0.40	-0.20	1.00**	1.00							-0.01
	ER2. Vulnerability	-0.20	0.80	-0.40	0.40	0.00	-0.40	0.40	-0.40	-0.40	0.20	0.60	0.60	1.00						
	ER3. Local economy	-0.20	0.80	-0.40	0.40	0.00	-0.40	0.40	-0.40	-0.40	0.20	0.60	0.60	1.00**	1.00					
Social well-being	SW1. Decent Livelihood	0.80	0.00	0.40	1.00**	0.20	1.00**	-0.60	-1.00**	-0.40	-0.80	0.40	0.40	0.40	0.40	1.00				
	SW2. Fair trading practices	0.63	0.11	0.95	0.32	0.95	-0.32	-0.11	-0.32	0.74	-0.63	0.63	0.63	-0.21	-0.21	0.32	1.00			
	SW3. Labor rights	-1.00**	0.40	-0.80	-0.80	-0.40	0.80	0.80	0.80	0.00	1.00**	-0.20	-0.20	0.20	0.20	-0.80	-0.63	1.00		
	SW4. Equity	-0.80	0.20	-1.00**	-0.40	-0.80	0.40	0.40	0.40	-0.60	0.80	-0.40	-0.40	0.40	0.40	-0.40	-0.95	0.80	1.00	
	SW5. Human safety health	-1.00**	0.40	-0.80	-0.80	-0.40	0.80	0.80	0.80	0.00	1.00**	-0.20	-0.20	0.20	0.20	-0.80	-0.63	1.00**	0.80	1.00
	SW6. Cultural diversity	0.40	-1.00**	0.20	0.00	-0.40	0.00	-0.80	0.00	-0.20	-0.40	-0.80	-0.80	-0.80	-0.80	0.00	-0.11	-0.40	-0.20	-0.40

**Correlation is significant at 0.01 level. Trade-offs: results in red; and Synergies: results in bold.



Indigenous people adopt technologies for labor in traditional production systems (Sellers and Bilsborrow, 2020); (2) Oil activity (Rivera-Parra et al., 2020) has intensified, and this potentially represents a major transformation of their social, economic and environmental context (Codato et al., 2019), and to compound these changes, oil companies may offer access to employment, cash payments or health, and transportation services to indigenous communities in order to facilitate their work and/or comply with legal or internal “corporate social responsibility” mandates (O’Faircheallaigh, 2013; Billo, 2015); (3) The agricultural and extractive (hunting/fishing) frontier (Mena et al., 2017; Heredia-R and Hernández, 2019; Houssou et al., 2019) has advanced due to unsustainable agricultural activities (Heredia-R et al., 2020a,b,c), caused by a dependence on salaried jobs in the oil sector, according to the literature on the Dutch disease (Bozigar et al., 2016; Arsel et al., 2019; Erdogan et al., 2020), correlated with the majority of the EAR population being impoverished (Lang, 2017; Torres et al., 2017a), due to its externalities (Vasco et al., 2015). In addition, inequality in terms of sustainability in the groups evaluated is evidenced by the existence of new forms of land use and management, a

greater use of land for planting cocoa, African palm species, and pastureland for cattle. These activities are completely linked to the global market, and also imply an increased use of chemicals and fertilizers, given the low quality of Amazonian soils and the quantity of pests. Therefore, modifications are occurring and even more intensely due to the presence of other actors, such as extractive companies and the State (Vasco et al., 2015; Salinas Castro et al., 2020).

Synergies and Trade-Offs Within Sustainability Dimensions

To be sustainable, a system must be robust, sufficiently productive, and use resources efficiently to achieve its equilibrium. However, there are often synergies or trade-offs between the various goals of sustainability and their related objectives toward which sustainability is directed (NAS, 2010).

Greater synergies are observed between good governance dimension and economic resilience, as well as between environmental integrity and social well-being, which emphasizes the importance of good governance in influencing the level of

performance in the other dimensions of sustainability (Schader et al., 2016) demonstrating the importance of the dimensions of sustainability in rural contexts and their influence on the strategic decision-making of indigenous populations and migrant settlers for the management of traditional production systems (Coteur et al., 2020). This implies that a specific focus on good governance can improve sustainability performance in traditional production systems through synergistic interactions with other sustainability dimensions. However, several studies show that trade-offs and synergistic relationships are dynamic and can change over time (Haase et al., 2012; Li et al., 2019), and vary across a wide range of conditions (Walker and Salt, 2012). Therefore, interactions that enhance sustainability should be prioritized according to the context and state of traditional production systems, while policies can facilitate the transition to more sustainable production systems.

Policy Implications to Safeguard Traditional Agricultural Systems

It is evident that the differences in terms of agricultural sustainability (Figure 2) between indigenous populations and migrant settlers (Figure 3) are narrowing (Rubenstein, 2001; Sellers and Bilsborrow, 2020). The existence of identified synergies and trade-offs (Table 8) provide policymakers with specific information to design sustainable development policies and rescue traditional agricultural systems in the DLZ.

Considering the global importance of the YBR and the Amazon basin in terms of conserving its high diversity, the findings of this research contribute to the management model developed for the communities that make up the DLZ in 2015. They were carried out by several national and local public organizations (MAGAP, 2016), who aimed to (a) strengthen governance in the DLZ; (b) achieve a balance between environmental conservation and living conditions; and (c) salvage cultural dynamics. The management model is implemented through a special regime that guarantees sustainability and minimizes risk factors for indigenous communities and migrant settlers in the DLZ (MAGAP, 2016).

At the national level, the Ecuadorian government has created different territorial management instruments that seek to restore degraded and deforested areas. Traditional agroforestry systems, such as the *chakra*, *aja*, *kinkore*, and agroforestry system, can contribute to the implementation of the Agenda for Productive Transformation in the Amazon (APTA) concerning its objective of bringing about a move toward more sustainable production systems (MAGAP, 2014). In this respect, it should also encourage the rescue of traditional systems that have been in use for millennia by the indigenous groups.

In terms of future research, based on our findings, we recommend studying the relationship between rural household livelihoods (livelihood strategies) (Torres et al., 2018) and forest ecosystems (forest governance) (Torres et al., 2013), as well as investigating biotrade alternatives in the DLZ—for livelihood strategies (Torres et al., 2017b; Boeri et al., 2020), climate change mitigation and the conservation of flora and fauna diversity—as a tool for biological corridors.

CONCLUSIONS

The differences in terms of sustainability between the traditional production systems evaluated are influenced by the socio-demographic conditions and characteristics, access routes, and extractive activities in the Amazon basin. This confirms the theory that differences between indigenous people and mixed-race settlers are narrowing, since there is greater similarity between the social, environmental, economic, and governing dynamics between the Shuar and migrant settler populations, while the sustainability weightings are farther apart between the Waorani and Kichwa populations.

Synergies exist between the dimensions of good governance and economic resilience among all groups assessed, following the finding of Schader et al. (2016), who emphasized the importance of good governance in influencing performance levels for other dimensions of sustainability. This implies that a specific focus on the good governance dimension can improve the sustainability performance of traditional production systems through its synergistic interactions with the other dimensions of sustainability. Thus, decision-makers at the local level and future research projects can intervene in the two trade-offs found between good governance and environment integrity, as well as good governance and social well-being, to contribute toward United Nations Sustainable Development Goals. The aim would be to optimize resources and time in the execution of plans, programs, and projects with the populations of the Amazon basin and at the same time verify if the same theory by Schader et al. (2016) works with the trade-off found between economic resilience and social well-being.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethics Committee, Universidad Estatal Amazónica. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements. Ethics clearance was also not required at Brock University due to use of secondary data (April 2021).

AUTHOR CONTRIBUTIONS

MH-R and DB performed the fieldwork. MH-R, BT, LP, and LV performed the statistical analyses. MH-R, BT, LV, and CD-A wrote the first draft of the manuscript. All authors contributed to the conception and design of the study, revision of the manuscript, and reading and approval of the submitted version of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fsufs.2021.782633/full#supplementary-material>

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