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Bio-cultural Traits and Cultural Keystone Species, a Combined Approach: an Example of Application About Plants Used for Food and Nutraceutical Purposes in *Aga* Villages in Bali, Indonesia

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Abstract

Wild and semi-wild plants are factual resources for a local community when they satisfy its needs. According to the bio-cultural approach, these plants and associated knowledge help define the cultural identity of each community, and ethnobotanical plants constitute a particular facet of the cultural relationships between people and nature. By referring to the concept of Cultural Keystone Species (CKS), a group of species considered in the same way within a community represents a homogeneous bio-cultural trait. We tested the hypothesis that the CKS model and the related index, the Identified Cultural Importance (ICI) of species, could be useful tools to culturally define and describe groups of species as bio-cultural traits. As a dataset to test this hypothesis we considered the wild and semi-wild plants used for food and nutraceutical purposes in 13 *Aga* villages in Bali. Data were collected through an ethnobotanical study in 2014. A multivariate analysis method based on the Fuzzy Set Theory was used to perform quantitative analyses to find clusters of plants. The Graph Theory was instead applied in order to detect trajectories and similarity gradients in the system of groups of species. The results confirmed that groups of species can be considered as bio-cultural traits, spreading within a cultural area in different ways and conveying information about their relationship with the native culture. The ICI index and CKS concept helped us to interpret the bio-cultural traits in terms of their cultural salience, considering them as general descriptors of the bio-cultural system of a community according to bio-cultural diversity and Traditional Ecological Knowledge. In the case of the Bali *Aga* villages, the partition of species showed 11 groups, and several species resulted of relevant cultural importance. Among them, *Arenga pinnata* (Wurmb) Merr. can be considered a CKS.

Keywords Bio-cultural diversity · Cultural salience of plants · Ethnobotany · Fuzzy sets · Traditional ecological knowledge

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Introduction

A cultural trait is a unit of transmission of beliefs, values, traditions, symbols and meanings that are passed from one generation to another within a specific group of people (O'Brien *et al*. 2010; Panebianco and Serrelli 2016). Culture traits identify and coalesce a community because traits express the cohesiveness of the group (Panebianco and Serrelli 2016). Although often complex, cultural traits, or units, should be clearly identifiable or measurable on a discontinuous or continuous scale to be useful for an analysis (Cavalli-Sforza and Feldman 1981). In the fields of cultural anthropology, archaeology and, later, human geography and ecology, cultural traits have been used as basic analytical units to define salient cultural elements, identify homogeneous cultural characteristics and quantity cultural transmission (Lyman and O'Brien 2003; O'Brien *et al*. 2010). The inextricable links between cultural and biological diversity are at the core of the bio-cultural approach (Maffi 2005). The main idea behind this approach is to

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use a single and holistic methodology to deal with the complexity of linguistic, ethnographic, social and environmental systems (Maffi 2007). So, culture, languages, societies and ecosystems are different key aspects of a single system, often identified as "social-ecological system" (Collins *et al.* 2011). Traditional Ecological Knowledge (TEK) (Inglis 1993), linguistic diversity (Harmon 1996), and bio-cultural diversity (Maffi 2001) emerged as key concepts to describe some of the aspects of these inextricable links between cultural and biological diversity. Nowadays, the bio-cultural approach is acquiring a pivotal importance in the conservation of these diversities (Maffi and Woodley 2010; Gavin *et al.* 2015), in the analysis of cultural and biological erosion (Rapport and Maffi 2010), and the study of socio-ecological systems and Traditional Ecological Knowledge (Parrotta and Trosper 2011; Pieroni and Quave 2014; Berkes and Ross 2016). As regards wild and semi-wild plants, they represent material resources for a local community in numerous ways (Alcorn 1981). After a general investigation of the ethnobotanical knowledge of the *Aga* villages of Bali (Sujawo and Caneva 2015; Sujarwo *et al.* 2015; Sujarwo *et al.* 2016a), we describe different clusters of plants on the basis of their occurrence in the local communities of the same cultural area (Caneva *et al.* 2017). We also identified "core and satellite groups," where core groups identified the shared knowledge, about plants, in a wide area, otherwise satellite groups defined the specific knowledge of isolated communities. This heterogeneity of TEK could be related to several causes related to biological and cultural phenomena.

As regards the cultural meanings of plant species, Garibaldi and Turner (2004) proposed the term Cultural Keystone Species (CKS), as a metaphor of the well-known concept of keystone species in ecology (Paine 1966). According to the concept suggested by Garibaldi and Turner (2004), published roughly at the same time of a similar proposal by Cristancho and Vining (2004), CKS were identified as culturally salient species that shape the cultural identity of a group of people in a major and irreplaceable way. These species might have a role in the diet, material, and/or spiritual practices and are essential to the cultural identity and integrity of a community. Moreover, Garibaldi and Turner (2004) also introduced a quantification of this concept through an index, Identified Cultural Importance (ICI). This index is based on seven parameters, pertaining particular facets of their cultural influence, where CKSs score the highest values.

Even though quantitative assessments of bio-cultural diversity were suggested (Harmon and Loh 2004; Loh and Harmon 2005), its numerical evaluation using the concept of bio-cultural trait (defined as a cultural trait related to bio-cultural diversity) has not formally been applied to TEK yet. We used an approach based on the Fuzzy Set Theory (Zadeh 1965) since it allows to deal with the complexity of TEK (Berkes 2008). As such, the main goal of this study is to use groups of species as bio-cultural traits, defining them via the Fuzzy Set Theory and to combine the concepts of bio-cultural traits and cultural keystone species. The ethnobotanical data from the *Aga* ethnicity in Bali were used to test this combined approach in order to describe its bio-cultural system.

Methods

Study Area

The study was conducted on the island of Bali, located at the westernmost end of the Lesser Sunda Islands (Indonesia), between Java (to the west) and Lombok (to the east) (8°39'S115°13′E). The island has a surface area of 5577 km^2; about 18.2% of its area is occupied by forests, of which 7.8% represents primary forests, 10.1% secondary forests and 0.3% plantation forests. There are two active volcanoes, Mt. Agung and Mt. Batur on the island; the typical soils include alluvial soils, andosol, latosol and regosol (BPS 2017).

In general, the island has a sub-humid tropical climate. The average annual temperature ranges from 23 to 33 °C, with wide variations according to the altitude (the study area is between 242 and 1187 m above sea level). The average annual rainfall is between 1182 and 3696 mm. The rainy season occurs between November and April, and the dry season between May and October (BPS 2017).

In addition to biological diversity (Girmansyah *et al.* 2013), Bali is rich in cultural values and traditions. The island still hosts several *Aga* (indigenous) villages, inhabited by families whose ancestors have lived in Bali for many generations (Fig. 1). The settlements date back from the 11th to fourteenth century (Pringle 2004) and are typically composed of 2000 to 5000 inhabitants (Sujarwo *et al.* 2014). Building styles and social customs reflect traditional Balinese culture (Sujarwo and Keim 2017). People living in these villages generally lead a traditional lifestyle and have access to forests or natural areas (Sujarwo *et al.* 2015) although many of these areas have been significantly modified (i.e., by deforestation).

We selected for our study 13 *Aga* villages, 45–80 km from Denpasar, the capital of Bali. These villages are mostly located at higher altitudes in the north and east parts of the island, where the tourist pressure is lower (Sujarwo and Caneva 2016). Geographically, these villages belong to the districts of Buleleng, Bangli, Tabanan and Karangasem.

Ethnobotanical Evidence in *Aga* Ethnicity

Bali's *Aga* ethnic group identifies strongly with Hindu religious customs and traditions. In the past, their economy was based on wild natural resources, while nowadays is based on agriculture. They are considered as the indigenous Balinese people, since they were already inhabiting the island long

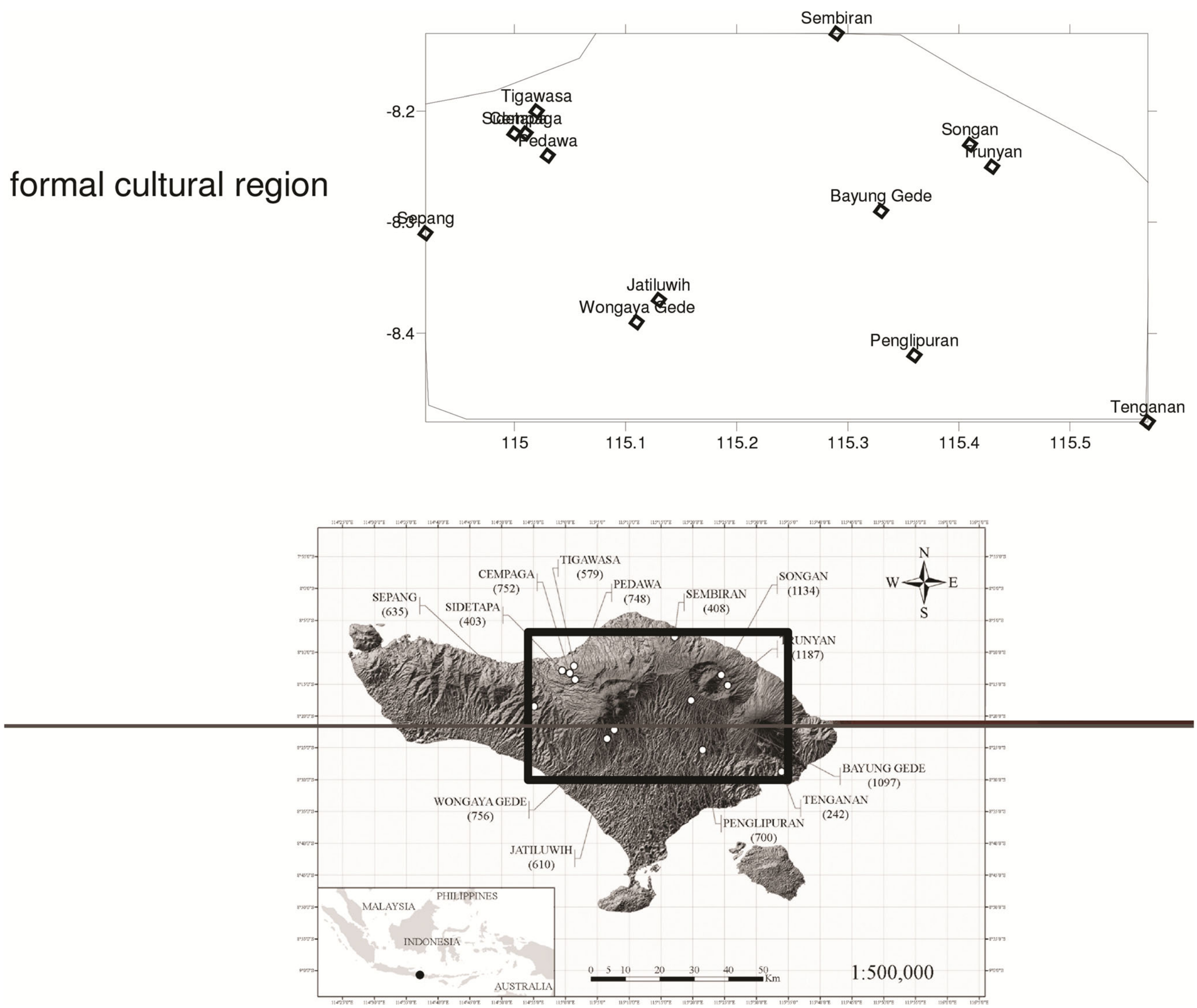

Fig. 1 Formal cultural region of the *Aga* ethnicity in Bali

before the arrival of the Later Bali people that are known as Bali Majapahit (Sujarwo *et al*. 2016b).

The island of Bali continues to be rich in Traditional Ecological Knowledge (TEK) as confirmed by a general inventory on traditional plant usages (Astuti *et al*. 2000), by detailed investigations on medicinal, aromatic, and cosmetic plants (Leurs 2010), and studies on wild and semi-wild edible plants (Sujarwo *et al*. 2016a). Bali's traditional foods and nutraceutical culture includes a wide variety of plants that are cultivated, gathered in forests or grown in home gardens that have a long tradition here (Sujawo and Caneva 2015; Sujarwo *et al*. 2015; Sujarwo *et al*. 2016a).

Data Collection

Following Alexiades and Sheldon (1996), we conducted both key informant interviews and semi-structured interviews. Informants were identified using the snowball method (Bernard 2002) because it was the only possible option for our surveys and it is also commonly adopted in similar studies. By the snowball sampling, we selected key informants based on the information obtained from village leaders, and then one informant was randomly selected in each village (we selected at least three informants per village, generally four).

We interviewed 50 respondents, with ages spanning from 14 to 76 years. The gender of informants was not equally represented (45 males and only 5 females), because females were less available for an interview. This is due to social attitudes that reflect the predominant role of men in Bali's traditional culture, especially in rural areas (Sujarwo *et al.* 2014). Interviews were conducted in Balinese and Indonesian to ease the communication.

Informants were asked to provide, by hearth, a list of traditional food and nutraceutical plants consumed, and grown in their village. The interviewees were asked questions related to their ethnobotanical knowledge of these plants (What is the plant name? Which parts are used? How are they used?). Respondents were made aware of the aims of this study and prior informed consent was requested verbally (Rosenthal 2006). Interviews were conducted following international codes of ethics (ISE 2006).

Plant specimens were identified in the field by the first author. Representative specimens of the ethnobotanical flora were collected, pressed and dried in the field (Martin 2003), and the unidentified species were analysed at the Herbarium Hortus Botanicus Baliense (THBB) in the Bali Botanic Garden, where the collected specimens were deposited. The scientific nomenclature used in this study was updated using relevant databases (The Plantlist 2018).

Data Collection About the Cultural Salience of Species

Several Indexes have been proposed to measure the cultural value of a species (e.g., CFSI, UV, RFC, RI, CVs, and ICF). In our previous study about the Bali's ethnoflora, none of these indices, alone, was appropriate to describe the cultural value of plants, and only their combined use resulted adequate (Sujarwo and Caneva 2016). Then, in this study we adopted the ICI index, proposed by Garibaldi and Turner (2004), which considers seven parameters to quantify the cultural importance of a species (namely: intensity of use; multiplicity of uses; specific name in the local language; use in narrative, ceremony and other collective expression of the local community; ubiquity in the collective cultural consciousness; uniqueness; trade item). Five weights were utilised to describe each parameter on the basis of its level of occurrence in the community: very high (5), high (4), moderate (3), low (2), very low or null (1). This scale was slightly modified respect to Garibaldi and Turner (2004) since we grouped the very low and null weight, considering that such weights resulted very similar. Garibaldi and Turner (2004) also suggested the possibility to modify the scale in order to better describe the available data.

Weights were assigned following the criteria suggested by Garibaldi (2009), in a defined chronological order: 1) Informal conversations with community members about species' meanings; 2) Assignment of weights by expert judgment based on information gathered in a preliminary study involving a small group of the elderly of a community and in the literature; 3) Verification of weights given in the preliminary study.

Quantitative Analyses

Quantitative analyses were performed in order to obtain: 1) a description of a gradient of the cultural importance of species using Fuzzy Set Theory (Zadeh 1965, 1973); 2) the identification of the most similar groups of species through fuzzy clustering; 3) a definition of the meaning of the obtained groups of species and an analysis of their relationships using Graph Theory (West 2001). These analyses were based on theoretical approaches useful to explore the behaviour of complex systems in an effective and robust way.

Fuzzy Set Theory (FST) is an extension of the classical Set Theory, in which an element belongs to a set according to a membership function ranging continuously between 0 and 1, and not only assuming 0 and 1 as binary values. Graph Theory (GT) allows the description, the exploration and the graphical representation of graphs, which are mathematical structures used to model pair-wise relations between objects.

The matrix **F** of the frequencies of species used for food and nutraceutical purposes in the analysed *Aga* villages (113 species × 13 villages) and the matrix **I** of the species described by the weights assigned to the seven parameters of the ICI index (113 species × 7 parameters) were the data sets analysed.

Gradient of the Cultural Importance of Species Using Fuzzy Set Theory

Based on the matrix **I**, the ICI index for the species was calculated as the sum of weights, following the method described in Garibaldi and Turner (2004). The obtained score, sc, was transformed in a fuzzy score, fsc, according to the formula: fsc = (sc - scmin)/(scmax - scmin), where scmax and scmin are respectively the maximum and the minimum possible values of sc (i.e., 35 and 7). According to this transformation (Klir and Yuan 1995), the obtained result, fsc, is the degree of belonging, or membership function, of single species to the set characterised by the feature of the ICI index, expressed as a fuzzy set of cultural importance in order to define a continuous gradient of the "keystone-ness" of a species.

Identification of the Most Similar Groups of Species by Fuzzy Clustering

Based on the matrix **F**, fuzzy clustering was used to define the main groups of species. The classification method, based on Fuzzy Set Theory (Zadeh 1965), has the advantage of representing clusters in a non-Boolean way. Thereby, it is possible to describe a cluster according to a membership function, from 0 to 1, assigned to every object. The closest values to 1 are typical of the cluster; the closest values to 0 do not belong to the cluster at all; and the transition elements show intermediate values. Fuzzy-c-mean clustering (Bezdek 1981) was performed (with fuzziness coefficient m = 1.8) on the similarity matrix between species (De Caceres *et al.* 2007) obtained by applying the similarity ratio function (Podani 2000) to matrix **F**. The choice of the optimal fuzzy partition, **P**, was based on a normalized Dunn coefficient (Dunn 1973). The resulting matrix **P** is a partition matrix describing species according to a fuzzy membership function to each fuzzy cluster obtained from the optimal partition. A fuzzy cluster is interpreted as a fuzzy group of species.

Starting from the fuzzy partition **P**, the degree of belonging of villages to groups of species was calculated as the weighted mean of degrees of belonging of a species mentioned in a village, weighted by their frequencies of citation. To obtain a normal fuzzy set (i.e., a fuzzy set with at least one value close to 1), the degrees of belonging of villages to a group were transformed according to the ratio between the single value previously obtained and the maximum value reached in such group (Klir and Wierman 1999).

Definition of the Meaning of the Obtained Groups of Species and Analysis of Their Relationships by Graph Theory

The fuzzy partition matrix **P** was used to obtain a Boolean partition **R** in which the species belong to groups if and only if they show a membership greater than a suitable threshold to describe the typical elements (i.e., the representative species) of each group. In this way, the meaning of a group is clarified by the list of representative species associated to such group.

The similarity matrix between groups was obtained using a similarly ratio function on the basis of the fuzzy partition **P**, and it was used to perform a Minimum Spanning Tree (MST), (Gower and Ross 1969) between groups of species. MST graphically describes the path of the maximal similarity between objects to obtain a connected graph between groups of species that identifies the edges between pairs of elements only if their pair-wise relationship reaches the maximum value for such elements. So, it is always possible to find a sequence of groups of species that connects two given groups. Such sequence explains the structure of the similarity function matrix in order to detect the path of the maximum overlap between groups (Feoli and Lagonegro 1979; Feoli 1980) and their reciprocal relationships. We used the Gingko (De Caceres *et al.* 2007) and Syntax (Podani 1994) programs.

Results

Our results are described below and they were based on the data about the occurrences of the set of wild plants used for food and nutraceutical purposes in 13 *Aga* villages of Bali (matrix **F**), already used by Caneva *et al.* (2017) and reported in the supplementary materials as Table SI.

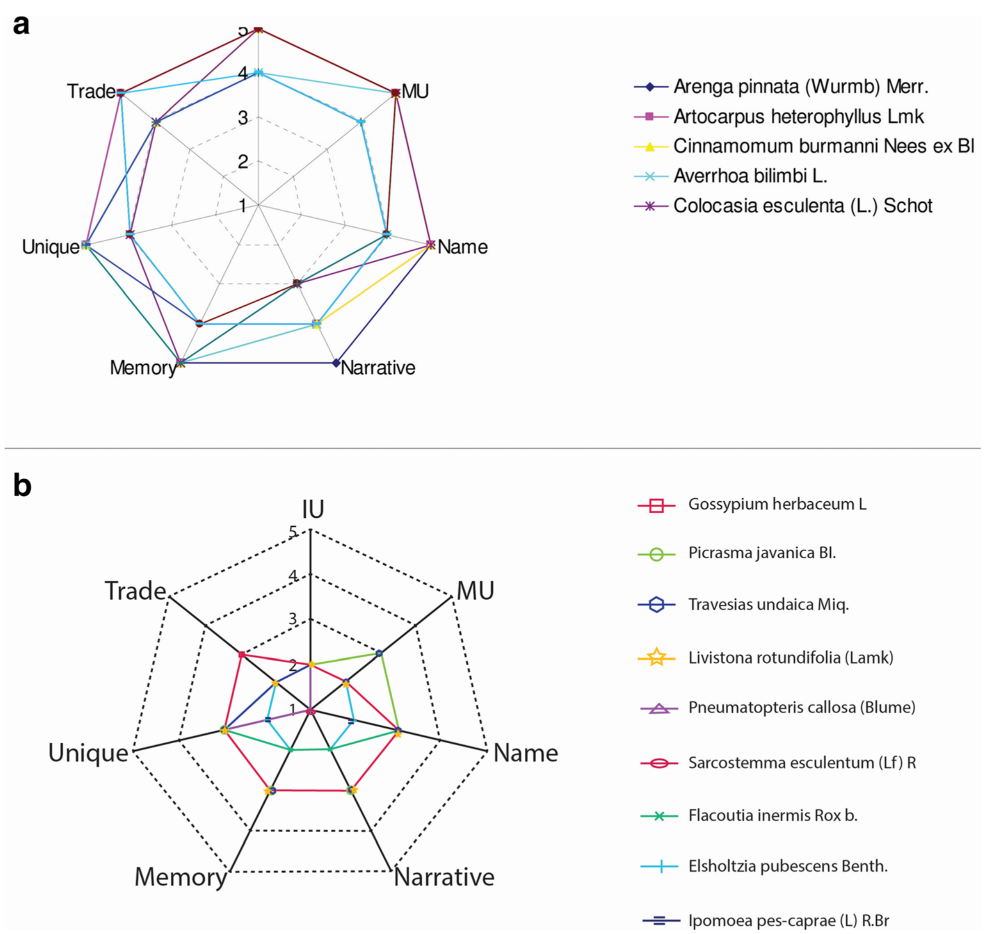

Fig. 2 Radar diagrams based on the seven parameters of ICI index. Culturally Prominent Species (**a**) and Culturally Unimportant Species (**b**). Radar diagrams summarise the behaviour of seven parameters of the ICI index, showing them at the same time. In the figure, the area related to a single species is proportional to its cultural salience defined by the ICI index. When there are high values of parameters, the occupied area is large, and its cultural salience is high

CKS and Related ICI Index of the Set of Species Used for Food and Nutraceutical Purposes

The main culturally salient species following the ICI index (based on the matrix **I**) are shown in Fig. 2a. The complete list is reported in the supplementary materials as Table SII. The evaluation of the fuzzy score of the ICI index, which indicates the degree of belonging of a species to a keystone species set, allowed the identification of two subsets of species: Culturally Prominent Species (CPS) (with a degree of belonging > .85) and Culturally Unimportant Species (CUS), weakly linked to the keystone species set (with a degree of belonging < .50). Five CPSs and nine CUSs were found. Radar diagrams of the CPS (Fig. 2a) and CUS (Fig. 2b) subsets show the contributions of the seven parameters of the ICI index. It is easy to recognise that CPSs reached the maximum values very often, while CUSs always showed low values, as expected.

Among the CPSs, the most important were *Arenga pinnata* (Wurmb) Merr., *Artocarpus heterophyllus* Lamk, *Cinnamomum burmanni* Nees ex Bl, *Averrhoa bilimbi* L. and *Colocasia esculenta* (L.) Schot. Following the definition provided in Garibaldi and Turner (2004), *A. pinnata* can be considered a CKS because it showed the maximal fuzzy score (Fig. 3).

The CUSs include *Gossypium herbaceum* L., *Picrasma javanica* Bl., *Travesia sundaica* Miq., *Livistona rotundifolia* (Lamk.), *Pneumatopteris callosa* (Blume), *Sarcostemma esculentum* (L.f) R, *Flacourtia inermis* Roxb., *Elsholtzia pubescens* Benth. and *Ipomoea pes-caprae* (L.) R.Br. The other species showed an intermediate cultural importance.

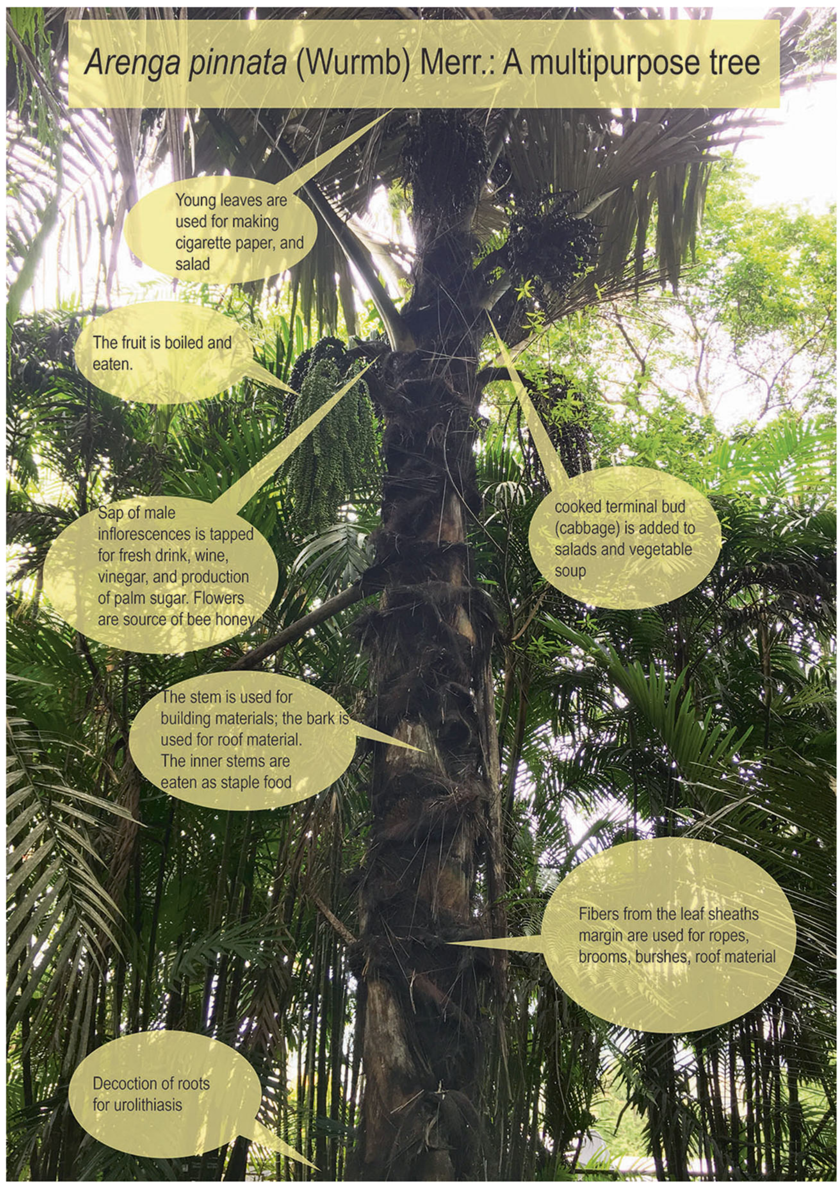

Fig. 3 *Arenga pinnata*, a Cultural Keystone Species as a multipurpose tree

Table 1 Representative species in groups. Representative species are the most important species to define biological information conveyed by the groups

Species	Groups of species										
	G-1	G-2	G-3	G-4	G-5	G-6	G-7	G-8	G-9	G-10	G-11
Acanthus ebracteatus									*		
Alocasia macrorrhiza								*			
Alstonia scholaris	*										
Amorphophallus campanulatus	*										
Anamirta cocculus											*
Andrographis paniculata	*										
Annona muricata										*	
Annona squamosa			*								
Antidesma bunius	*										
Areca cathecu									*		
Arenga pinnata	*										
Artocarpus heterophyllus	*										
Averrhoa bilimbi	*										
Azadirachta indica			*								
Bischofia javanica		*									
Blechnum orientale									*		
Borassus flabelifer			*								
Calamus reinwardtii										*	
Chrysophyllum cainito									*		
Cinnamomum burmanni	*										
Citrus aurantiifolia								*			
Citrus maxima				*							
Coccinia grandis					*						
Coleus parviflorus										*	
Colocasia esculenta	*										
Colocasia gigantea						*					
Costus speciosus						*					
Cucurbita moschata	*										
Cyclea barbata									*		
Dendrocnide stimulans									*		
Dioscorea alata	*										
Dioscorea hispida	*										
Diplazium esculentum	*										
Diplazium proliferum									*		
Elaeocarpus serratus										*	
Elsholtzia pubescens		*									
Erythrina hypaphorus						*					
Euchresta horsfieldii									*		
Ficus drupacea								*			
Ficus fistulosa				*							
Flacourtia inermis		*									
Garcinia dulcis			*								
Garcinia parvifolia					*						
Gardenia jasminoides							*				
Graptophyllum pictum								*			
Gynura aurantiaca			*								
Heliconia wagneriana					*						

Table 1 (continued)

Species	Groups of species										
	G-1	G-2	G-3	G-4	G-5	G-6	G-7	G-8	G-9	G-10	G-11
Hibiscus rosa-sinensis	*										
Hydrocotyle sibthorpioides			*								
Ipomoea pes-caprae			*								
Livistona rotundifolia							*				
Lygodium circinnatum							*				
Maranta arundinacea					*						
Momordica charantia										*	
Moringa oleifera	*										
Nicolaia speciosa								*			
Ocimum basilicum						*					
Orthosiphon aristatus	*										
Pangium edule	*										
Picrasma javanica											*
Piper betle	*										
Piper cubeba				*							
Pneumatopteris callosa									*		
Podocarpus imbricatus									*		
Psidium guajava	*										
Pueraria phaseoloides		*									
Rubus alpestris			*								
Rubus calycinus			*								
Rubus chrysophyllus			*								
Rubus fraxinifolius			*								
Rubus lineatus			*								
Rubus rosaefolius			*								
Sarcostemma esculentum					*						
Sauropus androgynus						*					
Schefflera aromatica									*		
Scheichera oleosa								*			
Sida rhombifolia						*					
Solanum americanum		*									
Spondias pinnata				*							
Strobilanthes crispa										*	
Syzygium samarangense								*			
Tamarindus indica			*								
Travesia sundaica							*				
Vernonia cinerea						*					
Vitex trifolia								*			
Zingiber montanum	*										
Zingiber zerumbet							*				

Groups of Species in the *Aga* Ethnicity

The best partition of species (matrix **P**) gave 11 groups. The representative species for each group were selected on the basis of their degrees of belonging, equal or greater than 0.8 (matrix **R**): the most connected taxonomical elements to the groups allowed us to characterise the representative species. Representative species of each groups are reported in Table 1. The number of representative species ranged from 2 (group 11) to 20 (group 1), showing a high variability. Twenty-seven species were not assigned to any groups because they did not reach the threshold (0.8).

The similarity pattern between groups was obtained using a Minimum Spanning Tree (MST) (Fig. 4). The longest path in MST identified the best trajectory to explain the intersection overlaps between groups of species on the basis of their frequencies among villages. Even if it is possible to find other sequences with the same number of elements, the sequence 1–3–5-4-11-2 was selected because it was the most connected one (i.e., the sum of similarity functions between elements along this trajectory reaches the maximum value). The resulting sequence described the best relationships between groups in a synthetic way, detecting the most important similarity gradient that can explain the variability of traditional knowledge.

The average membership of villages to groups (Fig. 5 and Table SIII in supplementary materials) detected only a group (group 1) spreading in the whole area of *Aga* ethnicity (with a degree of belonging greater than 0.5 in every village). Other groups showed a local relationship with one or few villages.

Bio-cultural Meaning of Groups Using the CKS Concept and the ICI Index

Group 1 included four CPSs, among which there was also a CKS (Table 1), and the fifth one belonged to group 3. CUSs belonged to group 2, 3, 5, 7, 9, and 11. The cultural influence of the group elements widely differs between groups on the basis of both the most prominent species and the culturally trivial species. The average values of the seven parameters of the ICI index and the fuzzy score are reported in Table 2. Group 1 has the maximal cultural influence according to the highest fuzzy score and every feature of the ICI index (Table 2 and Fig. 6).

The network based on the similarity relationships between groups identified a maximal resemblance path, as already said, and it was described using the fuzzy scores and the ICI index in order to detect trends of cultural salience along the trajectory. The cultural importance, considering the sequence previously detected, showed a decreasing pattern according to the fuzzy scores (Table 2) and the parameters of the ICI index (Fig. 7). Following the main trajectory of the traditional knowledge system of the species used for food and nutraceutical purposes, the reduction of cultural salience occurred starting from species in group 1 (well represented in the dataset and mostly linked to the Tigawasa, Sepang, Cempaga, Tenganan and Sidetapa villages), to species in group 11 (only characterising the Sembiran village).

Discussion

CKS Concept and Related Index

Certain authors expressed some criticism about the CKS concept due to the potential reductionist approach when using single species (Platten and Henfrey 2009), or due to its attribution through an expert-based approach (Sousa 2014; da Silva *et al*. 2016). Our data, however, confirmed its usefulness to numerically express the cultural importance of species belonging to an ethno-flora or its subset. The ICI index confirmed to be a useful and synthetic way to manage and integrate information about culturally salient elements. The application of the ICI index for the whole set of species was useful not only to compile a preliminary list where to find CKSs (Garibaldi 2009), but also allowed us to identify some species on the basis of their bio-cultural importance. Through such index, the "bio-cultural signature" of a species, i.e., the set of cultural elements related to the species, can be calculated summarising the weights of the seven parameters of the index and it can be easily showed by a diagram.

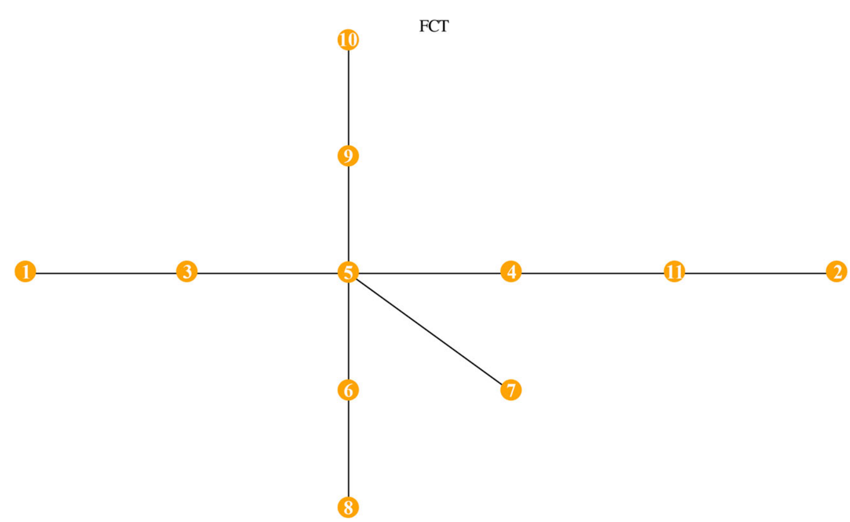

Fig. 4 Minimum Spanning Tree (MST) between 11 groups of species. MST is a graph that links groups according to their maximal similarity. It is a synthetic way to show the network of similarities in the dataset and to visualise only the most important relationships

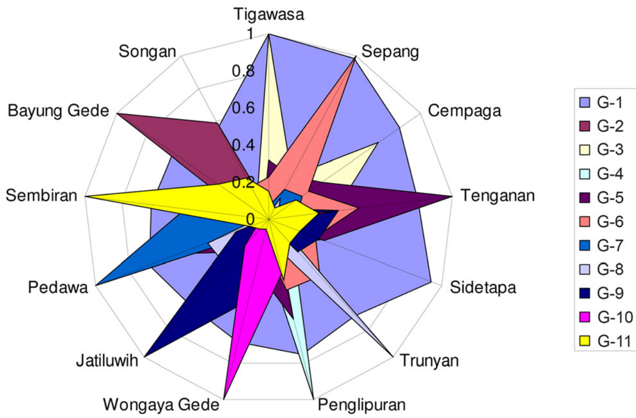

Fig. 5 The average membership of villages to groups of species. Memberships quantify the link between a village and a group of species

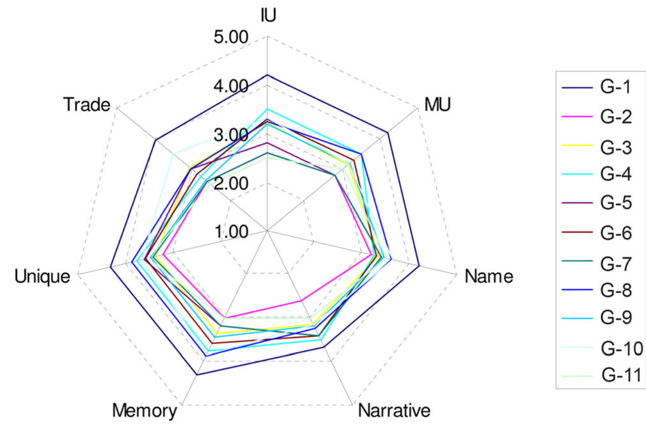

Fig. 6 Radar diagrams of groups of species based on the average of seven parameters of the ICI index for the representative species in each group. The importance of a group is directly related to its representativeness in terms of the cultural influence and depends on the area showed in the figure. If the group includes many culturally important species, average parameters will be higher, and the related area will be larger

The use of only a subset of the ethno-flora of the *Aga* ethnicity to identify its bio-cultural traits resulted a not highly limiting factor, since several culturally prominent species were found and one of these can be considered a CKS. It could mean that a single subset of species, used for a specific purpose, can still convey some information about the bio-cultural system.

Groups of Species as Bio-cultural Traits

This study showed that groups of species, which have a similar distribution pattern in the Bali *Aga* ethnicity, can be considered as bio-cultural traits. TEK fits with the concept of cultural traits representing a cumulative body of knowledge and beliefs, handed down through generations by cultural transmission, about the relationship of living beings, including humans, with one another and with their environment (Berkes 1993). The different species can be spread within an area in different ways, along with the information about their use within, or relationship with, the native culture. Since the importance of a bio-cultural trait is directly related to its representativeness in terms of cultural influence, the use of the ICI index for a bio-cultural trait allowed us to describe the cultural influence of each group of species. This description can be useful to analyse the relationships between different bio-cultural traits and the gradient of variation of their cultural influence.

Finally, the usefulness of such approach is related to the fact that the similarities among bio-cultural traits identify the main trajectory of groups of species in the bio-cultural system. The network based on the edges between pair of elements reveals the best path to link bio-cultural traits according to their similar distribution and frequency in local communities.

Table 2 The average values of the seven parameters of the ICI index, the ICI index and the fuzzy scores for groups of species

Groups of species	Parameters of ICI index							Score	Fuzzy score
	IU	MU	Name	Narrative	Memory	Unique	Trade		
G-1	4.20	4.20	4.20	3.65	4.30	4.30	3.95	28.80	0.79
G-2	2.60	2.80	3.20	2.60	3.00	3.20	2.60	20.00	0.50
G-3	3.21	4.14	3.36	3.41	3.36	3.36	3.07	22.64	0.59
G-4	3.50	3.50	3.25	3.50	3.75	3.75	2.75	24.00	0.63
G-5	2.80	2.80	3.40	3.40	3.20	3.60	3.00	22.20	0.57
G-6	3.29	3.29	3.29	3.43	3.57	3.57	2.86	23.29	0.61
G-7	2.60	2.80	3.40	3.40	3.20	3.40	2.60	21.40	0.55
G-8	3.25	3.50	3.63	3.25	3.88	3.88	3.00	24.38	0.65
G-9	3.18	3.18	3.45	3.18	3.45	3.45	2.64	22.55	0.58
G-10	3.33	3.17	3.67	3.17	3.83	3.67	3.50	24.33	0.64
G-11	2.50	3.00	3.50	3.00	3.00	3.50	2.50	21.00	0.53

Abbreviations. *CT* Cultural Traits, *ICI* Identified Cultural Importance, *IU* Intensity of Use, *MU* Multiplicity of Use

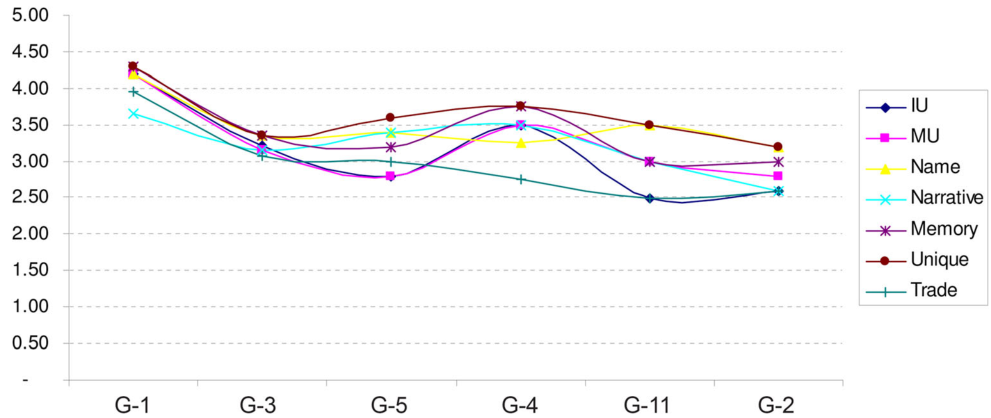

Fig. 7 The behaviour of the seven parameters of the ICI index along the longest trajectory in MST. The main trajectory between groups is detected in Fig. 4, see results

The identified pattern suggests explanations about the structure of TEK in a cultural area that can be useful to detect areas where TEK is homogenous, zones of maximal bio-cultural diversity and possible bio-cultural refugia (Barthel *et al*. 2013).

The Application of the Fuzzy Set Theory

Fuzzy logic and the cumulative score expressed by the Fuzzy Set Theory resulted to be a useful tool to investigate the indigenous knowledge of nature, to understand, or provide insights, on how local cultural systems organise a complex matter as TEK (Berkes 2008; Berkes and Berkes 2009). The interpretation of the ICI index via the Fuzzy Set Theory (FST) and radar diagrams can also facilitate the description of the relationships among the parameters of the ICI index.

In the context of bio-cultural traits, the description of groups of species by FST seems very suitable since it allows to use a flexible criterion to find their diagnostic elements and to link them to local communities in a continuous scale. Moreover, in this way, a complex element, such as a group of species, can be expressed in a simple way, and FTS is useful to manage and integrate information. The number of groups and their arrangements are dependent on the clustering approach used through the fuzzy clustering algorithm (Podani 2000), and that can explain the differences with our previous elaboration (Caneva *et al*. 2017).

Bio-cultural Traits and the Bali *Aga* Ethnicity

The results on the cultural importance of the ethnobotanical species fit with the data of the previous work by Sujarwo and Caneva (2016). The bio-cultural importance of a species became easily recognisable in comparison with a previous study (Caneva *et al*. 2017): we found that villages in the *Aga* ethnicity in Bali can be considered as local networks of homogeneous ethnobotanical knowledge (i.e., the same TEK is shared among people), and the pattern of groups of species shows a heterogeneous distribution among villages. Hence, the groups of species may represent cultural units spreading in characteristic ways within an ethnicity, expressing a bio-cultural trait. As the use of species and species groups as environmental indicators has a rich history and tradition in vegetation ecology since the early 1900s (Clements 1928), analogously, in this context, groups of species can be considered as state indicators of bio-cultural systems regarding TEK.

Conclusion

The combined approach of bio-cultural traits and cultural keystone species through a fuzzy method resulted significant in defining the relevance of ethnobotanical data. In fact, groups of useful species, which show a similar distribution pattern in the Bali *Aga* ethnicity, can be considered as bio-cultural traits, spreading within a cultural area in different ways and conveying information about their relationship with the native culture.

The usefulness of such approach is due to the fact that a bio-cultural trait not only identify a cultural element of a given community, but also embodies part of the traditions related to a specific cultural system. Thus, it could be interpreted as a unit of the bio-cultural system of a community related to the bio-cultural diversity and TEK. The ICI index and CKS concept helped us to interpret bio-cultural traits in terms of cultural salience. A description of a community based on bio-cultural traits may be useful to better define issues of cultural erosion and identify bio-cultural refugia. Groups of species as bio-cultural traits seem to be an effective and convincing tool to describe and analyse some inextricable links between cultural and biological diversity.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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