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Quantifying Evolution of Cultural Interactions with Plants: Implications for Managing Diversity for Resilience in Social-Ecological Systems

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ABSTRACT

The discipline of ethnobotany has gathered an abundance of data about the diversity of ecological resource management methodologies, but has yet to do so using standard units of measure such that cross regional comparisons can be made. Both biological diversity and sociocultural diversity are important factors to manage for resilience in social-ecological systems. Sociocultural evolution has strong links to biological evolution. Quantum ethnobotany provides theory and models to measure links between biological diversity and sociocultural diversity for comparisons across regions. Links between biological and cultural diversity are dynamic relationships cycling between processes of co-evolution and co-extinction. The ability to measure links between biological and sociocultural diversity is provided by quantum ethnobotany. This will be useful for resource managers, policy makers, stakeholders and cultural practitioners to manage both biological and cultural diversity through co-extinction cycles for the purpose of maintaining or increasing resilience in social-ecological systems.

Keywords: co-evolution, co-extinction, ethnobotanical evolution, quantum co-evolution units, quantum ethnobotany, social-ecological system resilience
Abbreviations: QCU, quantum co-evolution unit

INTRODUCTION

Ethnobotany research and ecological resource management

Human interaction with the natural world is a main focus of ethnobotany (Salick *et al*. 2003; Prance *et al*. 2007). Ethnobotanists have long been generating data about the relationships between sociocultural systems and ecosystems from different locations around the world; however, these data have rarely been produced using standardized methods or converted into common units so that true comparisons could be accomplished on regional or global scales. Reasons for avoiding regional or global studies include fundamental cultural differences, floristic and ecological differences, perceptions of cultural authenticity, longevity of plant-cultural interactions, and inabilities to see common threads across cultural experiences with plants. This paper sets out a theoretical model grounded in resilience (Holling 1973), social-ecological systems (Berkes and Folke 1998), and quantum ethnobotany (Bridges and McClatchey 2009). We will use Quantum Co-evolution Units (Winter and McClatchey 2009) to address evolution of fundamental interactions between human cultures (as the basis for sociocultural systems) and plants (as the basis for ecosystems). The purpose of this paper is to better understand the cyclical processes of co-evolution and co-extinction involved in human interaction with the natural world; and how knowledge of these processes can serve modern resource managers, policy makers, stake holders, and cultural practitioners.

Ecosystem resilience and biodiversity

Ecosystem resilience (Hollings 1973; Resilience Alliance 2002) is a measure of a system's relative ability to absorb disturbance without changing to a different state, such as a different biological community with different ecosystem services (Folke *et al*. 2004). Biological diversity has been shown to be a key factor in ecosystem resilience (Holling 1996; Walker *et al*. 2004) because it plays a major role in renewing and reorganizing ecosystems after disturbance, and it helps to maintain desired states of dynamic ecosystem regimes in the face of uncertainty and surprise (Folk *et al*. 2004).

Loss of biodiversity is of serious concern for all ecosystems (i.e., not just rainforests) because it leads to compromises in resilience and productivity of these systems. Furthermore humans (i.e., sociocultural practices) play a central role in either degrading or maintaining high levels of biodiversity, a key factor for system resilience (Berkes *et al*. 1995; Berkes and Folke 1998; Folke *et al*. 1998; Berkes 1999; Davidson-Hunt and Berkes 2003; Colding *et al*. 2003, Folke *et al*. 2003, 2004).

Social-ecological systems and resilience

There are three things that must be understood about social-ecological systems and resilience:

1. Humans are a part of ecosystems and cannot be separated out when developing management practices,
2. Humans can increase biodiversity,
3. Resilience depends on both biological and cultural diversity.

Each of these points will be elaborated on below.

For the purposes of biodiversity conservation there is a need to understand how human-nature interactions affect biodiversity (either positively of negatively). The discipline of ethnobotany, focusing on the juncture of the biological

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and the sociocultural world, can provide research theory and tools with which to guide ecological resource management that will be mutually beneficial to both the ecological and sociocultural sides of these linked systems (see Prance *et al*. 2007). In this paper we emphasize the concept that humans are a part of, not separate from nature (Balèe 2006), supporting the views of Berkes and Folke (1998), and Berkes *et al*. (2003) which hold that social and ecological systems are linked, and that delineations between social and natural systems are arbitrary and artificial. Such human-in-nature systems are referred to as "social-ecological systems" (Berkes and Folke 1998; Berkes *et al*. 2003).

The concept of the importance of biodiversity for system resilience has been applied to social-ecological systems (Berkes and Folke 1998; Berkes *et al*. 2003). Negative affects of sociocultural interactions with ecosystems on biological diversity have been well documented (Hooper *et al*. 2005). However, research has also shown that there are strong links forged between biological and cultural diversity (Gadgil 1987; Moore *et al*. 2002; Maffi 2005). Furthermore, particular traditional ecological management systems actually increase biodiversity (Posey 1985; Lewis 1989; Berkes *et al*. 1995; Folke *et al*. 1998; Berkes *et al*. 2003; Balèe 2006). As more research emerges we may see that instances of sociocultural interactions with ecosystems enhancing biodiversity may not be a rare occurrence. Research focusing on the process by which particular social-ecological management systems *increase* biodiversity is needed. Understanding the initiation and intensification of the relationships between people and plants within social-ecological systems may reveal insights that will help us to manage biodiversity and therefore resilience in these systems.

The idea of the importance of diversity in system resilience can be applied, not only to the biological side of the social-ecological system equation, but to the sociocultural side as well through historical ecology (Balée 2006). As witnessed in the loss of languages on the planet, cultures are going extinct at an alarming rate. Nearly 90% of existing languages are projected to be extinct by the end of this century (Nettle and Romaine 2000). With these extinctions varying world views and practices associated with interactions with the natural world will also be lost. Some of these world views and human-nature interactions undoubtedly are associated with practices that enhance biological diversity. In all areas of the world there exists a need to quantify these interactions for comparative analyses – before they are lost to time – as it is likely they include practices associated with increasing biodiversity. It is of vital importance that as these data are collected the studies are done in such ways as to be compared across space and time with other social-ecological systems.

Sociocultural and biological evolution

Sociocultural evolution (Trigger 1998) has been a contentious issue because some researchers have elected to equate cultural evolution with "cultural progress." Throughout this paper we are equating "evolution" and "cultural evolution" with "cultural change" and NOT with any sort of evaluation of the quality of that change. We are taking the approach that all cultures are equally evolved but on different trajectories.

Human interactions with the natural world are not static, but rather ever evolving. White's law (White 1959), as a cornerstone concept for the evolution of culture, implies that cultural evolution is related to changing intensities of interactions with the environment (as measured by efficiency of capturing and using environmental energy). Research has demonstrated patterned evolutionary relationships between humans and specific ecosystems (Conklin 1963), animals (Rappaport 1984), plants (Harris and Hillman 1989), and nature (i.e., ecosystems) and other complex systems (Boyd and Richerson 1985; Norgaard 1994). There has even been a question of which partner is driving the relationship (Pollan 2001). In all likelihood the evolutionary relationship is co-evolving – with no driver, and the intensity of the relationship can be measured as it changes over time.

Berkes *et al*. (2003) allude to the idea that understanding co-evolutionary processes of social-ecological systems is paramount to human survival on the planet:

"In the present era of the human-dominated biosphere, co-evolution now takes place also at the planetary level and at a much more rapid and unpredictable pace than previously in human history… Facing complex co-evolving systems for sustainability requires the ability to cope with, adapt to, and shape change without losing options for future adaptability." (Berkes *et al*. 2003: 353)

Despite the many calls to the importance of understanding co-evolutionary processes and their trajectories, researchers have yet to scale back from the larger picture to propose distinct units with which this co-evolution/extinction could be quantified. That is, until the emergence of quantum ethnobotany. We will focus on the cyclical, but sometimes also finite, processes of co-evolution and co-extinction in social-ecological systems, and put forth theoretical concepts about quantifying these processes. As will be presented below, the new field of quantum ethnobotany can demonstrate not only this, but also quantify how the links between biological and cultural diversity affect the resilience of social-ecological systems. However, perhaps more importantly quantum ethnobotany can demonstrate how these relationships evolve over time. This can give researchers and resource managers better ideas about the trajectory of evolution and its implications for social-ecological system resilience. Moreover, quantum ethnobotany provides theory and the models to collect and analyze these data in ways that are comparable across space and time. These should serve as simple models that are economical, clear, and able to detect useful generalizations in the midst of the complexity of human behavior (Richerson and Boyd 2005: 95).

This paper proposes the idea that the tools of quantum ethnobotany can be used to better understand how the trajectories of co-evolving relationships between plants and people are affecting diversity on both ecological and sociocultural levels, both of which are major factors in social-ecological system resilience. The ability to do this may enable resource managers, policy makers and others to not only mitigate potential threats to diversity, but also promote management methodologies that enhance diversity. The following discussion will cover the concepts of quantum ethnobotany, evolving interactions between plants and people, and the cyclical processes of co-evolution and co-extinction; then concludes with a set of hypotheses relating to the theories expressed in this paper.

QUANTUM ETHNOBOTANY

In relation to complex systems theory

Quantum ethnobotany is a theoretical field that attempts to identify fundamental measurable units of interaction between people and plants (Bridges and McClatchey 2009). The quantum units are scalable from the most basic (minimum) of interactions (one person and one plant) to very complex relationships (all of humanity and all plants interacting with humanity) (Winter and McClatchey 2009). Quantum ethnobotany specifically addresses hypotheses about potential for survival in environments based on implementation of different botanical and cultural tool kits. Quantum ethnobotany has not yet, however, addressed the origin and continuing change of the interactive relationships that form the basis of the quanta (units of plants and people) being studied. This paper aims to address continuing change (i.e., the cyclical co-evolution and co-extinction processes) within the complexity of social-ecological systems.

Complexity theory has addressed many relevant areas to social-ecological systems such as organizational and management studies (Anderson 1999), the management of ecological systems (Janssen 2002), landscape ecology (Green *et al*. 2006), and anthropology (Hannerz 1992). Nowotny (2005) points out that it is the emergent properties that come about due to an interface of two otherwise separate properties that gives rise to complexity. While complex systems often have synergistic affects whereabouts the whole is greater than the sum of the individual parts, there is value in understanding the most basal components of this complexity. Quantum ethnobotany examines the interface between the biological and the sociocultural, as well as the emergent properties of these interactions at the most fundamental level. Doing so could shed light onto the how the building blocks of social-ecological systems contribute to the complexity of such systems.

Quantum Co-evolution Units and ethnobotanical populations

A Quantum Co-evolution Unit (QCU) is the smallest unit through which interactions between human cultures and plants can be measured (Winter and McClatchey 2009); and, as discussed below, is the unit used to measure ethnobotanical evolution. We assert that the most basic of human interactions with plants are those between a person (as a member of a human culture) and a plant (as a member of a taxon that may be a species, landrace, population, etc.) (**Fig. 1**). A description of any people-plant relationship would be a “QCU profile” (Winter and McClatchey 2009). An example of a QCU profile would be ‘giving red roses on St. Valentine’s Day’ – the particular plant taxa being a specific color of rose (*Rosa* spp.) and an individual’s (or society’s) associated tradition of giving them to loved ones annually on February 14^{th}. All useful plants everywhere in the world and in every society by the nature of being useful are at some time part of a two subunit system and therefore can be described and quantified as QCUs. Each subunit has a set of intrinsic properties that define its set of limits and opportunities for interactions. It is the emergent properties of interactions within QCUs, and the complexity of QCU populations that likely gives rise to much of the complexity of human culture. These concepts are more fully discussed by Winter and McClatchey (2009).

All QCUs and their individual subunits found in a particular social-ecological system can be understood as comprising an “ethnobotanical population” (**Fig. 2**) (Winter and McClatchey 2009). An ability to quantify an ethnobotanical population at various points in time will help us to measure changes in QCU frequency over time (see discussion below). Subpopulations can also be used to analyze select subsets of the larger population (Winter and McClatchey 2009).

Quantum ethnobotany provides the tools for understanding the dynamics and evolution of ethnobotanical populations which can be key in maintaining both biological and cultural diversity – and therefore resilience – in social-ecological systems. This is not only true for understanding

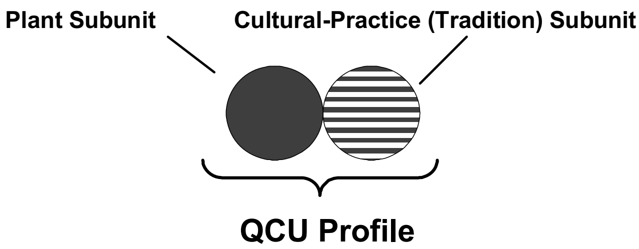

Fig. 1 A quantum co-evolution unit (QCU). A QCU is the unit of measure for ethnobotanical evolution. It is composed of two subunits: the plant subunit, and the cultural-practice (or tradition) subunit. The complete unit of the QCU is referred to and described by its QCU profile (Winter and McClatchey 2008). Through the linkage of two otherwise separate subunits into one unit emergent properties will come about that contribute to social-ecological system complexity.

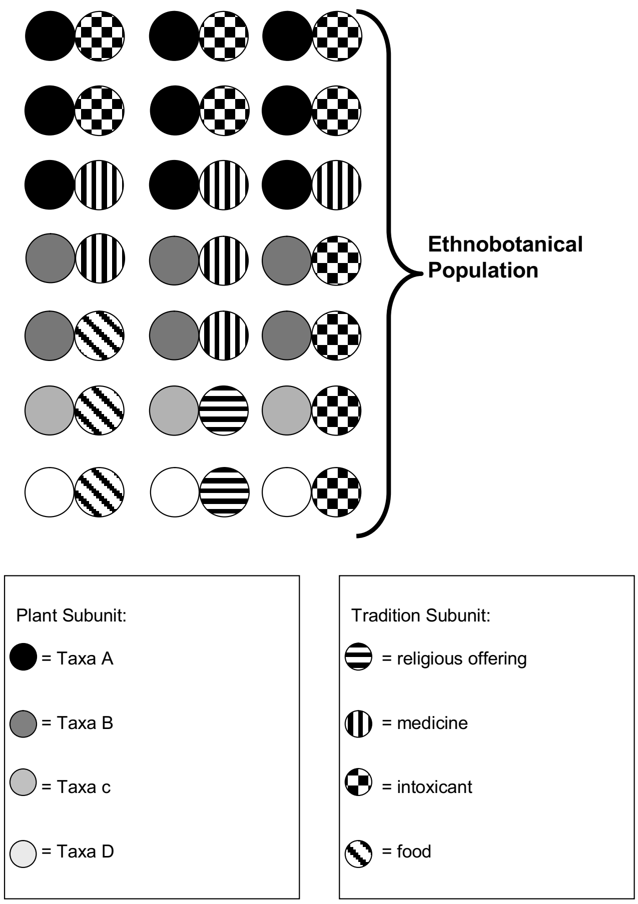

Fig. 2 An example of a highly simplified and generic ethnobotanical population. A measurement of a population of Quantum Co-evolution Units (QCUs) found within a social-ecological system showing proportionality and frequency of various QCUs in relation to one another. Over various intervals in time the ethnobotanical population of a social-ecological system could be sampled. Changes in composition, proportionality and frequency can be observed and further quantified (see **Fig. 4**). Such changes could include the adoption of new QCUs into the population, deletion of QCUs from the population, and changes in individual QCU frequency within the population.

human *pressures* on biodiversity, but as will be illustrated in the following section, perhaps more importantly for understanding human *promotion* of biodiversity.

EVOLUTION OF CULTURAL INTERACTIONS WITH PLANTS

Changes in composition of ethnobotanical populations

Humans, and not plants, determine if a relationship between plants and cultural practices is developed, maintained, changed, or abandoned. Humans, either voluntarily or involuntarily, determine if the interaction exists at all, or can link other subunits together to form new QCUs in a population or can separate subunits to lose QCUs in a population. If separated, the individual subunits can exist, but without the interaction, may in time cease to exist or change in ways that are possible because of the loss of constraints of the previously corresponding subunit. However, sociocultural interactions with plants change as a result of changes in plant genetics (e.g., phenotypic expression) over time. As a result we see that this co-evolutionary process has no real driver.

We refer to the joining of two otherwise unconnected subunits into a QCU as a “linking event.” Linking events are a major driver of changes in composition of ethnobotanical populations as they are adding diversity to the said population. Such events also play a key role in understanding

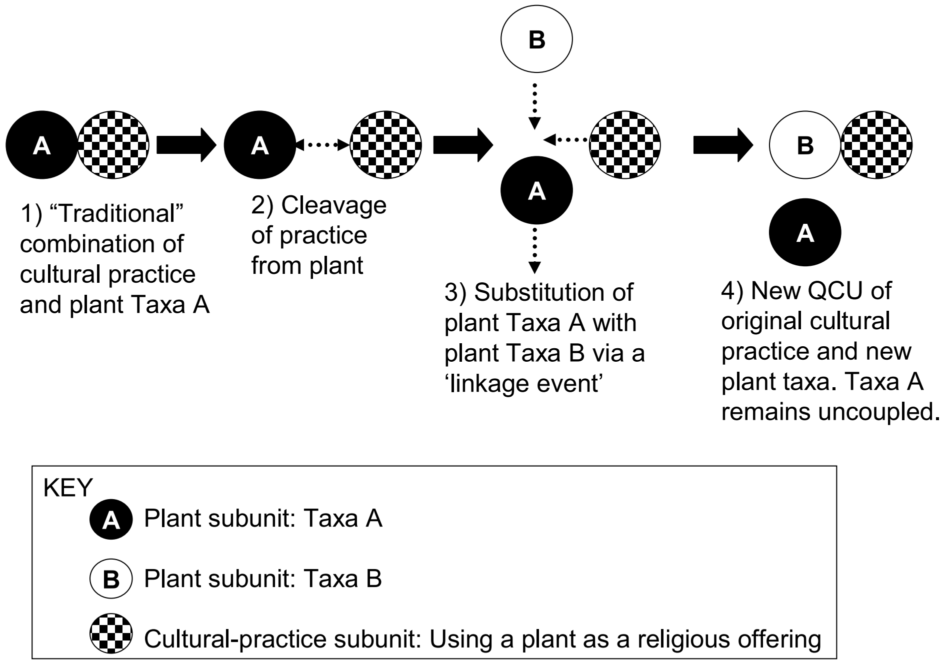

Fig. 3 An example of a QCU cleavage event and the subsequent substitution of a subunit via a linkage event. Parameter setting conditions such as environment, available biological diversity and available cultural diversity (see below section "The backloop cycle") are determining factors in both cleavage events and linkage events. In this example through a change in the parameter setting condition of religion the practice of using a particular plant taxa as an offering remains the same, but the taxa offered has changed. The process is: 1) Under a certain set of parameter setting conditions a particular QCU exists and contributes particular emergent properties to social-ecological system complexity; 2) A variable in the parameter setting conditions changes (religion in this example) inducing a cleavage event which separates the plant subunit from the cultural-practice subunit; 3) The same change in a parameter setting condition (i.e., religion) that caused the cleavage event induces a linkage event which rejoins the cultural-practice subunit to a different plant subunit creating a new QCU; 4) The new QCU linkage produces different emergent properties which contribute in different ways to social-ecological system complexity than the original QCU. The survival of the original, now de-coupled, plant (Taxa A) subunit is now in question. Its long-term survival (i.e., maintenance of genetic integtity) may be dependant on its ability to re-couple to a cultural-practice subunit. If able to survive on its own it will no longer have the constraints of the previously associated cultural-practice subunit, and may be set on a new evolutionary course not previously possible.

the co-evolution process between cultures and plants.

We refer to the breakup of a QCU into two disjointed subunits as a "cleavage event." Cleavage events may be temporary. If one subunit of a QCU is lost, people may attempt to replace it by finding a corresponding subunit (e.g., if a specific plant is lost a replacement may be sought, or conversely if a specific traditional practice is lost a replacement may be sought or developed) (**Fig. 3**). Cleavage events may also be permanent. If unable to find a corresponding subunit, the remaining plant or tradition may eventually be lost (i.e., die out), leading to an extinction event of that QCU. Cleavage events are also a major driver in changes to composition of ethnobotanical populations, and play an important role in understanding the co-extinction process between cultures and plants.

Changes in composition of ethnobotanical populations over time

Understanding the processes involved with evolution of ethnobotanical populations will be key in developing management strategies for resilient social-ecological systems across a range of scales. A large part of this depends on the ability to quantify changes in ethnobotanical populations (i.e., cultural relationship to plants) over time.

The ethnobotanical state of a social-ecological system (its ethnobotanical population) can be measured at various points in time. If an ethnobotanical population is measured at different points in time and is found to have changed, then the magnitude of the change may be measured. Biological evolution is traditionally discussed as change in allele frequency over time. Likewise, ethnobotanical evolution may be discussed as a process of co-evolution as a change in the QCU frequency within an 'ethnobotanical population' over time (changes in: allele frequency of plants, and/or cultural practices or traditions). In the following we proceed with our discussion of perspectives of human-plant co-evolution with limited analogy to genetic evolution. Within this structure, we produce a set of hypotheses that we hope will point to future theoretical ethnobotany and applied conservation research.

Richerson and Boyd (2005) produced a logical framework for discussion of how natural selection acts on transmission of cultural variation. Their reasoning may be extended with any or all of the following conditions being met in order for evolution to occur within an ethnobotanical population and/or subpopulation (e.g., QCU frequency or proportionality changes over time).

- Particular QCUs have increased in frequency because of selection.
- Particular QCUs have decreased in frequency because of selection.
- One or more QCU(s) have been added or lost through events homologous to those involved in the process of biological evolution (mutation, extinction, etc.).
- One or more QCU subunit(s) has changed (i.e., replacement of a lost or abandoned plant or tradition subunit) resulting in the creation of a new QCU.

Recognition that the above events are happening within cultural settings and not those of true natural selection is important. However, people are also excellent models of non-random selectors and therefore have been used as examples of evolution by Darwin and others. The foundational logic is the same in evolution of biological species and ethnobotanical populations. If none of the above conditions were to happen between intervals of time then an ethnobotanical population would be considered static and non-evolving (Winter and McClatchey 2009).

Based on the above discussion we propose the following equation to calculate QCU frequencies within ethno-

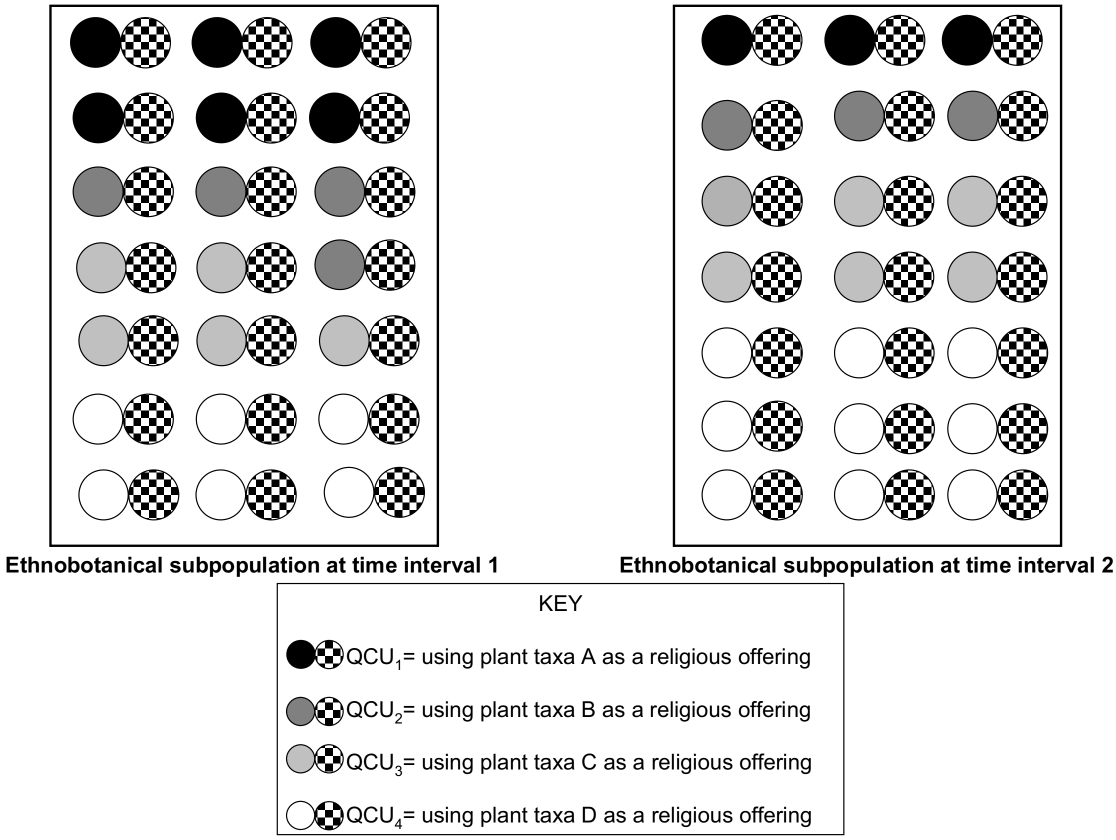

Fig. 4 A highly simplified and hypothetical ethnobotanical subpopulation measured at two intervals in time. This ethnobotanical subpopulation focuses on the cultural practice of using plants as a religious offering and measures all of the plant taxa linked with that practice. Between the two intervals in time that this ethnobotanical subpopulation was measured changes in frequency can be observed (**Table 1**) which would indicate that evolution within this subpopulation has taken place.

Table 1 Respective QCU frequencies of a highly simplified and hypothetical ethnobotanical subpopulation that focuses on plants involved with religious offerings as measured between two intervals of time. Each calculation represents the frequency of respective QCUs in an ethnobotanical subpopulation at a particular time. The frequencies have changed between intervals of time which indicates that ethnobotanical evolution has taken place.

	QCU_1	**QCU_2**	**QCU_3**	**QCU_4**
Time interval 1	0.2875	0.1905	0.2381	0.2875
Time interval 2	0.1429	0.1429	0.2875	0.4286

botanical populations, where the value for the ethnobotanical population will always be 1:

$$\sum_{n=\text{the number of QCUs in an ethnobotanical (sub)population}} = QCU_1/QCU_{total} + QCU_2/QCU_{total} + \ldots + QCU_n/QCU_{total}$$

For the purposes of illustration **Fig. 4** depicts a highly simplified and hypothetical ethnobotanical subpopulation focusing on plants within a social-ecological system that are used as religious offerings. A survey of the subpopulation was taken at two intervals of time. If the above formula is applied to this subpopulation it can be demonstrated that between the two intervals of time the respective QCU frequencies within the subpopulation have indeed changed (**Table 1**), indicating that ethnobotanical evolution has taken place.

Although there are many aspects of evolution in ethnobotanical (i.e., QCU) populations that may be explored, one is particularly germane for addressing systematic data collection across different regions for conservation and management of biodiversity. As human interactions with plants intensify researchers commonly observe that plant biodiversity also increases (Lunt and Spooner 2005; Sheuyange *et al.* 2005). This may subsequently result in a diversification of traditions – hence co-evolution (see discussion below) – a portion of which are associated with maintaining or further increasing this biodiversity. These relationships, therefore, warrant the attention of conservation biologists, resource managers and policy makers (Meffe *et al*. 2002; Cook *et al.* 2004). Quantum ethnobotany provides the model for measuring the above.

It is critical to understand how people-plant interactions intensify over time, becoming more complex and interdependent. Such relationships are likely to be similar to that which Berkes *et al*. (2003) described about social-ecological systems: they are either more resilient if complexity is maintained, or more brittle as a result of homogeneity. In relation to this idea quantum ethnobotany sets a model to identify and measure the linkages between plants and people as relates to social-ecological system resilience.

THE CYCLICAL PROCESSES OF CO-EVOLUTION AND CO-EXTINCTION

Co-*evolutionary* process of people-plant interactions: *Increases* in biocultural diversity

We contend that within social-ecological systems people-plant relationships are continually changing, but in a manner in which they influence each other's evolutionary trajectory. Changes in plant genetics (e.g., phenotypic variations) will change both the opportunities for and constraints upon interactions with people (i.e., cultures). Likewise, changes in culture (e.g., cultural priorities) will affect which phenotypes are managed and how, in essence influencing the trajectory of plant evolution. Thus this relationship is co-evolutionary.

We further submit that there are three classes of co-evolutionary relationships in the people-plant context: non-intensifying co-evolution, intensifying co-evolution, and deteriorating co-evolution (or co-extinction) – all of which are

Table 2 Classifications of co-evolutionary relationships, the respective state of the ethnobotanical population, and the potential insights that can be gained for managing diversity.

Classification	State of ethnobotanical population	Insights to be gained
Intensifying co-evolution	'Linkage events' > 'cleavage events' (i.e., growing)	Management practices that lead to increases in diversity
Non-intensifying co-evolution	'Linkage events' ≈ 'cleavage events' (i.e., relatively stable)	Management practices that maintain diversity
Deteriorating co-evolution (or co-extinction)	'Linkage events' < 'cleavage events' (i.e., shrinking)	Management practices that lead to decreases in diversity

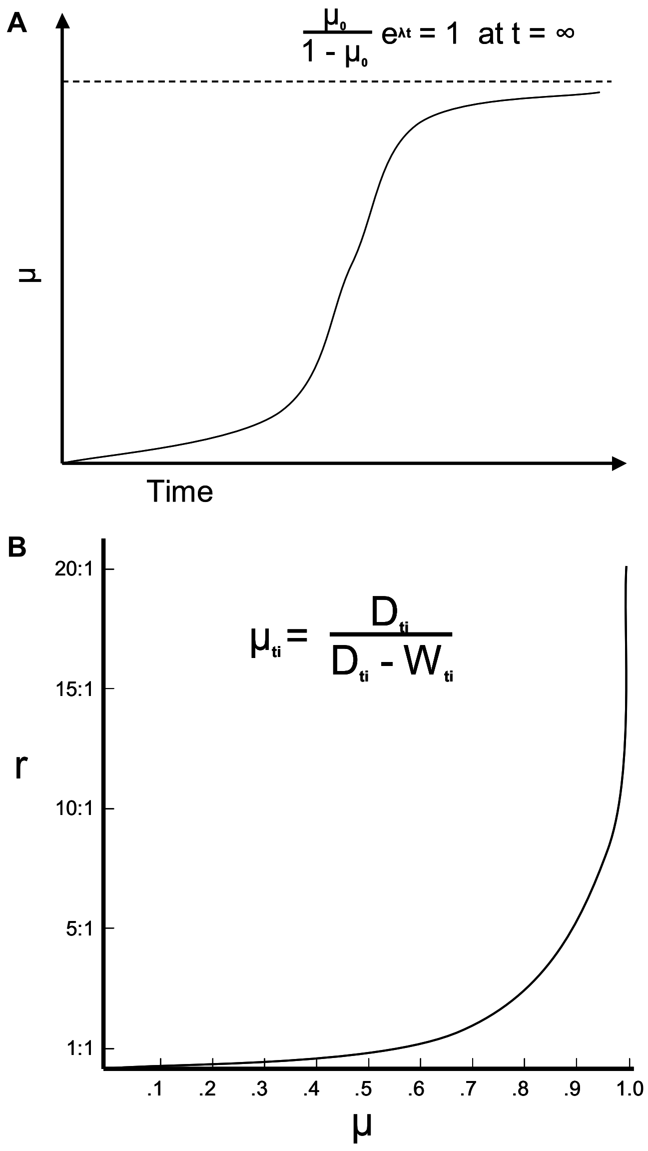

Fig. 5 (**A**) Increase in abundance of domesticates over time (After Rindos 1984, Figure 5.3) [μ is the relative abundance of domesticates as a fraction of the total possible in the environment. **λ** Is the logarithm of the relative increase in domesticates.]. (**B**) Relative contribution (r) of varieties of domesticated plants (D) verses wild plants (W) over time as a function of their relative abundance (μ) in the environment. (Adapted from Rindos 1984, Figure 5.2)

important to understand for conservation of biodiversity. The trajectory of a ethnobotanical population can be an indicator to aid in the classification of co-evolutionary relationships, and the kinds of insights that can be gained through observation (**Table 2**). Understanding the intricacies of a population in a state of expansion such as in an 'intensifying co-evolutionary relationship' would be important for understanding socioculturally driven increases in biodiversity, and is therefore the class of relationship that we will focus on in this section.

Sociocultural systems have the ability to not only increase biodiversity through management of natural systems, but also through the process of intensification, such as through agriculture (Balèe 2006). The number of plant varieties and landraces recognized by a culture demonstrates the relative importance of that plant to the culture (Rindos 1984). This is especially true for domesticated plants. In a broad sense several researchers have addressed the ideas of how and why plants came to be managed by people (e.g., agriculture) and how this relationship intensified (Sauer 1952; Böserup 1965; Rindos 1984; Rindos 1989; Zohary 1989). An important question is therefore: How is an increase in recognition of plant diversity correlated with cultural importance? An important model of this process was proposed by Rindos (1984) in which he hypothesized that the intensification of agriculture associated with increasing numbers of varieties of domesticated plants provides opportunities for population increases, and reduced dependency upon less predictable wild plant resources. His model (**Figs. 5A, 5B**) implies that the rate of change over time in the system is most dramatic in cultures that are fully dependent upon agriculture and have intensified their utilization of specific crops to include many varieties and landraces of the specific species that they utilize.

A better understanding of this trend can be seen by taking a closer look at the developmental process of plant management (e.g., cultivation) and the effects that subsequent diversification of a cultivated (or otherwise managed) plant has on the evolution of human culture (**Fig. 6**). Quantum ethnobotany scales down to the most basic level of people-plant interactions, and provides the models to quantify and analyze these changes.

As seen through the lens of quantum ethnobotany the process of intensifying co-evolution between people and plants results in a simultaneous increase in both biological and cultural diversity. The research of Berkes and Folke (1998) and Berkes *et al.* (2003) would suggest that such increases in diversity are related to social-ecological system resilience. As illustrated below in **Fig. 6**, on the sociocultural side an intensification of management leads to an increase in knowledge, which leads to an increase in practices, which leads to an increase in traditions. The ability for this to happen, however, hinges on increases in plant biodiversity along all levels of the process, as it increases the potential for human interaction (see discussion below). The process of co-evolution between people and plants in social-ecological systems can, under certain circumstances, lead to an intensification of this relationship which in turn increases diversity on both the biological and the sociocultural sides of the system. This process results in a complex and diverse relationship between people and plants that would likely have a high level of system resilience. Quantum ethnobotany provides the model, using QCUs, to better understand this process.

The 'intensified co-evolution' of people-plant relationships can be understood as a series of 'linkage events.' According to quantum ethnobotany theory as landraces are developed via agriculture or other management systems the only way that it can be maintained (i.e., survive) for the long term while keeping its genetic integrity is to be connected to a particular cultural practice via a linkage event. As management is intensified and more landraces are developed and recognized there will be more opportunities for linkage events. Particular taxa that become culturally important will continue to diversify and gain more associated

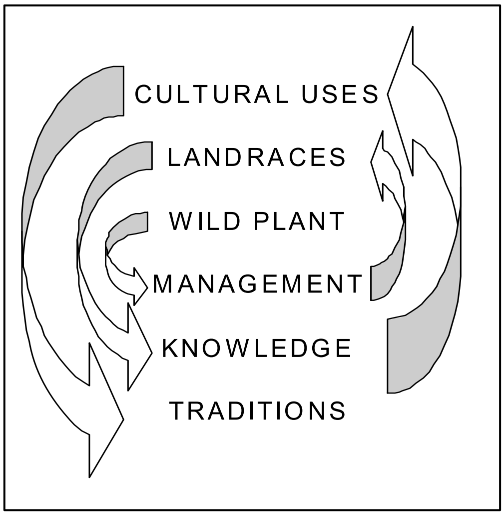

Fig. 6 Co-evolution of a cultivated (or otherwise managed) plant and the culture that cultivates it as depicted in an outwardly expanding spiral. This involves a six step process which depends on linkage events along the entire cycle: 1) A wild plant is determined to be useful in some way; 2) The plant is brought into a management system (e.g., agriculture); 3) Landraces are developed through selection; 4) Knowledge about each specific landrace is accumulated; 5) Diversification of associated cultural practices takes place; 6) These practices get passed on as traditions which will influence the evolution of the culture.

Fig. 7 The abating spiral depicting the co-extinction of plants and the sociocultural system that manages it. A six step process that involves cleavage events along the whole process: 1) A tradition associated with a plant use/management is no longer passed down to the younger generations; 2) Cultural interactions with particular landraces are discontinued; 3) In the absence of cultural-biological interactions with particular landraces knowledge about them will be lost; 4) Without having either knowledge or practices associated with landraces, plant diversity will be lost; 5) In the absence of management a plant will revert to wild plant; 6) The plant will remain wild – with greatly reduced biodiversity – and will continue as such until it is rejoined to a sociocultural system via a linkage event.

practices and traditions via further linkage events, a process that will likely result in the taxa becoming more and more important to the culture. This process is readily apparent in agricultural systems, but can be applied to many other natural resource management methodologies. Through this model we can see both how biodiversity is linked to cultural diversity, as well as the reasoning behind the idea that recognized diversity is directly related to cultural importance.

Co-*extinction* process of people-plant interactions: *Decreases* in biocultural diversity

Holling (1986) points out that ecosystems are dynamic and go through regular, non-linear cycles of organization, collapse and renewal. This also applies to social-ecological systems (Berkes *et al*. 2003). The process of co-extinction (**Fig. 7**) would be that "collapse" process that they referred to (the co-evolution process would relate to the 'organization' phase). This may be brought on for reasons such as cultural colonization (see below section). The process of co-extinction is very much the reverse of the process of co-evolution. This may happen rapidly or slowly, and may very well lessen resilience of social-ecological systems. Ebenman and Jonsson (2005) have shown that owning to interdependencies among species in ecological communities, the loss of one species can trigger a cascade of secondary extinctions with potentially dramatic effects on the functioning and stability of the community. We contend that the same is true for not only the ecological side of social-ecological systems, but for the sociocultural side as well. Furthermore this concept can be applied to linked biological-cultural relationships. Understanding this process is vital to preserving biodiversity as these relationships break down.

In the broad sense co-extinction of linked biological-cultural diversity is very much the opposite of the process described by Rindos (1984) and would be the inverse of the process illustrated in **Figs. 5A** and **5B**. This would imply that if a culture loses domesticates then this loss will be rapid when they are most dependent upon them. If this process of intensification is reversed, then it appears that the earliest and latest parts (Steps 1 and 6 in **Fig. 7**) of the cycle are slow and the middle parts (Steps 2 through 5) are rapid as defined by the steep slope depicted in **Fig. 5A**. The implications for cultures with intensified agricultural or other resource management traditions that are faced with changes are profound. It appears likely that changes will happen rapidly to both components of social-ecological systems.

In the terms of quantum ethnobotany theory, this process can be scaled down to analyze how it operates on the most basic level. Just as an intensifying co-evolution process can be understood in terms of 'linkage events,' an abating co-extinction process can be understood in terms of 'cleavage events.' Cleavage events break linkages that are key to connecting cultural and biological diversity. A better understanding of this process can help resource managers to maintain biodiversity and enable it to persist through the cycle until it can be reorganized back into the social-ecological system.

The backloop cycle: Reorganizing diversity between co-extinction and co-evolution cycles

People-plant relationships have been noted to go through processes of growth, dismantling and back into regrowth (Winter 2004; Winter and McClatchey 2009). Using ecological models (Holling 1986) and quantum ethnobotanical models (Bridges and McClatchey 2009; Winter and McClatchey 2009) a better understanding of these processed at the most fundamental level can be gained.

Holling (1986) articulated that ecological processes are a cyclical rotation between three phases: organization, collapse and renewal. The renewal (sometimes referred to as the 'reorganization') phase is important because that is the phase in which novelty and innovation occur (Holling 1986; Holling *et al*. 1995). Folke *et al*. (2004) point out that biodiversity is such an important factor in ecosystem resilience because is plays a major role in renewing and reorganizing ecosystems after disturbance. There are two important components of the renewal phase which involve the 'release' and 'reorganization' of elemental building blocks of larger systems. Such events correspond with periods of change which are collectively referred to as the 'backloop phase.' Backloop phases are the most neglected and least understood in conventional resource management (Berkes *et al*. 2003).

Berkes *et al*. (2003) state that sociocultural systems follow the same cyclical processes described by Holling (1986). We contend that people-plant relationships of social-ecological systems also cycle between processes of co-evolution, co-extinction, back into co-evolution and so on. This process can also be understood in the terms of Holling (1986) described above. The co-evolutionary process can be related to the phases 'organization.' The co-extinction process can be related to 'collapse' phase. The process by which a co-extinction phase cycles back into a co-evolution phase would be analogous with the 'renewal' phase. We further contend that the success of renewal cycles in social-ecological systems are dependant upon the diversity of linked sociocultural-biological relationships. Models provided by quantum ethnobotany allow us to understand what is happening in these processes on the most fundamental level.

Both the co-evolution and co-extinction processes have been discussed above. But how does a co-extinction cycle loop back into a co-evolution cycle. And why, as observed by Winter and McClatchey (2009), are people-plant relationships different at the end of two respective co-evolutionary cycles (as separated by a co-extinction cycle)? Insight may be gained by observing what happens to quantum co-evolution units as they cycle back and forth between co-evolution and co-extinction:

Linking events associated with an intensifying co-evolution process occur in a particular order, and under a certain set of parameter setting conditions. This plays a role in which subunits are linked and when. Examples of parameter setting conditions would be ranges of environment, available biological diversity, and available cultural diversity. The order of linking events work in concert with parameter setting conditions to set a trajectory of co-evolution.

Cleavage events associated with an abating co-extinction process also occur in a particular order, but not necessarily in exactly the reverse order as they were linked. Cleavage events may initiate because the system is being operated under a different set of parameter setting conditions than the set associated with the previous co-evolution process. As these subunits are being separated this new set of conditions will determine which subunits survive long enough to be available for future linking events, and which subunits go extinct – forever taking them out of the pool of possible future linking events.

When an altogether new set of parameter setting conditions come to pass this may induce another co-evolution cycle. This different set of conditions will influence which subunits are involved in a new series of linking events. It is important to note that not the same set of existing QCUs will be at the foundation of this new co-evolution cycle as the previous co-evolution cycle. Furthermore, the new set of conditions may yield new subunits previously unavailable in the pool for potential linking events. As the co-evolutionary process continues some of the original subunits that are remaining in a pool of unlinked subunits may be re-linked, but not necessarily in the same order as they were lost. This, in conjunction with linking events creating entirely new QCUs, will change the structure of the ethnobotanical population and therefore affect trajectory of co-evolution. This is likely the reason why ethnobotanical populations are most likely to never be the same after going through a co-extinction process, even if it goes back through another co-evolution cycle.

Maintaining cultural diversity through cyclical evolutionary processes

While much of the research and theoretical discussion of resilience in social-ecological systems has focused on the importance of biodiversity (Berkes and Folke 1998; Berkes *et al*. 2003; Walker *et al*. 2006), it is likely that cultural diversity, as well as linked biocultural diversity, is just as important. This is especially probable when we consider that it is through the broad spectrum of cultural practices that we see management strategies develop that either increase, maintain or decrease biodiversity. This applies to both intra- and inter-cultural diversity within ecosystems. There exists a need to not only manage biodiversity, but also cultural (i.e., tradition/practice) diversity for understanding and maintaining – not to mention the potential to increase – social-ecosystem resilience.

Quantum ethnobotany provides the tools to analyze specific cultural interactions with specific taxa of interest. This, when compared to studies on that taxa's health in a social-ecological system, could give us better understanding of how a particular spectrum of cultural practices affect taxa over time. Quantum ethnobotany could potentially contribute to the answers that resource managers are seeking when making decisions regarding the health and resilience of social-ecological systems.

CONCLUSIONS

Applications of quantum ethnobotany for conservation of biodiversity

Before an understanding can be reaches as to what is being lost there needs to be an understanding of what exists. Biodiversity is often quantified in social-ecological systems, however the links between cultural practices and biological taxa have yet to be quantified in such a way as would lend to comparisons across regions and disciplines. The theoretical model we have presented here provides an actual measure of culture and cultural change as it relates to biodiversity and changes in biodiversity. It will help us to better understand and manage the cultural practices that both promote and threaten biodiversity. It may also provide a way to early-on identify stress/pressure factors within sociocultural systems, and parts of culture that are under pressure to change and those that are not. Despite what we have said above it is important to keep in mind that social-ecological systems are exceedingly complex. What we are proposing to measure is the minimum of change in order to detect useful generalizations within the complexity of social-ecological systems. Because of expected synergy within complex systems any actual evolutionary change will no doubt be greater than that of the sum of the parts we propose to measure.

Proposed hypotheses

Just as humans have been directing the evolution of plants through management practices and selection since before the advent of agriculture, humans can also influence the evolution of culture by selecting for cultural practices. For cultures that have lost plant or cultural practice diversity, either may be recreated, but it is difficult to determine if the newly linked QCU is the same or different from those of the past. It also may not matter.

We propose several hypotheses about human interactions with plants on the basis of the above discussion:

1. Quantum co-evolution units can be used to measure how specific sociocultural practices influence biodiversity within a social-ecological system.
2. There is a set of criteria that can be used to test whether an ethnobotanical population is evolving. If any/all of the criteria are met then the population is evolving. If none are met the population is static. The criteria are:
    a. Particular QCUs have increased in frequency because of selection.
    b. Particular QCUs have decreased in frequency because of selection.
    c. One or more QCU(s) have been added or lost through events homologous to those involved in the process of biological evolution (mutation, extinction, etc.).
    d. One or more QCU subunit(s) has changed (i.e., replacement of a lost or abandoned plant or tradition subunit) resulting in the creation of a new QCU.
3. Co-evolution and co-extinction of plant-culture rela-

tionships are cyclical processes and quantum ethnobotany can be used to understand how these affect the trajectory of evolution in ethnobotanical populations.
4. Re-emerging cultures may resurrect traditional recognition of plant diversity and create or borrow practices in order to restore (redevelop) relationships with plants, and therefore social-ecological system resilience.

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