Chapter 9
Utilitarian Redundancy: Conceptualization and Potential Applications in Ethnobiological Research

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9.1 Introduction

Human populations develop bodies of knowledge, beliefs, and practices from their relationships with other human populations and living beings as well as the environments in which they live. These relationships are modulated by adaptive processes (Berkes et al. 2000), and knowledge is passed down to future generations through social learning, which forms complexes known as social-ecological systems. Social-ecological systems have many functions that are performed by structural components, e.g., plants, animals, and fungi can be used to treat different diseases.

Ethnobiological research focusing on the use of medicinal plants by human populations has shown that different species are used to treat the same diseases (Gazzaneo et al. 2005; Almeida et al. 2006; Ceuterick et al. 2011; Molares and Ladio 2012; Kunwar et al. 2015). This statement prompts the following question: could this therapeutic overlap of medicinal plants promote adaptive advantages for the

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U.P. Albuquerque et al. (eds.), *Evolutionary Ethnobiology*,
DOI 10.1007/978-3-319-19917-7_9

human populations that use these resources? To answer this question, Albuquerque and Oliveira (2007) proposed an investigative ethnobiological model analogous to functional ecological redundancy: the utilitarian redundancy model (URM).

In summary, the URM considers the different conditions that are treated with the natural medicines as functions to be fulfilled by the local medical system, and it further considers the multiple species used to treat the same illness as a functional redundancy within the system. Based on these premises, the model aims to answer the following questions: What are the ecological and evolutionary implications of potential redundancies of use? Are certain species preferable to others under redundancy conditions? If so, does this preference somehow change the use patterns of the species with redundant functions?

The goal of this chapter is to show how the URM could answer these questions and the interesting theoretical and practical framework for ethnobiological research that it offers. We will initially explain the original ecological redundancy model and its concepts and definitions before presenting the applications of the URM. We will show how the model can illustrate the ways in which people relate to the resources available in their local environments.

We assume that the ways in which species are functionally organized determine the dynamics of a system. Therefore, this chapter focuses on species within a functional context to determine how the knowledge and use of resources by local populations influence how traditional medical systems change or evolve.

9.2 The Ecological Redundancy Model

Understanding the role of species in ecosystem regulation is a growing concern in conservation that has led ecologists to examine several processes and systemic relationships, such as the relationship between ecological function and species richness (Bengtsson 1998; Peterson et al. 1998; Cadotte et al. 2011). Numerous explanations have been formulated to help clarify this relationship, including the ecological redundancy (ER) model proposed by Walker (1992), which is based on several assumptions. First, the species in an ecosystem perform ecological functions, such as pollination, dispersal, photosynthesis, and decomposition. Second, when different species fulfill the same ecological role, there is an overlap in function, so functionally analogous species can occur. Third, certain ecological functions are redundant because they are performed by multiple species (Walker 1992; Wellnitz and Poff 2001). The ER model shifts our understanding of ecosystems away from the conventional taxonomic approach to one focused on function (Walker 1992). Wellnitz and Poff (2001) argue that “complete functional redundancy would occur if, following the removal of one species, the remaining species increase their densities to compensate for the lost functional contribution of the removed species.” In this hypothetical state, a biological entity may become locally extinct without compromising the entire system because its function will be performed by the redundant species. In other words, the focus would shift from the individual species to the functions of those species at the ecosystem level.

Despite the potential of ER to guide biological conservation initiatives, many problems may occur when researchers attempt to quantify the relationship between species richness and ecosystem function (Bengtsson 1998) or identify the functions of each species inspired by the complex dynamics among species. ER offers a practical approach to developing strategies for ecosystem management despite the aforementioned difficulties. Thus, the ER approach could be used to assess the composition of the pollinator guild in an area where conservation studies will be conducted on native vegetation. Plant species evolved along with their pollinators and include adaptations that allow greater reproductive success when both plant and pollinator species co-occur (Machado and Lopes 2004). Therefore, knowing the organisms that perform this ecological function in the region and determining the species that are in population decline are necessary for the development of more appropriate conservation strategies.

Political decisions related to biodiversity management and conservation must consider both functional diversity and ER (Walker 1992; Low et al. 2003). Functional diversity and ER are based on the principle that species richness generates stability, although there is evidence showing that this is not always true (see Reynolds 2002). According to the ER model, a given area may have a great number of species with certain ecological functions performed by a limited number of species (low redundancy). Thus, a local pollination guild can consist of many species and still have only one hummingbird species, which would compromise ornithophilic functions (bird-mediated pollination) despite the occurrence of several other pollinator species in the area. Therefore, biodiversity management and conservation initiatives should focus on ecosystem functions with little or no redundancy.

Considering that redundancy is present in many systems (e.g., genetic, ecological etc.), we can assume that it is a characteristic or attribute of a system (Low et al. 2003) and not necessarily costly. According to Low et al. (2003:86), "Costs are always associated with redundancy because building more than one unit involves the use of energy, materials, and time that could be used for other purposes. System performance can, in turn, be measured along multiple dimensions, e.g., capacity to cope with risk and uncertainty; adaptation to exogenous change; error reduction through repetitive learning or learning from others; matching system responses to local conditions; and ability to reduce the probability of system failure. Whether the benefits (of improved system performance) are worth the costs (of added time, effort, and resources used to build multiple units) of redundancy depends on: (1) the type of problems faced in governing a system, (2) how the particular kind of redundancy copes with these problems, and (3) the cost of the particular type of redundancy".

The concepts presented above can be transposed and used to study the ecological/evolutionary relationship between people and natural resources. The established bridge between the discussed ecological concepts and ethnobiology framework provides insight into the functioning of local knowledge systems, and it can be used to determine if a wide diversity of species with functions that meet the same demand reflects a more resilient body of knowledge, i.e., one that is capable of sustaining its structure and dynamics even if the use of one or more species is locally abandoned.

9.3 The Utilitarian Redundancy Model

The URM emerges from the ER by adopting a functional perspective in the analysis of natural resource use by human populations, and it evaluates the role of functional overlap in knowledge systems and local management (see Albuquerque and Oliveira 2007). This analytical perspective arose from the observation that several species are traditionally used for similar functions, i.e., they are culturally redundant regarding local use indications. Therefore, the redundancy concept applied to ethnobiology can be a useful tool for evaluating local natural resources management and conservation strategies under an adaptive perspective.

The URM model is based on the following assumptions: (a) species have different functions within social-ecological systems, but a level of overlap in function (i.e., redundancy) occurs; (b) increased redundancy promotes resilience in social-ecological systems, and (c) redundancy depends on the knowledge characteristics and practices of a given human community. Therefore, the URM is an operational concept used to determine the (a) role of redundant species in the structure and dynamics of a cultural system; (b) contribution of redundant species to the resilience of knowledge and local practices; and (c) effects of human activities on biodiversity.

We attempt to explain the conceptual connection between ecological and utilitarian redundancy before proceeding to the analysis of different topics. Consider any social-ecological system, such as that of plants and animals used as food or raw materials used in construction. Redundant species share the same **function** and fulfill the same local demand, i.e., they have the same **use**. In a local medical system, the term function is used as the **therapeutic target** to which the species is associated. Therapeutic targets are the indications to which medicinal plants and animals are employed, according to local classifications. Therefore, therapeutic targets may designate only one symptom (e.g., pain or cough) or several symptoms of a more serious condition (e.g., flu or tuberculosis) that may be recognized as a "disease" by biomedicine. Our decision to use the term therapeutic targets instead of diseases reflects the local concepts of health and illness (or the local nosology) because these concepts may be important in selecting a treatment (see Beiersmann et al. 2007). The URM model is advantageous because it enables the quantification of the relationship between species richness and function within a system, despite the complex dynamics of traditional ecological knowledge.

As previously stated, the URM may be used to assess whether a medical knowledge system is resilient, in other words, if a local medical system is able to absorb disturbances, reorganize and maintain its functions and structure (see Holling 1973). The dynamics of a system depend on the integrity of its functions. In addition, the same ecological assumption of the dynamics in an unchanged system regardless of species loss occurs when other entities performing the same function fill the void of the initial loss. Therefore, if a local medical system experiences a loss of knowledge (e.g., the death of a person holding the knowledge) or the loss of use of a species (e.g., by local extinction) that is a treatment for a redundant therapeutic target, such losses do not affect the overall functioning of the medical system despite the reduction in the diversity of the useful species in the system.

We further analyze the contribution of the URM to the understanding of the effective use of a species and, consequently, human pressures on natural resources. Initially, we might logically assume that the occurrence of a number of species with the same function will minimize the use pressure on specific species if the exploitation of those species is evenly distributed. Therefore, higher redundancy is implied by the existence of more species that may be subject to collection, thus reducing the impacts on individual species. However, we must consider an additional factor, which is that certain resources are locally preferred and receive increased attention with rising demand. The species known as "best" or most important will be preferred despite a larger set of species being available to fulfill the function. Here, preference is related to the conscious selection of a species instead of another that is equally available (Albuquerque et al. 2005), so mutual reinforcement ends when there is preference for a specific species in a given category. Thus, utilitarian redundancy would not lead to single species protection but only to the maintenance of local function.

Finally, we highlight the potential application of the URM model to other areas of ethnobiological research despite being initially conceived from the perspective of medicinal plants. For example, the use of fish species by coastal communities may be studied through the URM with different fish categorized as functions: alimentary, medicinal, commercial, mystical-religious, and companion. The same assumptions of the URM could be applied to such a situation, leading to the following predictions: (a) fish species belonging to less redundant use categories could be subject to greater pressure; (b) in the case of greater preference for a specific fish species, the most preferred use category would be subject to greater use pressure; and (c) greater redundancy within fish use categories makes the fish knowledge system more resilient. However, it is noteworthy that different knowledge systems have peculiar use dynamics, and these peculiarities must be considered to reach a more accurate conclusion about which adaptive mechanisms explain the observed patterns. We must also consider the importance of social dynamics in shaping the access, use and knowledge of natural resources (e.g., intracultural dynamics) and the functioning of social-ecological systems.

9.4 Applications of the Utilitarian Redundancy Model

Most of the therapeutic targets treated with medicinal plants in a local medical system may have low redundancy, which could indicate high specialization in the local medical system (Albuquerque and Oliveira 2007). According to the assumptions of the URM, greater specialization in the local medical system would result in the system being more susceptible to disturbances and less resilient with the loss of a species having the potential to lead to a loss of function.

However, the definition of "function" must be standardized to avoid incorrect interpretations of the URM. In a medical system, for example, we may consider uterine inflammation as a function and obtain a certain number of plants capable of treating it (redundancy), or we may consider it as overall inflammation and obtain a different number of plants. Although inflammation is redundant, when the URM was applied for the inflammatory subcategories recorded in a rural community in northeastern Brazil, certain inflammation subcategories were not redundant (e.g., throat, ear, vaginal, and wound inflammation) (see Ferreira Júnior et al. 2011). Thus, it is important analytically define a system's functions, because the results may differ depending on how the functions are classified (e.g., an overall category for inflammation or a specific classification for a type of inflammation). It is important to include the local classification of an illness (considering the local nosology) to make the scientific data relevant to the local people.

Because the distribution of intracultural knowledge is not homogeneous among the individuals of a population, certain people within a community will know more than others on specific topics (see Araújo et al. 2012), and this unequal distribution of knowledge may affect the interpretations of the URM (see Ferreira Júnior et al. 2013). If a single person within the community retains much of the local knowledge and withholds it from the rest of the population, his or her death or migration may lead to the loss of a function from the system (e.g., shamans or specialists). A study conducted in the Brazilian Caatinga, for example, reported that the redundant knowledge of therapeutic conditions was restricted to a small portion of the population (Ferreira Júnior et al. 2011). This situation is a major impediment to resilience because the disappearance of one of the informed people may cause a shift in the system (Albuquerque and Oliveira 2007). It also may have important cultural implications in terms of sacred knowledge and access to knowledge that might not be available to everyone in a group.

The URM may also be used to identify species that are under greater pressure from local use due to preferences for the treatment of slightly redundant or unique therapeutic targets. For example, the preferred tree species in a rural community of the Brazilian Caatinga (seasonal dry forest) were subject to bark extraction over larger areas, and a greater number of individuals were exploited, which confirms the hypothesis that preferred species experience greater use pressure (Ferreira Júnior et al. 2012).

However, precautions are required when evaluating the use pressure on slightly redundant therapeutic targets because such species may be uncommon in the community (Ferreira Júnior et al. 2011). In this case, the pressure of use on the species involved in treating therapeutic targets would be reduced despite the low redundancy (rare occurrence) of these species, which would lead to the decrease in resource collection frequency.

We can distinguish two situations for the URM assuming specificities in resource usage by local communities. The first situation would be an ideal condition in which only functional redundancy and its preference status interfered in the pressure of use for a species. In this situation (a) a greater functional redundancy is implied when there is a lower pressure of use in the absence of preferred resources and (b) the preferred resource will always suffer greater pressure when available, regardless of other alternatives. The second situation acknowledges that the local requirements for a certain use motivate people to try new species (see Ladio and Lozada 2008).

Other precautions are required when applying the URM, such as when an ideal functional overlap does not occur and there is no complete redundancy. Two species may be redundant for some functions and not others. Redundancy, therefore, is not specific to a group of species but to the interaction among species (see Peterson et al. 1998). The function headache treatment, for example, may consist of species V, W, X, Y and Z. However, species X is exclusive and has no redundancy for the function "wound treatment." This example shows that misinterpretations may occur when we disregard the knowledge system to understand redundancy. To analyze the therapeutic target "headache" separately, we could imagine that species X is protected from overuse once multiple species are available with the same function. However, such an assumption ignores that species X is the only alternative treatment for wounds; thus, the species could be compromised from an ecological perspective because of a greater pressure of use.

An analogy to the ecological functional redundancy was also used in a study on the utility potential of forest fragments in Madagascar (Brown et al. 2011), although the URM as described here was not applied. Brown et al. (2011) studied tree species used in six categories of use (fuel, construction, food, medicine, and material for tools and furniture) in a forest fragment near rural communities. A null model was used to simulate the functional diversity expected for each fragment, and the number of species with overlapping functions in these fragments (redundancy) was estimated from the expected functional diversity. According to the researchers, a greater utilitarian redundancy within the fragment lowered the risk of losing local utilitarian functions when faced with a disturbance that had the potential to cause the disappearance of a species; thus, lower redundancy led to higher risk.

Assessing the availability of resources used by rural communities (Brown et al. 2011) is an interesting strategy for evaluating redundancy. Analyses of forest fragmentation can assess if species subject to higher use pressure under the URM are actually threatened. However, the system may extend beyond forest fragments, and applying the URM-limited areas reduces the access to information on the redundancy and resilience of the system that constitutes the uses of plants in a human population. Certain exotic plant species, for example, may only be found in backyards or overall anthropogenic areas and are absent in forest fragments. However, these species may provide significant contributions to the redundancy of categories and resilience of the local medical system.

The characteristics of the local medical system and use of medicinal species that are detected by the URM may also be applied to research on medicinal animals. Ethnozoological research has reported the use of several animals to treat the same diseases and suggests that usage overlaps may be important in the adaptation of human populations that utilize such resources because certain functions can be maintained in the absence or limited availability of resources. Absence or limited availability could occur due to seasonality or a species' migration cycle. For example, Ferreira et al. (2012) applied the URM to zootherapy research. Their study was conducted in the public markets of five large cities in northeast Brazil, and the results show that most therapeutic indications could be treated by a large number of animal resources (i.e., the animal species were redundant). These results show that the medical system in the public markets (represented by a hybridization of different medical systems, see Ladio and Albuquerque 2014), leads to greater resilience in the local medical system according to the URM. Resilient environments have many alternatives for use and are more likely to absorb various disturbances that have the potential to compromise system functionality. Public markets are spaces where cultural information and influences from other regions are exchanged (Albuquerque et al. 2007). Therefore, it is understandable that a large number of redundant therapeutic targets would be found in these markets because the sellers must include species from other regions to their stores to diversify their treatments of therapeutic targets. This strategy may be highly functional in these systems because it ensures the provision of a wide range of products to buyers from different origins, which contributes to system functionality by providing species that may compensate for the local absence of others due to seasonal variations.

The URM must be evaluated in specific contexts, and it is important to understand the characteristics and dynamics of the knowledge system under study before making inferences regarding the system's behavior under the URM (see Alencar et al. 2014). For example, Santoro et al. (2015) observed that species richness was associated with the frequency of therapeutic targets (popularity) in a local medical system and negatively correlated with severe or lethal illnesses.

9.5 Perspectives

The URM is a valuable tool for evaluating redundancy in uses or functions in a knowledge system and the environmental impacts resulting from human activities that may enhance or decrease the resilience of a specific social-ecological system. We refer to such impacts in terms of the local knowledge system instead of the local medical system. The model is not restricted to medical use despite its original application, and the model may be easily used to test hypotheses in other areas of ethnobiology.

Social-ecological systems are complex, and inferences based on the URM must consider the dynamic characteristics and adaptive components of the system that could explain the observed behaviors. The level of overlap may result from different variables, such as the history of experimentation of the local populations with the resources available in the environment or locally perceived resource quality, which ultimately determine the redundancy of a resource (see Alencar et al. 2014). Thus, studies should be conducted to determine why human populations prioritize certain uses and species to understand if the frequency of occurrence of a therapeutic target increases the level of experimentation with a species used as a treatment.

In addition, the model is not intended to provide a complete explanation of the characteristics of a social-ecological system because other factors, such as historical events within the community and contact with other human groups, may be influential. There are also limitations to the understanding of the dynamics and complexities of social-ecological systems, specifically the social and cultural meanings of some species as therapies and their interrelationships with belief systems. Therefore, new studies are required to test the model in real situations and contribute to a better understanding of different social-ecological systems.

Acknowledgements We thank Isabel Díaz Reviriego, a PhD student from the Ethnoecology Lab (ICTA-Universitat Autònoma de Barcelona), for her helpful comments on the first draft of this chapter. This work was supported by funding from the Pernambuco State Foundation for Science and Technology (FACEPE—APQ—1264-2.05/10) and the National Council of Technological and Scientific Development (CNPq—Proc. 471989/2012-6).

References

Albuquerque UP, Oliveira RF (2007) Is the use-impact on native Caatinga species in Brazil reduced by the high species richness of medicinal plants? J Ethnopharmacol 113:156–170

Albuquerque UP, Andrade LHC, Silva ACO (2005) Use of plant resources in a seasonal dry forest (northeastern Brazil). Acta Bot Bras 19:19–38

Albuquerque UP, Monteiro JM, Ramos MA, Amorim ELC (2007) Medicinal and magic plants from a public market in northeastern Brazil. J Ethnopharmacol 110:76–91

Alencar NL, Santoro FR, Albuquerque UP (2014) What is the role of exotic medicinal plants in local medical systems? A study from the perspective of utilitarian redundancy. Rev Bras Farmacogn 24:506–515

Almeida CFCBR, Amorim ELC, Albuquerque UP, Maia MBS (2006) Medicinal plants popularly used in the Xingó region—a semi-arid location in northeastern Brazil. J Ethnobiol Ethnomed 2:15. doi:10.1186/1746-4269-2-15

Araújo TAS, Almeida ALS, Melo JG, Medeiros MFT, Ramos MA, Silva RRV, Almeida CFCBR, Albuquerque UP (2012) A new technique for testing distribution of knowledge and to estimate sampling sufficiency in ethnobiology studies. J Ethnobiol Ethnomed 8:11. doi:10.1186/1746-4269-8-11

Beiersmann C, Sanou A, Wladarsch E, De Allegri M, Kouyaté B, Müller O (2007) Malaria in rural Burkina Faso: local illness concepts, patterns of traditional treatment and influence on health-seeking behaviour. Malar J 6:106. doi:10.1186/1475-2875-6-106

Bengtsson J (1998) Which species? What kind of diversity? Which ecosystem function? Some problems in studies of relations between biodiversity and ecosystem function. Appl Soil Ecol 10:191–199

Berkes F, Colding J, Folke C (2000) Rediscovery of Traditional Ecological Knowledge as Adaptive Management. Ecol Appl 10(5):1251–1262

Brown KA, Flynn DFB, Abram NK, Ingram JC, Johnson SE, Wright P (2011) Assessing natural resource use by forest-reliant communities in Madagascar using functional diversity and functional redundancy metrics. PLoS ONE 6(9), e24107. doi:10.1371/journal.pone.0024107

Cadotte MW, Carscadden K, Mirotchnick N (2011) Beyond species: functional diversity and the maintenance of ecological processes and services. J Appl Ecol 48(5):1079–1087

Ceuterick M, Vandebroek I, Pieroni A (2011) Resilience of Andean urban ethnobotanies: A comparison of medicinal plant use among Bolivian and Peruvian migrants in the United Kingdom and in their countries of origin. J Ethnopharmacol 136:27–54

Ferreira Júnior WS, Siqueira CFQS, Albuquerque UP (2012) Plant stem bark extractivism in the northeast semiarid region of Brazil: A New aport to utilitarian redundancy model. Evid Based Complementary Altern Med. doi:10.1155/2012/543207

Ferreira Júnior WS, Ladio AH, Albuquerque UP (2011) Resilience and adaptation in the use of medicinal plants with suspected anti-inflammatory activity in the Brazilian Northeast. J Ethnopharmacol 138:238–252

Ferreira Júnior WS, Santoro FR, Nascimento ALB, Ladio AH, Albuquerque UP (2013) The role of individuals in the resilience of local medical systems based on the use of medicinal plants—a hypotheses. Ethnobio Conserv 2:1 ISSN 2238-4782

Ferreira FS, Albuquerque UP, Coutinho HDM, Almeida WO, Alves RRN (2012) Alves RRN (2012) The trade in medicinal animals in Northeastern Brazil. Evid Based Complementary Altern Med. doi:10.1155/2012/126938

Gazzaneo R, Lucena RFP, Albuquerque UP (2005) Knowledge and use of medicinal plants by local specialists in a region of Atlantic Forest in the state of Pernambuco (Northeastern Brazil). J Ethnobiol Ethnomed 1:9. doi:10.1186/1746-4269-1-9

Holling CS (1973) Resilience and stability of ecological systems. Annu Rev Ecol Syst 4:1–23

Kunwar RM, Acharya RP, Chowdhary CL, Bussmann RW (2015) Medicinal plants dynamics in indigenous medicines in farwest Nepal. J Ethnopharmacol 163:210–219

Ladio AH, Albuquerque UP (2014) The concept of hybridization and its contribution to urban ethnobiology. Ethnobio Conserv 3:6. doi:10.15451/ec2014-11-3.6-1-9

Ladio AH, Lozada M (2008) Medicinal plant knowledge in rural communities of North-Western Patagonia, Argentina. A resilient pactice beyond acculturation. In: Albuquerque UP, Ramos MA (eds) Current topics in ethnobotany. Ed Research Signpost, Kerala, pp 39–53

Low B, Ostrom E, Simon C, Wilson J (2003) Redundancy and diversity: do they influence optimal management? In: Berkes F, Colding J, Folke C (eds) Navigating social-ecological systems: building resilience for complexity and change. Cambridge University Press, Cambridge, UK

Machado IC, Lopes AV (2004) Floral traits and pollination systems in the Caatinga, a Brazilian tropical dry forest. Ann Bot 94:365–376

Molares S, Ladio A (2012) Mapuche perceptions and conservation of Andean *Nothofagus* forests and their medicinal plants: a case study from a rural community in Patagonia, Argentina. Biodivers Conserv 21:1079–1093

Peterson G, Allen CR, Holling CS (1998) Ecological resilience, biodiversity, scale. Ecosystems 1:6–18

Reynolds CS (2002) Ecological pattern and ecosystem theory. Ecol Model 158:181–200

Santoro FR, Ferreira Júnior W, Araújo TAS, Ladio A, Albuquerque UP (2015) Does plant species richness guarantee the resilience of local medical systems? A perspective from utilitarian redundancy. PLoS ONE 10(3), e0119826. doi:10.1371/journal.pone.0119826

Walker BH (1992) Biodiversity and ecological redundancy. Conserv Biol 6:18–23

Wellnitz T, Poff NL (2001) Functional redundancy in heterogeneous environments: implications for conservation. Ecol Lett 4:177–179