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Review

Nurse plant theory and its application in ecological restoration in lower subtropics of China

Hai Ren *, Long Yang, Nan Liu

Heshan National Field Research Station of Forest Ecosystem, South China Botanical Garden, Chinese Academy of Sciences, Guangzhou 510650, China

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Abstract

Nurse plants are those that facilitate the growth and development of other plant species (target species) beneath their canopy because they offer benign microhabitats that are more favorable for seed germination and/or seedling recruitment than their surrounding environment. Nurse plants have been mainly used to restore vegetation in arid and sub-arid zones in recent years. Based on summarizing the definition of nurse plant and target plant, we review the nursing effect mechanisms, ecological factors that influence nursing effect, relationships between nurse plant and ecological restoration. This review also brings forward possible pairs of nurse and target species at lower subtropical areas. Furthermore, we provide the potential tendency in nurse plant research and application.

Keywords: Nurse plant; Target species; Forest restoration; Nursing effect

1. Introduction

The relationship between plants, mainly including competition (negative effect), neutral, and facilitation (positive effect), is an important driving force of plant community succession or vegetation restoration. Ecological research has been focused on competition. Research on positive interaction between plants is still ignored [1] although it is gradually known as competition and facilitation (at least one side benefit) in the plant communities of the main biome of the world in the past 15 years. Nurse plants are those which facilitate the growth and development of other plant species (target species) beneath their canopy because they offer benign microhabitats that are more favorable for seed germination and/or seedling recruitment than their surrounding environment, for adjusting light, temperature, soil humidity and nutrient, as well as avoiding grazing [2,3]. Nurse plants can also establish the seedlings of target species through positive interaction between plants. Nursing effect is mainly accomplished by the interactions between plants, which influence community structure and dynamic performance intensively and the appearance or absence of specific species [2,3]. So the research on nurse plant can validate, consummate and enrich the theory that interactions among plant species drive the natural succession, which also provides the meaning of ecological restoration. In this paper we review the application of nurse plant in restoration ecology and the future development of this research field and especially discuss the possible pairs of nurse and target species at lower subtropical areas and its applications in forest restoration.

2. Nurse plant and target species

2.1. Nurse plant

Nurse plant plays an important role in recovering the structures and functions of primary ecosystem and is

* Corresponding author. Tel.: +86 20 37252916; fax: +86 20 37252831.
E-mail address: renhai@scib.ac.cn (H. Ren).

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thought to be a driving force in the succession of certain environments, especially in extremely degraded ones. In recent years, the phenomenon of nurse plant has been investigated in degraded habitats, including Mediterranean mountain, alpine habitat, arid desert, semi-arid shrub-land, northern dry forest, savanna, ecotone between farmland and pasture, swamp, tropical sub-humid forest, marshes, and so on [2,4–9].

The selection of nurse plants determines the success of the ecological restoration project. Some nurse plant and target species pairs have been confirmed in the study of the world's main biomes in the past few years. In the extremely degraded environment, the best nurse plants are the native species that offer microhabitat for target plant establishment or recruitment. Although some exotic species (e.g. *Robinia pseudoacacia* in southern England) are successfully used as nurse plant, the biological invasion of those species should also be prevented. Unpalatable species can be used in heavily grazed sites, because these nurse plants can provide refuges for small animals and target species [2,10,11]. It has been found that acervate plants evidently facilitate target plant seedling survival in rainless years. Legumes species are potential nurse plants which can improve the survival and growth of target species in desert and Mediterranean semi-arid habitat for their amelioration in soil nitrogen and overshadow function. However, the effect is undesirable when both nurse and target plants are legumes [12]. In desert, shrubs usually act as nurse plants for other seedlings, especially cacti. In forest, seedling establishment may be enhanced in the vicinity of adult plants that improve some extreme ecological factors [7]. This kind of positive effect by adult plants on their surrounding seedlings is called Nurse Plant Syndrome. The selection of nurse plants should avoid those species that release allelopathic compound. It is reported by Sanchez-Velasquez et al. [10] that different shaded levels formed by the nurse plant in the tropical sub-humid forest are significantly related to seedling establishment of target species.

Field survey is the foundation of nurse plant research. Generally, the species richness under nurse plant is higher than that in the open sites. Therefore, the nursing relationship between plants can be approximately estimated by interspecific association. Furthermore, the influence of nurse plant on seed germination of target species is examined by sowing seeds under nurse plant [13]. Seedling inseminations are mostly introduced in the confirmation of nurse plant and nursing effect between plants. In these experiments, the differences of seedlings of target species under the nurse plant and on the open (or between two crowns) are usually compared by analyzing survival rate and growth rate between them, combining observation of microhabitat. However, it should be indicated that the differences of soil physiochemical properties and microhabitat between under nurse plant and in the open are not obvious in some cases of facilitation [14,15].

2.2. Target species

The effect between plants is dependent on characteristics of each species, which means the selection of target species (regenerated ones) would also influence the restoration effect. Furthermore, the balance of the interaction is decided by the ecological requirement of target species and capability of dealing with incompatible habitat [16].

The positive effects of nurse plant on the shaded-tolerant pine and shrubs in late succession period are more than those on pioneer species and shaded-intolerant species [12]. The survival rate of *Ambrosia dumosa* in the open of arid environment is higher than that under shrubs because of its better adaptation in the open habitat, wherein, the interaction between *A. dumosa* and the nurse plant is competition, so that this species is not suitable as a target species. If the tolerance of target species is poor in abiotic habitat or the environment is extremely serious (such as dry year), nurse plant cannot increase the seedling establishment [17].

The age and size of target species should also be considered for the balance of facilitation and competition according to different life periods. The nurse plant has a stronger positive effect when the target species is young, whereas, competitive interaction is dominant when there are older or bigger target plants. When the age and size of the nurse plant is similar to that of the target species, the negative effect of tussock plants will be enhanced [18].

2.3. Positive and negative nursing effect

Only when the intraspecific competition exceeds interspecific competition, can plant species coexist in a community. Most interactions among species are represented through some intermediary, for example, light, nutrition, pollinator, herbivore and microbe. Competition actualizes by competing resources directly, but facilitation is realized by intermediary (such as soil) among species interaction [1,19,20].

Higher recruitment success near the nurse plant cannot eliminate the negative effect on target species, but it is sure that positive effects exceed negative ones, which result in the higher survival rate of target species under the nurse plant than that in the open [21,22]. When artificial methods such as shading or watering are used, the survival rate of target species may be lower than that under the nurse plants. For example, *Neobuxbaumia tetetzo*, a cactus in Mexico, is nursed by *Mimosa luisana*, a leguminous shrub, but the former species restricted the growth of the nurse plant and consequentially substituted it. Further research indicated that the survival rate under the nurse plant was higher than that on the artificial measures such as shading. In addition, it is shown by the experiment on Savanna in south Texas that nurse plants grew better by clearing the target species under the nurse plants, which can be described as the interaction of the parasite/host [23,24].

Plants, when growing closely, compete directly for limited resources (such as light, water, nutrition and space) if negative effect predominates. However, if positive effect predominates, the neighboring plants will show this interaction by increasing survival, growth and fitness. Both effects would take place simultaneously and change according to time and places, which are balanced by expression of the positive and negative ones. Some factors (such as physiological and developmental characteristics) may influence the balance [18], wherein the abiotic factors are mostly important for increasing the importance of positive effect in stressful habitats [4].

3. Reasons and mechanism of nursing effect

The nursing effect may not be attributed to single factor, but to the ultimate performance of some compound factors, including the crown architecture effect (influencing extinction coefficient, photosynthetic availability radiation, and temperature buffering), shading increment, buffering extreme temperature in microhabitat, increasing water, nutrition availability (litter of nurse plants), protection against herbivores, impact epiphyte and azotobacter in soil, and so on. However, among the above environmental factors, key factors should be explored in finding out the reasons of nursing effect [2,25].

Nurse plants facilitate target species by shading from crown architecture. Dewpoint temperature in winter under nurse plant *Cercidium microphyllum* was higher than that in the open of Sonoran Desert. Shading can protect plants under the nurse plant from strong radiation. Kulheim et al. [26] reported that light influences plant physiological process directly and indirectly, and interspecific differences are found in response to illumination in forest plants. Strong irradiation may destroy reaction centers of photosystems and produce oxidative damages. Shade-tolerant species under abundant sunlight will suffer from photoinhibition. Shading can avoid higher temperature, maintain higher soil humidity and lower transpiration of target species, moreover, it increases rhizosperic nutritious availability and circulation. All the processes above will improve physical and chemical property of soil and increase survival rate of target species [2,27,28].

Establishment of target species is affected by rainfall redistribution of nurse plant canopy. Shrubs constrain available understory water by rainfall redistribution at a lower intensity of rainfall, whereas, when there is a heavy rainfall, its redistribution by shrub crown arrives at understory through stem flow, which will influence the development of target species [29]. The distance between target species and nurse plant is another important factor and the stressful condition is ameliorated gradually from the center to the edge of canopy [30]. Castro et al. [29] planted two pine species (*Pinus sylvestris* and *Pinus nigra*) in the open, under the crown of sage (*Salvia lavandulifolia*) and beneath the crown of thorny shrubs (north and south directions), thus finding out that the survival rate was much higher under the north aspect of thorny shrubs. Nurse plants influence mainly target species on germination and seedling stage, wherein, positive effect may be showed evidently on seedling stage. It is believed that, nurse plant of predominant species in one successional stage will facilitate plants in the next successional stage by allelopathy. Changes of physiological balance between shading and drought were discussed by graph model [2]. In addition, some factors such as competition, consumption of resources by the nurse plant and superposition of root space between the nurse plant and target species should also be considered. Competition or disturbance of non-target species under the crown of the nurse plant (i.e. herbaceous plants) will play positive roles [1–4].

4. Ecological factors that influence positive effect

Even if positive effect takes place between nurse plant and target species, ambient condition (such as rainfall, soil humidity, grazing intensity and microhabitat) influences the radiation, soil, temperature and moisture under the crown of nurse plant, thereby changing the nursing effect. Positive effect of nurse plant increased with stressful abiotic conditions which was obviously stronger in higher mountains and on earlier restoration stage of degraded ecosystem [4].

In the overexploited area of Mediterranean Basin, 11 woody species were planted under 16 pioneer shrubs, which could aid in the establishment of woody species on later successional stage. The successful rate was improved in different habitats by using meta-analysis to analyze survival and growth among those species [31].

In a relatively nice habitat, spatial association among plants may be negative, but not positive. In a fertile habitat it was not positive by using nurse plant for its exhausting of soil resources. However, in an unfertile habitat, crops with small crown and poor growth facilitated the survival of sycamore seedlings [1,2].

In dry areas, changes in precipitation may alter the interactions among plants from competition to facilitation and vice versa. Ibanez and Schupp [32] conducted an experiment in Logan Canyon. They found that when the seedlings of curl-leaf mountain mahogany (*Cercocarpus ledifolius*) were placed under big sagebrush, facilitation was apparent in a dry year whereas negative effects were obvious during a wet year.

5. Case studies of nurse plants in vegetation restoration in lower subtropical areas of China

The nurse plant should be used in ecological restoration, mainly because the establishment of target species is greatly influenced by abiotic habitat and disturbance. Natural nurse plants were firstly put into ecological restoration in southeast Spain, where Castro et al. [29] found that native shrubs did not restrain the growth of two pine species but decreased their death rate. They comprehensively

considered some ecological and biological characteristics, such as rainfall, nurse species and target species, when applying nurse plants to improve seed germination and seedling establishment in ecological restoration.

Through extensive field investigation, interspecific association studies and field experiments, possible corresponding nurse and target species pairs were found in lower subtropics in China (Table 1).

Tussock plant *Evolvulus alsinoides* L. with 20 cm root system and only 3 cm high above ground is the unique nurse plant grown on a bare land of extremely degraded ecosystem at Xiaoliang, Guangdong Province. We found that *E. alsinoides*'s target species *Phyllanthus cochinchinensis* can grow with 60 cm root length and 42 cm root spread range with 27 cm height above ground. In severely degraded ecosystem, there exist two kinds of thresholds during ecosystem restoration, which are the initial threshold characterized by extremely harsh physical environmental conditions (including high temperature, aridity and poor soil) and the secondary threshold controlled mainly by biodiversity level and landscape context to seed provenance and establishment. In this circumstance, nurse plants are grass clustered with deep root, and so are target species. The formed tussock community is not only propitious to themselves but also advantageous in their resistance to poor environmental conditions. Enlightened by the above field phenomenon, exotic leguminous species, *Acacia auriculaeformis*, with fast growth rate and better resistance to infertility, was introduced as nurse plants at the severely degraded bare land of Xiaoliang. We planted several *A. auriculaeformis* individuals clusterly, then removed 1–2 individuals of 2-year-old plants from the fascicular *A. auriculaeformis* and some native species were planted under its canopy, including *Psychotria rubra*, *Pithecellobium clypearia*, *Syzygium hancei*, etc., whose survival rate could reach 80%. The survival rate is about 0% if those native plants are directly planted in bare lands. Similar experiment was also successful when carried out at Nan'ao island [33–35].

Table 1
Possible nurse and target species pairs at south subtropical areas in China

Places	Nurse plants	Target species
Bare land at Xiaoliang	*Evolvulus alsinoides*	*Phyllanthus cochinchinensis*
Artificial forest at Xiaoliang	*Acacia auriculaeformis*	*Psychotria rubra*
	Acacia auriculaeformis	*Pithecellobium clypearia*
	Acacia auriculaeformis	*Syzygium hancei*
Hillyland at Heshan	*Neyraudia montana*	*Rhodomyrtus tomentosa*
	Rhodomyrtus tomentosa	*Pinus massoniana*
Artificial forest at Heshan	*Acacia auriculaeformis*	*Psychotria rubra*
	Acacia mangium	*Michelia macclurel*
Hillyland at Dinhushan	*Neyraudia montana*	*Rhodomyrtus tomentosa*
Coniferous and broad-leaved mixed forest at Dinghushan	*Pinus massoniana*	*Schima superba*
	Castanopsis chinensis	*Schima superba*
Broad-leaved forest	*Castanopsis chinensis*	*Cryptocarya concinna*
Artificial forest at Nan'ao Island	*Pinus massoniana*	*Schima superba*
	Acacia auriculaeformis	*Psychotria rubra*
	Acacia auriculaeformis	*Pithecellobium clypearia*
	Acacia auriculaeformis	*Schima superba*
Artificial mangrove in National Natural Reserve of Zhanjiang	*Sonneratia apetala*	*Rhizophora stylosa*
	Sonneratia apetala	*Kandelia candel*

It was found that a pioneer grass *Neyraudia montana*, as the nurse plant of pioneer shrub *Rhodomyrtus tomentosa*, provided better microhabitat at grasslands of Heshan Station and Dinghushan Station, Guangdong Province, which were considered to be mild degraded ecosystem. *Pinus massoniana*, for its amelioration in light environment and soil property, was the nurse plant of *Schima superba* at Heshan Station, Dinhushan Station and Nan'ao Island. *Castanopsis chinensis* can facilitate *Schima superba* and *Cryptocarya concinna* at Dinghushan Station, probably because of the effects on shading, moist increment and enhancing available nutrient in soil [33].

Exotic species *Sonneratia apetala* has nursing effect on native mangrove plants *Rhizophora stylosa* and *Kandelia candel* at the coastal mudflat in the tideland area of Zhanjiang [36]. We had found that the survival rate of planted native mangrove species was very low at the severely degraded mudflat, however, the survival rate of *S. apetala* reached 95%. *S. apetala* grew fast and became a closed artifical forest within four years which could efficiently prevent the swashing of tidal wave, and increase soil nutrient therefore facilitating the invasion of some native mangrove species. The number of species and intensity of native species came to a peak in the artificial forests after six years of growing.

From these nurse plants and target species, the pattern [36–40] is found as follows. (1) The phenomenon of nurse plants takes place mostly on the early stages of restoration in degraded ecosystem or succession in plant community. (2) The phenomenon of nursing effect on the earlier stage of restoration or succession is mostly carried out as shrubs nursed by grasses and trees nursed by shrubs. (3) Nursing phenomenon usually happens among the native species in corresponding pairs. (4) Exotic leguminous species, *Acacia auriculaeformis* and *Acacia mangium*, are considered as good nurse plants for ameliorating N condition in soil and providing shade for target species including shrubs and trees. (5) Nurse plants have better characteristics than

those of target species, including being light-dependent, fast-growing, infertility resistant and drought tolerant. (6) The individuals of target species are generally smaller than those of nurse plants in the early stage. (7) Seedlings can successfully establish around the adult plants in forests for the amelioration of some extreme ecological factors. (8) Nurse plants are considered not only to play a key role in recovering the properties and functions of the primary ecosystem, but also to drive succession in poor environments on the early stage of restoration.

6. Perspective in the study and application of nurse plants

Recently, most researches are focused on seedling survival of the target species, but less on the research of seed germination, seedling growth and fitness. Most researches rest on describing the phenomenon of the nurse effect, less on the structural and functional mechanisms of positive effects towards ecophysiological and morphological aspect. With the purpose of ecological restoration, most researches concern about the influence of nurse plants on target species, but less on the feedbacks of target plants and without long-term observation in their interactions. Most species studied are native ones due to easy manipulation and prediction, lacking studies in exotic species. Nurse plants are mostly tussock shrubs, but not herbaceous or woody species, and fewer studies combine nurse plant with target species representing different successional stages. Nurse plants were less investigated in degraded ecosystem, especially in China, therefore, further tests are needed to find out the potentials of nurse plants in reforestation.

Currently, the main forest recovery methods include closing hillsides to facilitate afforestation (natural succession), artificial reforestation (rebuilding artificial pure forests or mixed forests directly), rebuilding forest construction (planting native species after picked logging) and Miyawaki's method (growing seedlings of native species directly). All of these methods have both strong or weak points. Some reforestation technologies, such as nutritive cup, water retaining agent, nodules, and shading, were developed to match the above methods [38–42].

The nurse plant technique is different from the above reforestation methods. Due to the functions of nurse plant in ameliorating microhabitat (such as shading and water increment, extreme temperature buffering in microhabitat, and so on) suitable target species were grown under the crown of nurse plants. Even more, positive effects among plants make target species establish successfully and shortened restoration course. The successful utilization of nurse plants may become a novel reforestation method which will explore excellent native species, accelerate natural recovery and enrich species diversity.

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