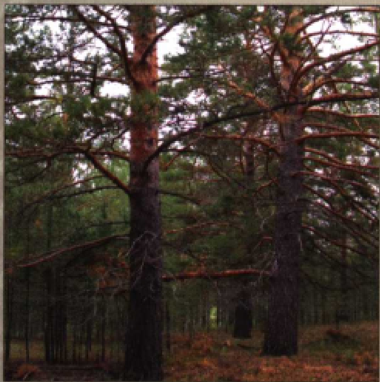
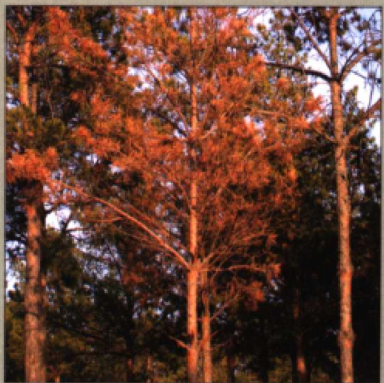
朱教君 曾德慧 康宏樟 吴祥云 范志平／著

沙地樟子松人工林衰退机制

Decline of *Pinus sylvestris* var. *mongolica* Plantations on Sandy Land



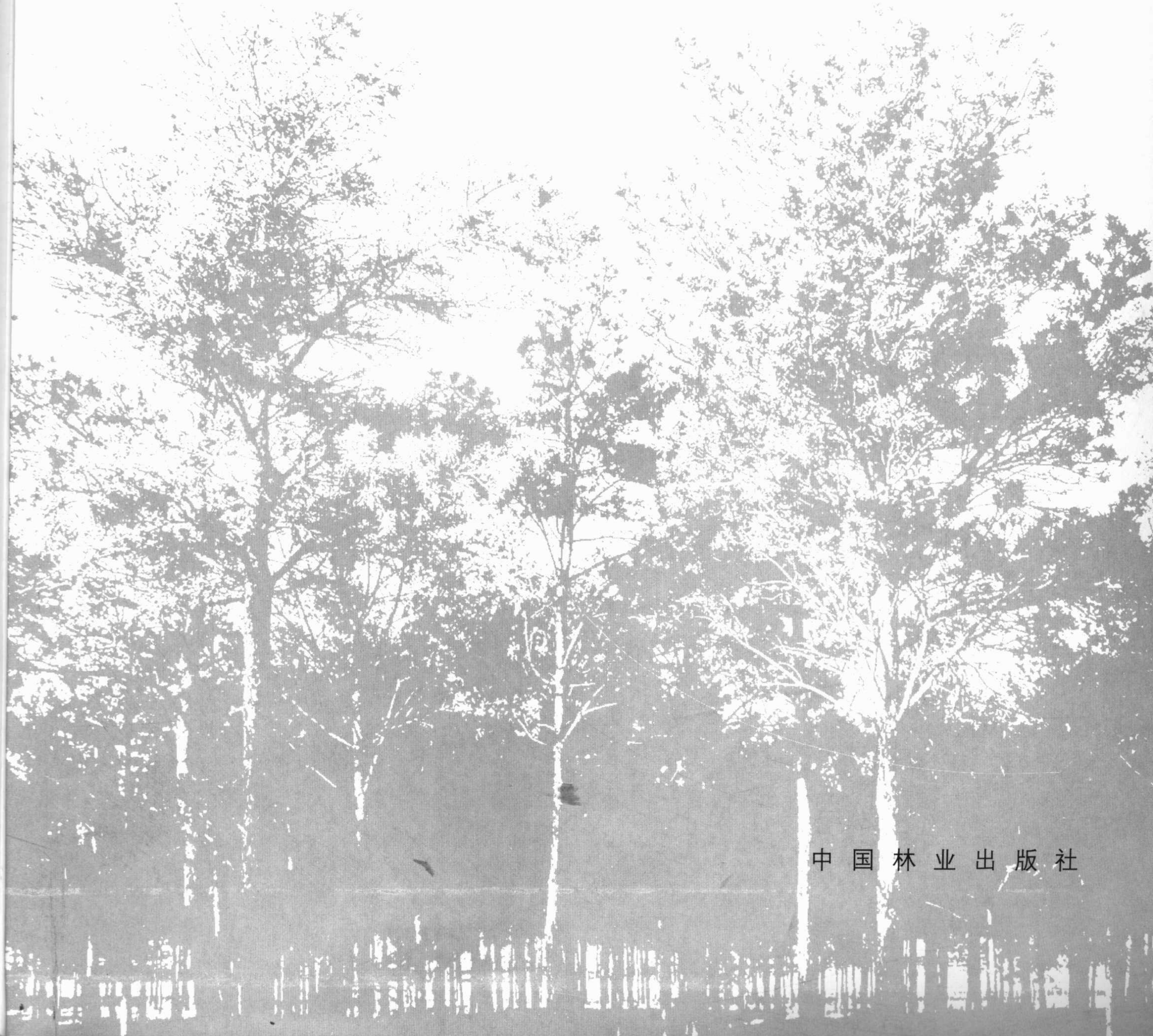



中国林业出版社

本专著由中国科学院知识创新工程重要方向项目(KZCX3—SW—418)、中国科学院“引进国外杰出人才(百人计划)”项目和辽宁省自然科学基金(博士启动基金)项目(2002110016)资助。

沙地樟子松人工林衰退机制

朱教君 曾德慧 康宏樟 吴祥云 范志平／著



中国林业出版社

图书在版编目(CIP)数据

沙地樟子松人工林衰退机制/朱教君等著. -北京：中国林业出版社，2005. 12
ISBN 7-5038-4124-9

Ⅰ. 沙… Ⅱ. 朱… Ⅲ. 沙漠-樟子松-人工林-研究 Ⅳ. S791. 253

中国版本图书馆 CIP 数据核字（2005）第 111943 号

沙地樟子松人工林衰退机制

出版 中国林业出版社(100009 北京西城区德内大街刘海胡同 7 号)
网址:www. cfph. com. cn 电话:(010)66184477
发行 新华书店北京发行所
印刷 北京市昌平百善印刷厂
版次 2005 年 12 月第 1 版
印次 2005 年 12 月第 1 次
开本 889mm×1194mm 1/16
印张 18. 25
字数 540 千字
印数 1～800 册

定价 60. 00 元

编写人员：

朱教君 曾德慧 康宏樟 吴祥云 范志平 姜凤岐
李凤芹 王贺新 徐 慧 谭 辉 许美玲 于立忠
胡理乐 张金鑫 徐大勇 陈广生 陈伏生 赵 琼
杨 涛 何 跃 王 巍 段海峡 刘宝勇

Editorial Members:

Jiaojun ZHU, Dehui ZENG, Hongzhang KANG, Xiangyun WU, Zhiping FAN, Fengqi JIANG, Fengqin LI, Hexin WANG, Hui XU, Hui TAN, Meiling XU, Lizhong YU, Lile HU, Jinxin ZHANG, Dayong XU, Guangsheng CHEN, Fusheng CHEN, Qiong ZHAO, Tao YANG, Yue HE, Wei WANG, Haixia DUAN and Baoyong LIU

Forward

序

樟子松（*Pinus sylvestris* var. *mongolica*）是欧洲赤松（*Pinus sylvestris*）分布至远东的一个地理变种，天然分布在中国大兴安岭（北纬50°以北）和大兴安岭西麓的呼伦贝尔沙地草原（红花尔基沙地）。樟子松以其抗寒、抗旱和较速生等优良特性已成为我国北方半干旱风沙区营造防风固沙林、农田/草场防护林、水土保持林和用材林的主要树种。自20世纪50年代辽宁省彰武引种樟子松固沙造林试验成功以来，人工樟子松林发展十分迅速，三北地区的辽宁、内蒙古、陕西、甘肃和新疆等13个省（自治区）300多个县（旗）先后引种栽培。但自20世纪90年代以来，较早引种的沙地樟子松人工林出现了不同程度的衰退现象，并呈大面积蔓延的趋势。与此同时，樟子松人工造林仍在北方干旱、半干旱地区大范围推广。因此，探明沙地樟子松人工林衰退的原因，切实做到适地适树，建立有效的防控对策，实现可持续经营，对我国三北防护林/人工林建设具有重大意义。

《沙地樟子松人工林衰退机制》是近十几年来中国科学院沈阳应用生态研究所林业生态工程领域科研成果的凝聚，是作者在该领域长期研究实践的总结。本书作者在连续主持国家科技攻关、国家自然科学基金和中国科学院知识创新工程项目等研究的基础上，对樟子松的分布、沙地樟子松的引种与栽培、沙地樟子松特性与生长发育规律等进行了全面总结，通过分析沙地樟子松人工林生物、生态适宜性，阐述了沙地樟子松人工林衰退的主要特征、衰退规律以及衰退的水分、养分和微生物机制，在此基础上，提出了沙地樟子松人工林的发展方向及相关的管理措施。相信本书的出版对沙地樟子松人工林的合理经营将产生重要的指导作用。

在本书即将面世之际，我谨向作者表示衷心祝贺，希望这部凝集着科技工作者心血的科研成果为我国人工林/防护林建设做出应有的贡献。

2005年11月25日

前言

樟子松（*Pinus sylvestris* var. *mongolica*），东北俗称海拉尔松，为松科（Pinaceae）松亚科（Pinoideae）松属（*Pinus*）双维管束松亚属（Subgenus *Pinus*）油松组（Sect. *Pinus*），中国大兴安岭（北纬50°以北）和大兴安岭西麓的呼伦贝尔沙地草原（红花尔基沙地）为其主要天然分布区。与中国主要森林树种相比，虽然樟子松的天然林分面积和木材蓄积量较小，但其具有较强的耐寒、耐旱、耐贫瘠土壤和较速生等优良特性，加之其树干通直，材质良好，适生于沙地，又能起到防风固沙等作用，因此，在中国北方，尤其是干旱、半干旱风沙地区，已经成为营造防风固沙林、农田/草场防护林、水土保持林和用材林的主要树种。

沙地樟子松的引种要追溯到20世纪50年代初。1952年东北人民政府颁布了营造东北西部与内蒙古东部防护林的决定，同年，辽西省人民政府于现辽宁省彰武县章古台建立了“辽宁省章古台固沙造林试验站”（现辽宁省固沙造林研究所），1953年中国科学院林业土壤研究所（1987年更名为中国科学院沈阳应用生态研究所）也来到章古台开展相应的研究工作。沙地樟子松的引种工作始于1955年春，中国科学院林业土壤研究所从黑龙江省牡丹江市苗圃和带岭苗圃引种2年生樟子松苗（6508株）和1年生樟子松苗（3889株）到科尔沁沙地东南缘（辽宁省彰武县章古台大一间房西南1.5 km处的固定沙丘）；同年秋季，辽宁省章古台固沙造林试验站也进行了樟子松引种造林试验，从而开创了樟子松治沙造林的先例。引种试验初步成功后，逐渐在周边地区推广。自1978年三北（东北、西北、华北简称三北）防护林体系工程建设启动以来，先后在辽宁、内蒙古、陕西、甘肃和新疆等13个省（自治区）300多个县（旗）引种栽培取得了成功，并在三北风沙区开始大规模引种栽植。据不完全统计，全国沙地樟子松面积达到3.0×10^5 hm^2。这些樟子松防风固沙林在三北广大沙区发挥了巨大的生态、经济与社会效益。目前，辽宁省彰武县章古台地区的沙地樟子松人工林面积已达1.5×10^4 hm^2。然而，自20世纪90年代初以来，最早引种的辽宁省彰武县章古台地区的沙地樟子松人工固沙林出现了枝叶变黄、生长势衰弱、病虫害，继而全株死亡的大面积衰退现象。调查结果显示，辽宁省3.83×10^4 hm^2樟子松人工固沙林中已有2.50×10^4 hm^2发生衰退，占65.27%；其他部分地区也出现了类似情况。樟子松人工固沙林的衰退已严重危害了现存林分的正常生长，继续发展下去相当部分的沙地樟子松人工林将被毁掉，尤其是现存植被已产生了巨大变化，致使部分原已固定的沙地出现了流沙。然而，目前中国沙地樟子松人工造林仍在北方干旱、半干旱沙区大面积推广。面对如此巨量赋有特殊意义的能提供多种生态服务功能的防风固沙林，解释为什么大面积沙地樟子松人工林衰退，揭示其机理并探讨防治措施，解决目前沙地樟子松人工林发

展方向及培育等理论和实践问题，正是编著本书的基本目的。

为探明沙地樟子松人工林衰退的原因，更好地经营管理该树种沙地人工林，自20世纪90年代以来，中国科学院沈阳应用生态研究所林业生态工程研究组开展了相关研究；尤其是本书作者相继主持和参与了国家“八五”科技攻关项目“现有防护林合理经营与改造技术研究”（1991～1995，姜凤岐、朱教君主持），国家自然科学基金项目“樟子松人工固沙林稳定性研究”（1994～1996，姜凤岐主持）、“固沙林经营基础研究”（1996～1998，姜凤岐主持）、“樟子松天然更新障碍因子研究”（1998～2000，曾德慧主持），中国科学院知识创新工程重要方向项目“典型人工用材林与防护林衰退机理及可持续经营研究”（2002～2005，朱教君主持）等多项包括樟子松在内的防护林研究课题。为适应研究工作的需要，先后在内蒙古自治区科尔沁左翼后旗甘旗卡、辽宁省彰武县章古台、辽宁省昌图和康平等地建立了多个试验站、点，多次到樟子松原产地呼伦贝尔草原的红花尔基沙地进行了调查，并开展了不同起源沙地樟子松林的比较研究；同时，与辽宁省固沙造林研究所、辽宁省风沙地农业研究所和辽宁省工程技术大学等单位协作，开展包括沙地樟子松人工林衰退在内的系列研究。另外，以中国科学院沈阳应用生态研究所大青沟沙地生态实验站为基点，建立了沙地樟子松疏林草场试验示范林。本书在多项研究的基础上，分析了沙地樟子松人工林生物、生态适宜性，总结了沙地樟子松人工林衰退的主要特征、衰退规律，阐述了沙地樟子松人工林衰退的水分、养分和微生物机制，在此基础上，提出了应以恢复生态学、近自然林业、森林分类经营和森林生态系统管理等先进的林业经营理论与基本原则为依据，对沙地樟子松人工林实施生态经营与管理。

水分是沙地树木生长的主要限制因子，大气降水和地下水是沙地土壤水分的主要来源。多年的降水特征表明，科尔沁沙地的降水少且集中；生长季内林分蒸腾耗水量较大，土壤含水量及林内地下水位越来越低。由于樟子松固沙林土壤含水量的减少（有效性差），致使树木在生长发育过程中受到水分胁迫；而地下水位的下降，使土壤水分难以通过毛细管作用得到补偿，从而加重土壤水分亏缺，不能满足树木正常生长的水分要求，这是造成樟子松人工固沙林生长衰退的一个最重要、最直接的原因。由于水分的不足，导致养分、微生物（外生菌根菌）等不协调，诱发树势衰弱，极易受到病（A型松球壳孢菌）、虫（松梢螟）害等侵入。另外，樟子松的生物、生态适宜性表明，天然沙地樟子松原产区与引种的人工林区气候因子的差异主要体现在水分与热量两个方面；尤其是极低气温是影响沙地樟子松适生与否的关键因子之一。由于多数生物种类当它们被迁移到其非自然分布区时，固有遗传特性的生境发生变化，其生存、发展就会受到一定的限制。沙地樟子松（包括山地樟子松）原生长在北方较寒冷地带，适应那里气候条件，向南迁移5个纬度后（由红花尔基的N47°35′～48°36′，E118°58′～120°32′到章古台N42°43′～43°20′，E122°22′～123°22′），历代生活条件得以形成的动态平衡便被打破，即该树种本来适应短暂的夏天，在引种区较长的生长季节条件下，生长节律加快，但却不能有效地利用引种区的水、热资源；使樟子松在原产地形成的遗传特性不能与引种区实际季节性水分、温度变化相协调；因此，使得樟子松原有的生长发育节律改变，导致其生命周期的缩短。

科尔沁沙地东南缘章古台地区的沙地樟子松人工林是受到强烈人为干扰的生态系统，林内每年的凋落物大部分都被人为收集带出林外；同时，林内的草本植物，因为长期的放牧活动，生物量亦极低，即大量的养分因为上述原因和林木生物量的收获而从生态系统中流出。因此，在这种养分不断流失而又得不到补充的情况下，沙地樟子松人工林生态系统中的树木针叶的养分再吸收效率及树木的养分利用效率的高低就直接影响到整个系统的养分水平、植物的生产力水平、林分和土壤的衰退速度及系统的健康状况等。沙地樟子松人工林地土壤N有效性随着林龄的增加有所增加，增加的有效N形态为NO_3^-－N，而NH_4^+－N变化则不随林龄的变化而变化；不同林地土壤有效N的形态存在明显的差异，尤其树种特性对土壤NH_4^+－N/NO_3^-－N具有重要的影响，而长期放牧使林地土壤NH_4^+－N和/NO_3^-－N变得越来越少。沙地樟子松人工林土壤N周转速率表明，近成熟林比中龄林具有更强的N矿化能力和更高的N周转速率，但也发现林龄越大，土壤NH_4^+－N转化为NO_3^-－N

的能力越强。沙地樟子松人工林地土壤全磷和速效磷含量都极低，全磷仅为0.05～0.18 mg/g，表层土壤速效磷为1.50～2.24 mg/kg，处于中国土壤磷素含量的最低水平，且磷素的有效性差，速效磷含量不到全磷的0.5%。从沙地樟子松针叶养分再吸收效率看，樟子松树木叶片N、P、K、Mg的再吸收效率表现了随年龄增加而减少的趋势；随着年龄的增加沙地樟子松树木单位养分的生产力（养分利用效率）也表现出下降的趋势。因此，可以推断在章古台地区随着樟子松生长时间的增加，樟子松表现出了在养分利用上的逐步衰退特征。另外，与沙地樟子松天然林林地土壤养分比较发现，章古台地区的樟子松人工林的土壤有机质及土壤酶活性明显低于红花尔基地区的同龄林土壤，特别是人工林土壤有机质的显著低下，可能致使林地养分不足、失衡；由于养分的失衡，诱发树势衰弱、病虫害发生；这可能是导致樟子松人工固沙林衰退的另一个重要原因。

无论是引种区尚未衰退的沙地樟子松人工林（章古台）还是原产区（红花尔基）的沙地樟子松天然林，都可以观察到随着林龄变化，土壤微生物（细菌、放线菌和真菌）数量与林分年龄之间存在着密切相关关系，即随林龄增加，土壤微生物数量增加，一定年龄后降低；但土壤微生物数量峰值的出现时间在引种区（章古台）比原产区（红花尔基）要提前40年左右。沙地樟子松人工林内微生物数量的减少主要是由于干旱及高温引起的。比较沙地樟子松赖以生存的外生菌根菌数量与多样性发现，引种区尚未衰退的沙地樟子松人工林低于天然林，尤其是沙地樟子松的外生菌根菌在干旱胁迫（－1.20MPa 水势）和高温（＞37℃）条件下不能生长或死亡的事实，证明外生菌根菌数量的减少或死亡可能是导致沙地樟子松人工林衰退的又一个原因。

另外，沙地樟子松引种区的其他环境系统，如林分密度的调控环境、大气降水的化学环境及病虫害的发生与危害环境等，也是导致沙地樟子松人工林衰退的可能原因。

基于沙地樟子松人工林衰退的机制，沙地樟子松人工林经营的总体方向应遵从恢复生态学原理和近自然林业原理。即根据植物群落演替理论，在植被演替的某个阶段引进新的物种进行植被改良时，应充分考虑植被演替阶段所处的生态环境和物种的适应程度。从沙地樟子松人工造林的最初设想出发，最早引种沙地樟子松造林就是为了防风固沙，其最初的目的乃至现今的经营目标，就是想努力把沙地樟子松人工林发展成大面积沙地森林生态系统，这种经营理念本身就违背了植被演替的自然规律。科尔沁沙地东南缘属于典型的半干旱气候类型，根据传统生态学与经典植被自然演替理论，半干旱气候类型的科尔沁沙地生态系统演替的顶极群落应为疏林草原和草甸草原。在没有人为干扰的条件下，这种顶极群落经过漫长的时间应该是可以达到的。但是，在人工植被建设中，如沙地樟子松人工林的引种与栽培，在造林之后形成了一种沙地特有的植物群落；在这种人工植被演替的过渡阶段，原有的优势种（沙地樟子松）可能会出现衰退甚至死亡的现象，而新的优势种可能尚未形成，因此，整个植被系统必然会出现衰退。在这种情况下应尽量减少人为干扰，使其自然发展；或者采取适当的措施，控制大面积沙地樟子松纯林，充分重视乡土树种或物种的使用，在宏观上控制森林发展的比例，使沙地生态系统向其顶极群落，即“疏林草原”方向发展。另外，要充分考虑恢复生态学中的限制性生态因子原理，对引进的外来种一定要适合当地的生态条件及所引物种的生物、生态特性。

对于目前现有的沙地樟子松人工林的具体经营应从以下3个方面考虑：一是在现已衰退的林分中，清除已彻底衰退的林分，对清除后的林地进行封育。因为衰退的林分内已形成以草本植物为主的植被层，封育后可保证现已固定沙地的稳定，在此基础上任其自然发育；或采取人为措施使其向疏林草原方向发展。二是对于现在尚未明显衰退的林分，由于大面积沙地樟子松纯林消耗当地大量的水资源，对不同年龄的林分进行不同强度间伐（主要包括：高强度间伐、斑块状皆伐），使现有林分生长与当地水资源情况基本达到平衡。三是对于将来重新营造或改造的林分，应根据当地具体情况，如植被退化的程度、特点、经济与技术承受能力等确定未来林分营建、发展目标，使重建的林分与当地的顶极植被发展方向相一致；再不能营造大面积樟子松纯林，大面积樟子松纯林的经营是不符合自然发展规律的。

本书是一部在知识创新思想指导下，立足于防风固沙林工程建设和经营发展需要的学术专著。但必须指出的是，由于本书所涉列的研究对象仅为沙地樟子松林，尚未能与其他樟子松林（如山地樟子松天然林）进行比较研究；此外，本书以较早引种区（科尔沁沙地东南缘）的沙地樟子松人工林为主要研究对象，对其他地区引种的沙地樟子松人工林没有进行系统研究。所有这些不足，特别是对沙地樟子松人工林衰退的风险评价理论与技术研究等，都将是沙地樟子松人工林未来研究的发展方向。

全书由朱教君主持编写，具体分工如下：朱教君负责编写大纲的制订、前言、第三章、第四章部分、第五章部分、第七章和第八章部分；康宏樟负责编写第一章、第二章、第五章部分、全书图片加工；吴祥云负责编写第四章；曾德慧负责编写第六章；范志平编写第八章部分；徐大勇协助编写第五章部分；徐慧、许美玲协助编写第七章部分；陈伏生、陈广生协助编写第六章部分。全书初稿经朱教君全面修改，最后由朱教君、李凤芹、康宏樟统稿；于立忠、张金鑫进行了文字处理。

本书承蒙我国著名生态学家、中国科学院院士孙鸿烈教授在百忙之中拨冗赐序，在本书出版之际，谨向孙鸿烈院士表示衷心的感谢。在本书的编写过程中，主要引用了本书作者的研究成果，同时参考了相关领域的国内外文献，参考文献列于全书最后；在此，向文献作者们致以真诚的谢意。

本书受中国科学院知识创新工程重要方向项目（KZCX3-SW-418）、中国科学院“引进国外杰出人才（百人计划）”项目、辽宁省自然科学基金（博士基金）和国家自然科学基金（30371149）项目资助；同时，书中内容很多是近20年来中国科学院沈阳应用生态研究所林业生态工程研究组（防护林工程组）科研工作的凝聚。在此，我们谨把它当作一份礼物，献给原中国科学院林业土壤研究所（中国科学院沈阳应用生态研究所）在50年前曾为沙地樟子松人工林引种、营造与经营做出贡献的所有科学家和工作人员！对于现在正在从事该领域研究的人员，期望它能起到铺路石的作用，为今后的研究提供一些参考。

朱教君

2005年7月27日

Preface

前言

Pinus sylvestris var. *mongolica*, a geographical variation of Scotch pine (*P. sylvestris*), naturally distributes in Daxinganling Mountain and Hulunbeier sandy plain of China, and parts of Russian and Mongol (N46°30′ - 53°59′, E118°00′ - 130°08′). *P. sylvestris* var. *mongolica* is a strongly cold - resistant and drought - resistant tree species, which can grow healthily in infertile soil, although its natural distribution range is narrow and its stocking volume is low compared with most forest tree species in China. In addition, because *P. sylvestris* var. *mongolica* has straight trunk, can grow on sandy land, and can shelter wind and fix sandy land, it has become one of the optimum coniferous tree species for constructing protective plantations on sandy land, farmland and grassland in "Three North" (Northwest, North and Northeast of China) areas.

The introduction of *P. sylvestris* var. *mongolica* on sandy land can date back to the beginning of 1950s. The first introduction of *P. sylvestris* var. *mongolica* to the southeastern Keerqin sandy land (N42°43.508′, E122°32.89′) was conducted by the researchers from Institute of Forestry and Pedology, Chinese Academy of Sciences (The current name: Institute of Applied Ecology, Chinese Academy of Sciences.) in the spring of 1955. After the primary success of the introduction, *P. sylvestris* var. *mongolica* plantations on sandy land have been established in northern China, especially, since the "Three North" (Northwest, North and Northeast of China) Protective Forest System Project (TNPFSP) started in 1978, the tree species has been broadly introduced to more than 300 counties, belonging to 13 provinces, such as Liaoning, Neimenggu, Shanxi, Gansu and Xinjiang in the "Three North" areas. The plantation area of *P. sylvestris* var. *mongolica* on sandy land in northern China had reached more than 3.0×10^5 hm^2. These *P. sylvestris* var. *mongolica* protective plantations have brought marvelous ecological, economical and social benefits to the sandy land in "Three North" areas. Since the beginning of 1990s, however, *P. sylvestris* var. *mongolica* plantations in the earliest introduction area (southeastern Keerqin sandy land) have declined, which are characterized by top withered, lower growth rate, dead stems occurred and no natural regeneration. Investigation reports indicated that 2.5×10^4 hm^2, i.e., 65.27% of the *P. sylvestris* var. *mongolica* plantations in Liaoning Province, had degraded. The similar situation has taken place in other regions in the *P. sylvestris* var. *mongolica* plantation areas as well. Thus, the *P. sylvestris* var. *mongolica* plantations on sandy land in northern China were threatened. Moreover, the further *P. sylvestris* var. *mongolica* plantations are planting in arid and semi - arid regions in the north of China. However, the natural forests on sandy land (i.e., in Honghuaerji, Hulunbeier sandy plain in Inner Mongolia of China) have showed a very healthy situation at the same growth stage of the plantations.

The objectives of this book are trying to explore what the decline mechanisms are through summarizing the research results of many research projects related to the problems of *P. sylvestris* var. *mongolica* plantations on sandy land in the recent decades. The major projects presented over by the authors of the book from Institute of Applied Ecology, Chinese Academy of Sciences (CAS) since 1990s included: Key National Science and Technology project in the 8th five-year planning, Management and Improvement Technology for Current Protective Plantations (1991 - 1995, presided by Fengqi Jiang and Jiaojun Zhu); 3 National Nature Science Foundation projects, Stability of *P. sylvestris* var. *mongolica* Sand-fixation Plantations (1994 - 1996, presided by Fengqi Jiang); Foundational Management for Sand - fixation Plantations (1996 - 1998, presided by Fengqi Jiang) and Obstacle Factors of Natural Regeneration of *P. sylvestris* var. *mongolica* (1996 - 1998, presided by Dehui Zeng); and CAS Knowledge Innovation Research project: Degraded Mechanism and Sustainable Management of Typical Timber Plantations and Protective Plantations (2002 - 2005, presided by Jiaojun Zhu). For the requirements of these research projects, many experimental stations and field plots were established in Ganqika, Keerqin Zuoyihouqi County of Inner Mongolian Autonomous Region (Daqinggou Ecological Station, Institute of Applied Ecology, CAS), Zhanggutai, Zhangwu County, Shuangjingzi, Changtu County, and Kangping, Kangping County of Liaoning province, respectively. In addition, for the comparisons between natural forest and plantations of *P. sylvestris* var. *mongolica* originated differently, many investigations had been carried out in the natural distribution area of *P. sylvestris* var. *mongolica* forests, i. e. Honghuaerji, Hulunbeier sandy plain of Inner Mongolian Autonomous Region, China. Moreover, experimental demonstration plantations of *P. sylvestris* var. *mongolica* on sandy land, i. e., sparse - trees distribution in the grassland, were established in Daqinggou Ecological Station, Institute of Applied Ecology, CAS. Meanwhile, the projects were cooperated with Institute of Sand Fixation and Afforestation, Academy of Agricultural Sciences, Fuxin Branch, Liaoning province and Technical University, Liaoning Province etc. A series of research experiments and observations related to the degradation mechanisms of *P. sylvestris* var. *mongolica* plantations on sandy land were conducted during the researches of the projects.

Based on the integration of the research projects mentioned above, this book summarized the comprehensive situations of *P. sylvestris* var. *mongolica* forests/plantations on sandy land. The book tried to answer the following question: Why did large area of *P. sylvestris* var. *mongolica* plantations degraded? What are the mechanisms? How to stop or avoid the decline phenomena? What are the development directions of *P. sylvestris* var. *mongolica* plantations on sandy land and how to manage the plantations? The contents of the book included: Distribution of *P. sylvestris* var. *mongolica* forests/plantations on sandy land, Introduction and culture of *P. sylvestris* var. *mongolica*, Characteristics of the growth and development of *P. sylvestris* var. *mongolica* forests/plantations on sandy land, Decline characteristics and environmental systems of *P. sylvestris* var. *mongolica* plantations, Decline mechanisms of *P. sylvestris* var. *mongolica* plantations from water balance, nutrient views and microbe views, respectively, and Management of *P. sylvestris* var. *mongolica* plantations from ecological views. These contents gave the analyses on the biological and ecological adaptation of *P. sylvestris* var. *mongolica* plantations on sandy land, summarized main characteristics and law of its decline, and elucidated the decline mechanisms from views of water, nutrients and microbes. Based on these results we appealed to ecological management of *P. sylvestris* var. *mongolica* plantations on sandy land according to the advanced management theory and foundational laws, including restoration of ecology, next - to - nature forestry, management of forest classification and management of forest ecosystem.

There were three obvious decline features for the *P. sylvestris* var. *mongolica* plantations on sandy land comparing with the natural *P. sylvestris* var. *mongolica* forests on sandy land, i. e. , first, the plantations could not regenerate naturally, but the natural forests could regenerate very strongly; second, the decline phenomena characterized by top withered, lower growth rate and dead stems in the plantations, but very healthy in the natural forests at the same development stage as the plantations; third, the mature age of the plantations was about 60 years shorter than that of natural forests.

Aimed at the three decline features, many experiments and investigations such as long term observation of soil water in content and ground water table, effects of water conditions on germination of *P. sylvestris* var. *mongolica* seeds from different provenances, eco – physiological characteristics of *P. sylvestris* var. *mongolica* plantation saplings, heterogeneity of soil water for *P. sylvestris* var. *mongolica* plantations, transformation & efficiency of nitrogen & phosphorus in *P. sylvestris* var. *mongolica* plantations, effects of ectomycorrhizal fungi inoculation on growth of *P. sylvestris* var. *mongolica* seedling, and effects of nutrient, pH, drought stresses and temperature on growth of ectomycorrhizal fungi in *P. sylvestris* var. *mongolica* plantations etc. were conducted in series. The major results were summarized as follows.

Water is one of the most important limiting factors to the survival and growth of trees on sandy land. Water in sandy land mainly comes from precipitation and underground water. Precipitation of long term observation showed two traits of low amount and convergence in Keerqing sandy land. During the growth period, tree transpiration and soil evaporation were very strong, thereby soil water became less and less, and underground water table became lower and lower, which was difficult to support the normal growth of *P. sylvestris* var. *mongolica*. This may be the important and direct cause for the degradation of *P. sylvestris* var. *mongolica* plantations on sandy land. Due to water shortage, the balance in nutrients and microbes (ectomycorrhizal fungi) was broken, and the growth potential and the ability resistant to diseases and insects, e. g. *Sphaeropsis sapinea or Diplodia pinea* (pathogenicity), *Dioryctria rubella* (splendid knot – born moth), decreased. Furthermore, the traits of biological and ecological adaptation of *P. sylvestris* var. *mongolica* indicated that the factors of water and temperature were significantly different between the natural distribution area and introduction area. Especially, the extreme lowest temperature is one of key factors determined whether *P. sylvestris* var. *mongolica* could adapt to grow in the introduction area or not. Generally, it is natural for many plant species that their inherent genetic characteristics will change to acclimatize the new environments. Their survival, growth and development will be limited when they are introduced to non – natural distribution area. *P. sylvestris* var. *mongolica* on sandy land (including mountain *P. sylvestris* var. *mongolica*) naturally distributes in northern China, where it is rather cold, e. g. , Honghuaerji (N47°35′ – 48°36′, E118°58′ – 120°32′). However, when it was introduced to Zhanggutai (N42°43′ – 43°20′, E122°22′ – 123°22′), the latitude decreased 5 degrees, and the summer became longer, therefore, the growth processes were accelerated. However, *P. sylvestris* var. *mongolica* trees could not use the water and heat resource effectively, so the original life rhythm or the dynamic balance of *P. sylvestris* var. *mongolica* trees was broken. Therefore, the growth and development laws of *P. sylvestris* var. *mongolica* in the plantations were changed, which gave rise to shortening its life cycle.

The *P. sylvestris* var. *mongolica* plantations at Zhanggutai in the southeastern edge of Keerqin sandy land has been seriously disturbed by human activities. For example, most of the litter had been moved out from the plantation stands. Meanwhile, the productivity of the herb in the stands was also very low because of the long – term grazing, i. e. , most nutrients had lost through those mentioned activities and wood harvest. Therefore, the nutrient resorption of needles and the nutrient use efficiency of trees in the plantations of *P. sylvestris* var. *mongolica* on sandy land would affect the nutrient balance of the whole system, which influenced the productivity of vegetation, the growth rates and the health of the plantation stands. The availability of nitrogen with nitrate form in the plantation soil increased with the stand ages, but the nitrogen with ammonia form didn't vary with stand ages. There had significant differences among nitrogen availabilities of soil in different stands, especially the characteristics of tree species had important effects on nitrogen with nitrate or ammonia forms in the soil. It was found that the transformation ability of nitrogen from ammonia form to nitrate form increased with stand ages. The rate of nitrogen turnover in the plantations indicted that there had stronger nitrogen mineralization and higher nitrogen turnover rate in near – mature (more than 47 years old) plantations than that in half – mature (about 30 years old) plantations. Both total phosphorous and available phosphorous of soil in *P. sylvestris* var. *mongolica* plantations were very low, i. e., 0.05 – 0.18 mg/g and 1.50 – 2.24 mg/kg for total phosphorous and quick phosphorous in the surface soil, respectively, which were at the lowest level among the phosphorous contents of soils in China. From the view of nutrient resorption efficiency of needles of *P. sylvestris* var. *mongolica* trees on sandy land, the resorption efficiency of nitrogen, phosphorous, potassium and magnesium in needles decreased with stand ages. Meanwhile, the nutrient use efficiency also exhibited the declined trend for the above mentioned nutrient elements with stand ages. Therefore, we deduced that the characters of degradation on nutrient utility had displayed with the increase of *P. sylvestris* var. *mongolica* tree ages. On the other hand, compared with the natural *P. sylvestris* var. *mongolica* forests, the soils of plantations at Zhanggutai had less soil organic materials and lower activity of soil enzymes, especially the soil organic materials of plantations significantly decreased, which might lead to lack of nutrients and nutrient imbalance. The nutrient imbalance would make the weakness of tree vigor and cause the pest outbreak, which could be another important cause that led to the degradation of *P. sylvestris* var. *mongolica* plantations on sandy land.

Wherever in the plantations at Zhanggutai or in the natural forest of *P. sylvestris* var. *mongolica* in Honghuaerji, we could find there had close relationships between soil microbe biomass and stand ages, i. e., the microbe biomass increased with increasing of stand age at first, and then decreased at certain ages. The maximum of the soil microbe biomass in the plantations had reached much earlier than that of the natural forest, at least 40 years. It was found that the decrease of soil biomass in plantations were mainly induced by drought and high temperature. The comparison results of ectomycorrhizal fungi between plantations and natural forests indicated that both the number and the diversity of ectomycorrhizal fungi in the plantations were much lower than those in the natural forests. In particular, most ectomycorrhizal fungi strains collected from the *P. sylvestris* var. *mongolica* plantations could not grow at the drought stress (– 1.2MPa) or under high temperature (>37℃), and could not survive at the drought stress (– 1.35MPa) or under high temperature (>40℃). These matched the site conditions in the plantations. Therefore, the decrease or the death of ectomycorrhizal fungi might be another cause that led to the degradation of *P. sylvestris* var. *mongolica* plantations.

Additionally, other environmental factors in the introduction area, such as chemical elements in the precipitation (nitrogen sedimentation), the outbreak and harm of pests and diseases, and the high stand density etc. might also contribute to the degradation of the *P. sylvestris* var. *mongolica* plantations.

On the basis of decline mechanisms of *P. sylvestris* var. *mongolica* plantations, the trend of management for *P. sylvestris* var. *mongolica* plantations should follow the principles of restoration ecology and near – nature – forestry. According to the succession theories of plant community, we should pay attentions to the relationships between the environment conditions and the adaptabilities of tree species when we introduce new species at one stage of the community succession. The primary purpose of introduction of *P. sylvestris* var. *mongolica* to sandy land was for establishing windbreaks and the sand – fixation systems, and the notion or the aim of the management for *P. sylvestris* var. *mongolica* plantations was to form a large area of forest ecosystems on the sandy land. However, the notion disobeyed the natural rules of plant succession. The climate at the southeastern edge of Keerqin sandy land is typically semi – arid, according to theories of traditional ecology and classical succession, the climax communities should be steppe – savanna and meadow steppe. Such climax communities might come true if there would not be disturbed by human activities for a long time. However, during the establishment of artificial vegetations, e. g., the introduction of *P. sylvestris* var. *mongolica*plantations into sandy land, which formed a special community there, the primary dominant introduced species might exhibit the phenomena of degradation or death in the process of the artificial vegetation (*P. sylvestris* var. *mongolica* plantations) development. This decline phenomenon should be inevitably for the whole system. In such circumstance, the disturbances induced from human activities should be reduced as little as possible, and let it develop naturally, or take some measures, e. g., reduce the area of the pure *P. sylvestris* var. *mongolica* plantations, and paying much attention to the native species, controlling the composition ratio of plantations in order to accelerate the system to develop towards the succession climax community.

We should consider the problems of management for the large area of *P. sylvestris* var. *mongolica* plantations on sandy land from the following three aspects. Firstly, for declined stands, they should be cleaned and conserved. Because there had the vegetation layer formed by herb in the degraded plantations, conserving the land of the declined plantations would fix the sandy land, and make the community develop naturally, or take some measures to make it develop towards steppe – savanna. Secondly, for normal stands or the declined stands appearing not obviously, we should thin the trees at different intensities in the stands for getting the balance between the growth of trees and native water resource. This is because the pure plantations in large area have consumed much water resource. Thirdly, for the stands which would be replanted, we should make the aims according to the practical conditions, such as the degradation extent and features of vegetation and the capacity of economy and techniques, make the rebuilt stands develop as the native climax communities. Anyway, the large pure *P. sylvestris* var. *mongolica* plantations on sandy land should be avoided in the future vegetation establishment.

The publication of this book was supported by the knowledge innovation project (KZCX3 – SW – 418) and the 100 – young researcher project from Chinese Academy of Sciences, and Natural Science Foundation of Liaoning Province (2002110016).

Jiaojun ZHU
July 27, 2005

沙地樟子松天然林

A. 沙地樟子松天然林俯瞰图

B. 红花尔基沙包山上的沙地樟子松天然林

C. 60年左右经人工经营的沙地樟子松林

D. 樟子松 - 白桦山 - 杨混交林

A

A

B

B

B

B

C

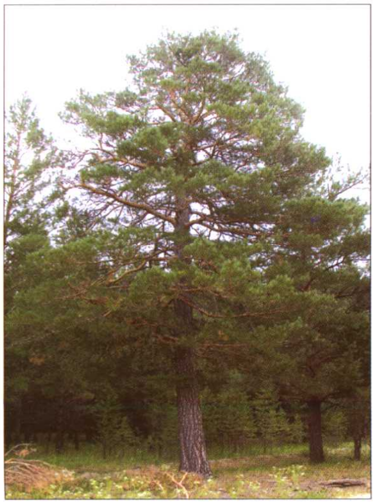
D

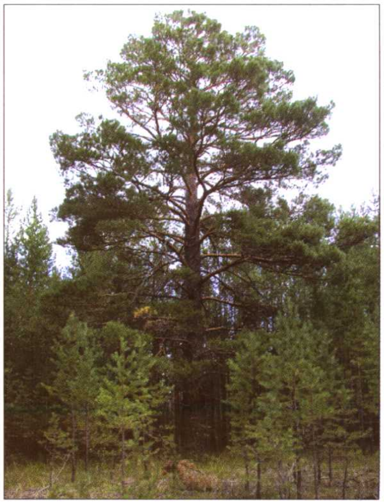
沙地樟子松天然林

沙丘顶部零星残留的樟子松老树







沙地樟子松天然林

A. 红花尔基沙地樟子松天然林林下植被

B. 樟子松林窗更新

C. 樟子松火烧迹地更新

植被一：以樟子松更新为主 A

植被二：以草本为主 A

植被三：以小灌木为主 A

植被四：以苔藓为主 A

B

B

C

C