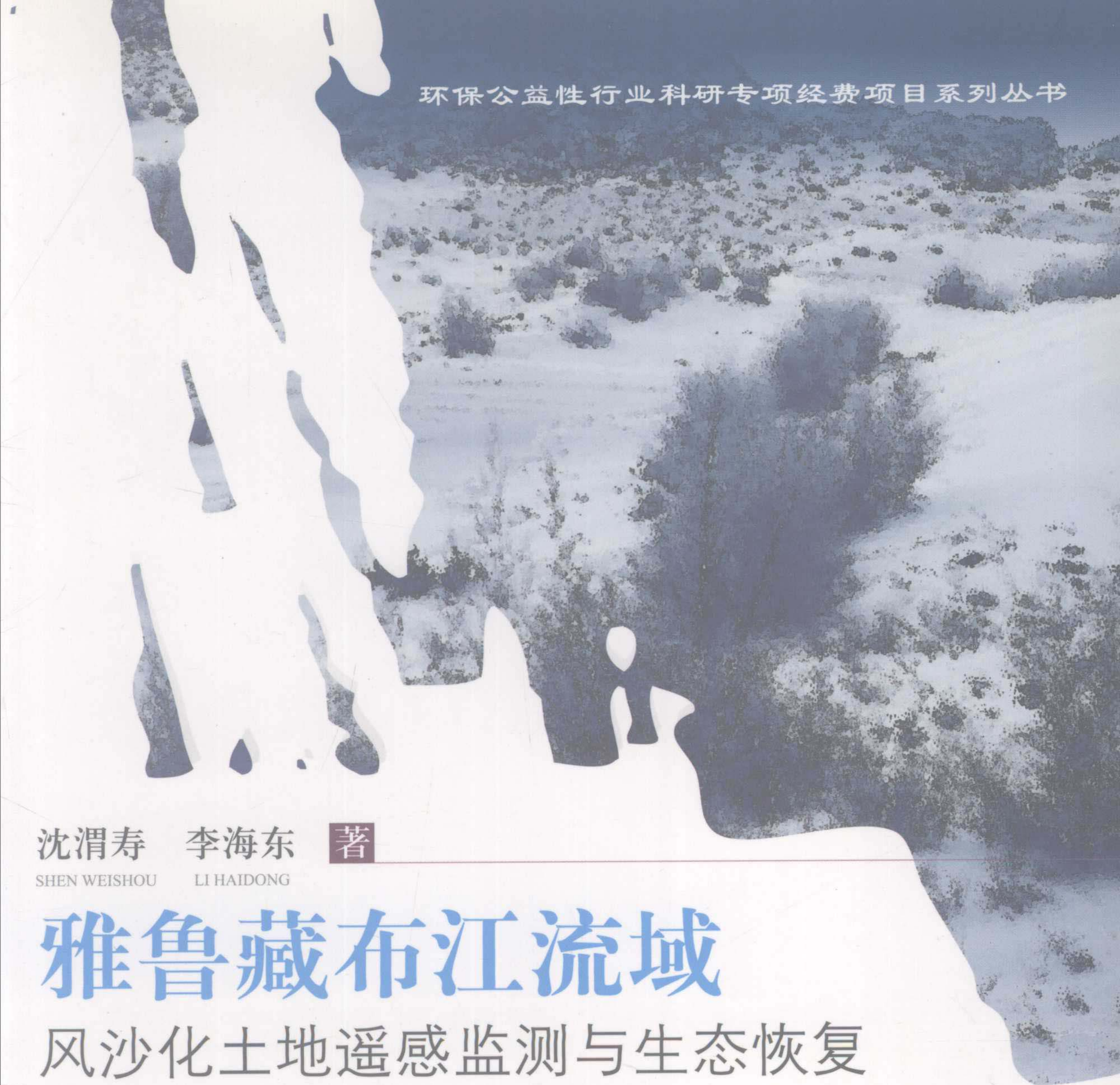

环保公益性行业科研专项经费项目系列丛书

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总　序

我国作为一个发展中的人口大国，资源环境问题是长期制约经济社会可持续发展的重大问题。党中央、国务院高度重视环境保护工作，提出了建设生态文明、建设资源节约型与环境友好型社会、推进环境保护历史性转变、让江河湖泊休养生息、节能减排是转方式调结构的重要抓手、环境保护是重大民生问题、探索中国环保新道路等一系列新理念新举措。在科学发展观的指导下，“十一五”环境保护工作成效显著，在经济增长超过预期的情况下，主要污染物减排任务超额完成，环境质量持续改善。

随着当前经济的高速增长，资源环境约束进一步强化，环境保护正处于负重爬坡的艰难阶段。治污减排的压力有增无减，环境质量改善的压力不断加大，防范环境风险的压力持续增加，确保核与辐射安全的压力继续加大，应对全球环境问题的压力急剧加大。要破解发展经济与保护环境的难点，解决影响可持续发展和群众健康的突出环境问题，确保环保工作不断上台阶出亮点，必须充分依靠科技创新和科技进步，构建强大坚实的科技支撑体系。

2006 年，我国发布了《国家中长期科学和技术发展规划纲要（2006—2020 年）》（以下简称《规划纲要》），提出了建设创新型国家战略，科技事业进入了发展的快车道，环保科技也迎来了蓬勃发展的春天。为适应环境保护历史性转变和创新型国家建设的要求，原国家环境保护总局于 2006 年召开了第一次全国环保科技大会，出台了《关于增强环境科技创新能力的若干意见》，确立了科技兴环保战略，建设了环境科技创新体系、环境标准体系、环境技术管理体系三大工程。五年来，在广大环境科技工作者的努力下，水体污染控制与治理科技重大专项启动实施，科技投入持续增加，科技创新能力显著增强；发布了 502 项新标准，现行国家标准达 1 263 项，环境标准体系建设实现了跨越式发展；完成了 100 余项环保技术文件的制（修）订工作，初步建成以重点行业污染防治技术政策、技术指南和工程技术规范为主要内容的国家环境技术管理体系。

环境科技为全面完成“十一五”环保规划的各项任务起到了重要的引领和支撑作用。

为优化中央财政科技投入结构，支持市场机制不能有效配置资源的社会公益研究活动，“十一五”期间国家设立了公益性行业科研专项经费。根据财政部、科技部的总体部署，环保公益性行业科研专项紧密围绕《规划纲要》和《国家环境保护“十一五”科技发展规划》确定的重点领域和优先主题，立足环境管理中的科技需求，积极开展应急性、培育性、基础性科学研究。“十一五”期间，环境保护部组织实施了公益性行业科研专项项目234项，涉及大气、水、生态、土壤、固废、核与辐射等领域，共有包括中央级科研院所、高等院校、地方环保科研单位和企业等几百家单位参与，逐步形成了优势互补、团结协作、良性竞争、共同发展的环保科技“统一战线”。目前，专项取得了重要研究成果，提出了一系列控制污染和改善环境质量技术方案，形成一批环境监测预警和监督管理技术体系，研发出一批与生态环境保护、国际履约、核与辐射安全相关的关键技术，提出了一系列环境标准、指南和技术规范建议，为解决我国环境保护和环境管理中急需的成套技术和政策制定提供了重要的科技支撑。

为广泛共享“十一五”期间环保公益性行业科研专项项目研究成果，及时总结项目组织管理经验，环境保护部科技标准司组织出版“十一五”环保公益性行业科研专项经费项目系列丛书。该丛书汇集了一批专项研究的代表性成果，具有较强的学术性和实用性，可以说是环境领域不可多得的资料文献。丛书的组织出版，在科技管理上也是一次很好的尝试，我们希望通过这一尝试，能够进一步活跃环保科技的学术氛围，促进科技成果的转化与应用，为探索中国环保新道路提供有力的科技支撑。

中华人民共和国环境保护部副部长

吴晓青

2011年10月

前言

西藏高原是青藏高原的主体，是世界上海拔最高、面积最大、形成最晚的高原，素有“地球第三极”和“世界屋脊”之称。它是东半球气候的启动区和我国乃至世界重要的气候调节器，更是我国、南亚和东南亚地区的江河源和生态源。但就是在这片神秘的高原上，疯狂的流沙正在日夜吞噬着耕地、草场、房屋、交通和水利设施。截至2009年底，西藏荒漠化土地和沙化土地面积分别达43.27万km^2和21.62万km^2，仅次于新疆和内蒙古，居全国第3位。雅鲁藏布江中部流域是西藏社会经济发展的中心，但也是遭受风沙灾害影响最严重的区域。位于雅鲁藏布江南岸、贡嘎县境内的拉萨国际机场是西藏自治区唯一开放的航空港。由于沙尘、扬沙、浮尘等风沙天气造成飞机停飞、返航，甚至机场关闭的情况时有发生。分布于雅鲁藏布江和拉萨河两岸，特别是拉萨机场和拉萨市周边的流动沙地，是本区土地沙漠化程度最高、面积最大、分布最集中、危害最严重的区域，它的治理与否关系到拉萨机场能否安全运营以及本区环境质量和城乡人们的生产、生活质量能否提高。

西藏高原是我国和亚洲的重要生态安全屏障。由于冰川退缩、雪线上升、冻土消融、湿地萎缩、沙化土地面积扩大、原生植被退化、水源涵养功能衰退，目前生态环境整体退化的形势已十分严峻。西藏高原的沙漠化问题已引起社会的广泛关注。党中央、国务院高度重视西藏的风沙灾害防治工作。2005年国务院审议通过的《全国防沙治沙规划》把西藏沙化土地治理，特别是雅鲁藏布江中游河谷的沙化土地治理作为重要治理区域。2007年国务院召开的全国防沙治沙大会，要求尽快启动实施一批新的重点治理工程，进一步加大对青藏高原等沙化扩展地区荒漠化治理力度。2011年6月国务院印发的《青藏高原区域生态建设与环境保护规划（2011—2030年）》指出，青藏高原“十二五”期间（2011—2015年）的主要目标是着力解决生态退化和环境污染问题，使部分地区环境质量明显好转。

本研究以处于特殊气候带下的雅鲁藏布江流域为研究区，运用遥感技术监测风沙化土地分布现状及近几十年的动态变化，结合气候变化和人类活动资料分析风沙化土地演变的驱动因素和响应关系，提出相应的环境管理对策与建议。通过4年的人工模拟飞播试验研究（2008—2011年），筛选和确定了西藏高寒河谷流动沙地人工模拟飞播的适生植物种和最佳播种时间，探讨了生境胁迫对高寒河谷流动沙地人工模拟飞播的影响，以期为西藏高原生态安全屏障建设和风沙化土地植被恢复与重建提供依据。

本书是作者及其所带领的研究团队近20年来在雅鲁藏布江流域风沙化土地监测与植被恢复等方面的研究结晶。研究工作主要得到了国家环保公益性行业科研专项“高

寒河谷沙尘治理技术试验研究”（200809010）和中央级公益性科研院所基本科研业务专项“雅鲁藏布江流域高寒沙地植被演替光谱识别及恢复潜力评估”（NIES2011）等项目的资助。

参与各章节编写和作出贡献的主要人员如下：第 1 章“雅鲁藏布江流域概况”由李海东编写，第 2 章“高寒风沙化土地动态监测与驱动力分析”由李海东、沈渭寿编写，第 3 章“江源区气候变化及风沙化土地动态响应”由沈渭寿、李海东编写，第 4 章“中部流域两个重要空港周边风沙化土地状况”由李海东、沈渭寿编写，第 5 章“雅鲁藏布江流域生态状况评估”由沈渭寿、赵卫编写，第 6 章“江源区高寒草地类型和植被盖度遥感监测”由沈渭寿、孙明编写，第 7 章“中部流域沙地植物区系、分类与排序”由沈渭寿编写，第 8 章“中部流域几种主要沙生植物种群分布格局”由李海东编写，第 9 章“高寒风沙化土地飞播可行性”由沈渭寿、李海东编写，第 10 章“高寒风沙化土地土壤水分时空异质性”由李海东编写，第 11 章“高寒风沙化土地土壤养分和粒度特征”由李海东、沈渭寿编写，第 12 章“高寒风沙化土地植被恢复试验”由李海东、沈渭寿编写，第 13 章“总结与生态恢复对策”由沈渭寿、李海东编写。

值本书出版之际，感谢环境保护部科技标准司与自然生态司在项目立项和执行过程中给予的关心和指导，特别要感谢环境保护部南京环境科学研究所高吉喜所长、李德波副所长等领导在研究过程中给予的支持和帮助，感谢西藏自治区环境保护厅庄红翔副厅长和普布丹巴处长在我们野外调研中给予的支持，感谢南京林业大学佘光辉教授和中国科学院寒区旱区环境与工程研究所颜长珍研究员在试验设计和监测技术上给予的指导。此外，还要感谢拉萨、山南、日喀则、林芝、那曲等地区环保局、林业局、畜牧局、国土局、水利局、气象局等部门为本研究提供所需的相关资料与素材。感谢硕士研究生张涛、袁磊、孙明、孙俊、林乃峰、纪迪、李佳承、杨凯以及我们的司机和向导布琼次仁同志等在资料收集、野外考察、试验调研等方面做的大量辛苦工作。

高寒风沙化土地遥感监测与生态恢复方面涉及生态学、环境科学、水土保持学、生物学、遥感科学和社会学等多个学科，许多理论和方法目前在西藏高寒地区仍处于研究探索与起步阶段，许多理论与技术问题还需要不断地完善。本书虽然做了大量的研究工作，但研究中难免存在一些不足甚至谬误之处，有待于今后在该领域和方向继续深入研究和不断探索。

摘　要

本研究基于大量野外调查和 1975、1990、2000 和 2008 年四期遥感数据，运用遥感技术监测雅鲁藏布江流域风沙化土地现状分布及近几十年动态变化，结合气候变化和人类活动，揭示了流域内风沙化土地动态变化的基本规律及其驱动机制。系统研究了当地乡土沙生植物的区系、分类与排序，以及几种主要沙生植物群落的物种组成、种群结构、空间分布和空间关联等，为高寒流动沙地植被恢复物种选择和配置模式奠定了基础。通过 2008—2011 年的人工模拟飞播试验研究，筛选和确定高寒河谷流动沙地适生植物种和最佳播种时间，探讨生境胁迫对人工模拟飞播植物种子发芽、生苗和生长的影响，以期为西藏高原生态安全屏障建设和特殊气候带下的风沙化土地植被恢复与重建提供依据。结果表明：

(1) 雅鲁藏布江流域现有风沙化土地 273 697.54 hm^2，呈由江源区马泉河宽谷向中下游逐渐递减趋势，其中马泉河宽谷风沙化土地面积最大，占流域风沙化土地总面积的 50.28%，其他依次为日喀则宽谷(25.52%)、山南宽谷(19.11%)和米林宽谷(5.08%)。1975—2008 年雅鲁藏布江流域风沙化土地呈缓慢增长趋势，近 34 年间共增长了 10.5%，其中 1990—1999 年增长最快，2000—2008 年增长最慢。流域内风沙化土地进一步扩展，是高原干旱多风的特殊气候条件下的缓慢的自然沙漠化过程，是由自然与人为因素共同作用、相互激发、相互促进所形成的人为加速与加剧过程。

(2) 雅鲁藏布江源区 1973—2007 年的多年平均降水量为 206.12 mm，多年平均气温为 2.77℃，最高气温为 10.72℃，最低气温为 −4.81℃，年平均风速为 2.92 m/s，年日照时数为 3 295.16 h。近 35 年来雅鲁藏布江源区气温变暖趋势明显，气温倾向率为 0.47℃/10a，尤其是 1986 年以后，气温倾向率为 0.77℃/10a，高于珠峰地区平均线性升温率（0.23℃/10a）。年降水量的波动较大，增加趋势不明显。年日照时数波动性较大，上升趋势不显著。年平均风速下降趋势明显。

雅鲁藏布江源区水土流失严重。轻度及其以上强度土壤侵蚀面积为 18 933.33 km^2，占源区总面积的 71.86%。冻融侵蚀是江源区土壤侵蚀的主要形式，风力侵蚀和水力侵

蚀面积所占比例较小。土壤侵蚀垂直分异明显。1975 年风沙化土地面积为 1 257.43 km^2，1990 年为 1 281.78 km^2，2000 年为 1 359.7 km^2，2008 年为 1 376.22 km^2。风沙化土地总体呈上升趋势，但增速有所放缓。1975—2008 年，近 34 年时间里风沙化土地面积共增加了 118.80 km^2。

(3) 雅鲁藏布江中游 1957—2007 年来气温倾向率为 0.27℃/10a，高于西藏地区平均值。气温变化以秋、冬季节较显著。1957—2007 年降水量增加趋势不显著。年降水量以 20 世纪 80 年代最少，2000 年后降水量与 20 世纪 90 年代、60 年代基本持平。年降水量存在准 3 年、8～11 年和 30 年的周期，以准 11 年周期最为突出。降水量变化以春季增长趋势最显著，可以在干旱季补充土壤水分，减轻风沙化土地的发生发展。秋季和冬季增长趋势不明显，夏季降水量呈减小趋势。

(4) 2008 年拉萨机场周边 5 县风沙化土地共有 42 462.38 hm^2，其中，由风积和风蚀活动引起的风沙化土地面积分别为 33 088.87 hm^2 和 9 373.51 hm^2，比例分别为 77.9% 和 22.1%。1975—2008 年拉萨机场周边风沙化土地共增加了 4.23%。丰富的沙物质来源和强劲的风动力条件是拉萨机场周边风沙化土地发生、发展的潜在条件。气温升高是造成风沙化土地进一步发生发展的主要动力，平均风速下降和降水量增长是抑制其发生发展的原因之一。2000 年后拉萨机场周边河谷地段人工林面积大幅度增加，裸露河床面积显著减少，在一定程度上减缓了河床沙源向河岸及山坡的搬运，这是近 10 年风沙化土地增长速度有所放缓的原因之一。

2008 年日喀则机场周边 9 县共有风沙化土地 49 871.61 hm^2，其中，距离机场 100 km 以内由风积和风蚀活动引起的风沙化土地面积分别为 26 656.61 hm^2 和 8 588.06 hm^2，比例分别为 75.6%和 24.4%。1975—2008 年日喀则机场周边风沙化土地共增加了 13.57%。

(5) 藏沙蒿、藏白蒿和砂生槐等是雅鲁藏布江中游主要沙生植物，揭示其种群结构、空间分布、空间关联对西藏高寒河谷风沙化土地植被恢复与重建具有重要意义。半裸露沙砾地和半固定沙地的藏沙蒿种群结构均呈增长型，固定沙地的藏白蒿和砂生槐种群结构呈衰退型。藏沙蒿和藏白蒿种群在所有尺度上均呈集群分布，砂生槐种群随着尺度增大表现为集群—随机—集群—随机分布。

几种沙生植物种间正关联往往存在于一定的尺度范围内，种间关联时常出现不同关联方式交替出现和摆动的现象。几种沙生植物种群均随植株形体增大，聚集强度减

弱，大小级较小时表现为集群分布，随着大小级增大，表现为随机分布或随机与集群分布交错出现。不同大小级的空间正关联随着植株形体大小差异的增大而减弱，甚至会转变为负关联，各大小级在较小的空间尺度上易表现为正或无空间关联。

(6) 雅鲁藏布江中游河谷及其支流拉萨河和年楚河沿岸地带，是西藏社会经济发展的中心，但也是遭受风沙灾害影响最严重的区域。分布于雅鲁藏布江和拉萨河两岸，特别是拉萨机场和拉萨市周边的河岸流动沙地，是本区土地沙漠化程度最高、面积最大、分布最集中、危害最严重的区域。该区域雨热同季，光温水配合较好，对植物生长极为有利。同时5月至7月播种期风向交换频繁，有利于种子自然覆沙。选择能够适应西藏高寒风沙化土地特殊生境条件的乡土植物种和解决种子播后的位移问题，将是风沙化土地飞播试验成败的关键。

(7) 土壤水分是西藏高寒河谷风沙化土地植被恢复和演替的主要限制因子。高寒风沙化土地不同深度土壤含水量均具有明显的季节性变化，试验地春季土壤水分平均值为4%～6%，夏季为6%～14%，秋季为9%～12%，表现为随着土壤深度的增加，土壤水分随之增大的趋势。＞60 cm 深度的土壤水分含量是限制植物种子发芽和生长的关键因子，它直接影响植被恢复的盖度和物种丰富度。降水量大小、河流水位高低、相对高程和小地形是决定不同季节土壤水分含量的主要因素。土壤水分的时空异质性研究对正在进行的区域植被恢复具有重要启示作用。

(8) 高寒风沙化土地土壤呈中性、碱性和强碱性，土壤有机质和全氮含量均很低，但全磷和全钾均很高。土壤粒度组成表现为砂粒含量（53.83%～95.93%）＞粉粒含量（3.3%～40.5%）＞黏粒含量（0.77%～5.68%）。土壤养分含量与黏粒、粉粒、极细砂粒和细砂粒等细沙物质含量的相关性较强，与中砂粒、粗砂粒和极粗砂粒等粗沙物质含量呈负相关或相关性较弱。其中，黏粒和极细砂粒含量的增加对土壤养分的增加贡献较大。流动沙丘随风沙运动而不断往复摆动的现象和土壤细颗粒的迁移和损失，对不同类型沙地和沙丘部位的土壤养分状况及其再分配过程产生较大影响。

(9) 北方优良沙生植物种的人工模拟飞播效果优于西藏乡土沙生植物种。籽蒿、花棒、沙拐枣、杨柴和砂生槐高寒河谷流动沙地的适应性较好。籽蒿在播后第2年便有花序和种子出现，花棒和沙拐枣在第3年开花结实，籽蒿、花棒和沙拐枣均能完成生活史。籽蒿的再繁殖能力较弱，花棒和沙拐枣的再繁殖能力较强。不同类型沙丘的形态特征对人工模拟飞播效果影响较大，最适宜型（第Ⅰ类）流动沙地的人工模拟飞

播效果最好，植被盖度达 35%；较适宜型（第II类）流动沙地的效果较好，植被盖度达 30%；不适宜型（第III类）流动沙地的效果最差，植被盖度尚不足 10%；基本适宜型（第IV类）流动沙地的效果较差，但采用沿等高线人工脚踩回头撒播法，植被盖度可达 20%。不同沙丘部位的人工模拟飞播效果差异明显。

ABSTRACT

Based on a large amount of data acquired from both *in situ* field surveys and four sets of remote-sensing images from 1975, 1990, 2000 and 2008, the types, status and spatial distribution of aeolian sandy lands, as well as the dynamcis rules and response mechanisms of this land to climate changes and human activities over the past 34 years, were studied in the Yarlung Zangbo River basin. The floristic features, classification and sorting of native psammophyte vegetation, as well as the population structure, spatial distribution and association of several psammophyte populations, were studied systematically, whose purpose was to provide theoretical foundation for potential species resources and plant configuration modes for vegetation restoration on sand dunes. The suitable plant species and best sowing period on sand dunes in the alpine valley were tested and determined by field artificial seeding trial from 2008 to 2011, and the habitat stress factors influencing seed germination, emergence and plant growth greatly were discussed. The purpose of this study was to provide a scientific basis for ecological security barrier construction and vegetation restoration and reconstruction of aeolian sandy land under special climate zone on the Tibetan plateau. The results showed:

(1) There was a total of 273 697.54 hm^2 of aeolian sandy land in the Yarlung Zangbo River basin in 2008. In different wide valleys of the basin, the area of aeolian sandy land exhibited a decreasing trend from the headwater area to the middle and lower reaches. The Maquanhe wide valley contained the largest proportion of aeolian sandy land (50.28% or 137 622.94 hm^2), followed by the Shigatse wide valley (25.52% or 69 861.15 hm^2), the Shannan wide valley (19.11% or 52 310.08 hm^2) and the Mainling wide valley (5.08% or 13 903.37 hm^2). During the period from 1975 to 2008, aeolian sandy land in the basin exhibited a slow increasing trend, which increased by 10.5% over 34 years, especially during the period from 1990—1999 and it spreaded most quickly, whereas in the 2000—2008 period its mean annual increase rate was the slowest. The aeolian sandy lands in the basin were found to increase further due to the slow natural desertification process under the arid and windy climate conditions of this region, and the combined effects of natural and anthropogenic factors. These factors stimulated and promoted the processes of anthropogenic acceleration and aggravation.

(2)The source area of the Yarlung Zangbo River belongs to the cold and semi-arid highland climate zone with the mean annual precipitation of 206.12 mm, annual mean temperature of 2.77℃, maximum temperature of 10.72℃ and minimum temperature of −4.81℃, mean annual wind speed of 2.92 m/s, annual sunshine hours for the 3 295.16 h from 1973 to 2007. There was

an obvious increasing trend for daily mean temperature in recent 35 years, especially after 1986, the mean temperature of the linear growth rate was 0.77℃/10a, which was higher than that of 0.47℃/10a in the past 35 years and the average of 5 stations around Mt. Qomolangma region of (0.23℃/10a). The fluctuation of mean annual precipitation was larger, and its increasing trend was not significant. The declining trend of mean annual wind speed was significant.

Soil and water loss in the source area of the Yarlung Zangbo River was serious, and the area under soil erosion above light was 18 933.33 km^2, accounting for 71.86% of the total source area. Freeze-thaw erosion was the major form of soil erosion, accounting for 82.53%, while wind erosion occurred only in wide sections of this river valley, accounting for 5.33%, and water erosion, often mild in intensity, was small in area. Geographical distribution of the soil erosion was highly influenced by altitude with significant vertical differentiation. The area of aeolian sandy land in the source area was 1 257.43 km^2 in 1975, 1 281.78 km^2 in 1990, 1 359.7 km^2 in 2000 and 1 376.22 km^2 in 2008, respectively. Aeolian sandy land exhibited a increasing trend, and it had increased by 118.80 km^2 in the past 34 years.

(3) The annual mean temperature presented a significant increasing trend and the linear growth rate was 0.27℃/10a from 1957 to 2007 in the middle reaches of the Yarlung Zangbo River. The warming trend was more obvious in autumn and winter than that in summer. The minimum precipitation occurred in the 1980s. Annual precipitation increased from 1957 to 2007, while it was not significant. Annual precipitation from 2000 to 2007 was roughly equal to that in the 1990s or 1960s. Annual precipitation cycles were obvious with 3 years, 8-11 years and 30 years, especially 11 years. The increasing trend of precipitation was the most obvious in spring, while it was not significant in autumn and winter. Precipitation took on the decreasing trend in summer. Spring precipitation could supply soil water during drought and prevent desertified land spreading.

(4)The area of aeolian sandy land around Lhasa Airport in 2008 was 42 462.38 hm^2, versus 40 737.30 hm^2 in 1975, 41 440.61 hm^2 in 1990 and 42 068.89 hm^2 in 2000, representing a 4.23% increase from 1975 to 2008. The areas of aeolian sandy land caused by windblown sediments and wind erosion in 2008 totaled 33 088.87 hm^2 and 9 373.51 hm^2, respectively, representing 77.9% and 22.1%. The increased area of aeolian sandy land mainly resulted from the abundant sand source, region's harsh climate and fragile environment, combined with a warmer and drier climate that accelerated the desertification process. The air temperature increase appeared to be the main driving factor for the development and spread of aeolian sandy land. The slightly higher precipitation and lower wind speed in this region since 2000 were natural factors that slowed the expansion of aeolian sandy land during this period, and an increased area of forest plantations, combined with a declining area of bare riverbeds, also slowed this expansion, possibly by preventing or reducing sand transport from riverbeds and dunes to river banks and hillsides in the valley.

The area of aeolian sandy land around Shigatse Peace Airport in 2008 was 49 871.61 hm^2, versus 4 4071.38 hm^2 in 1975, 46 334.59 hm^2 in 1990 and 49 064.70 hm^2 in 2000, representing a 13.57% increase from 1975 to 2008. The areas of aeolian sandy land caused by windblown sediments and wind erosion within 100 km from Shigatse Peace Airport in 2008 totaled 26 656.61 hm^2 and 8 588.06 hm^2, respectively, representing 75.6% and 24.4%.

(5) *Artemisia wellbyi*, *Artemisia younghusbandii* and *Sophora moorcroftiana* are the major psammophyte populations on the aeolian sandy land in the middle reaches of Yarlung Zangbo River, whereas few studies were carried out to examine their spatial distribution or their spatial association. Population spatial patterns of these species were therefore studied, the objectives were mainly to illustrate how spatial scales were related to population their patterns, and to provide theoretical foundation for vegetation restoration on sand dunes. The population structure of *Artemisia. wellbyi* on semi-exposed sandy gravel land and semi-fixed sandy land were that of a growing population, while *A. younghusbandii* and *S. moorcroftiana* on fixed sandy land both had the structure of a declining population. *Artemisia wellbyi* and *A. younghusbandii* both had a clumped distribution at different scales, while the distribution pattern of *S. moorcroftiana* changed from clumped to random to clumped to random as the scale increased.

There was a scale effect among the studied populations, and positive spatial association occurred mainly at certain scales. Spatial association was often affected by plant size and environmental heterogeneity. The degree of aggregation weakened with increasing plant size. The smaller size class had a clumped distribution, and the larger had a random distribution or random and clumped. The positive spatial association between different size classes of the same species appeared to weaken when the difference of plant size became greater and even changed into negative spatial association, while the spatial association of various size classes at a smaller scale often was positive or independent.

(6) The areas along the middle reaches of the Yarlung Zangbo River and their tributaries, the Lhasa River and the Nianchu River, are the center of social and economic development in Tibet, and also regions that are seriously affected by aeolian sands. The regions alongside the Yarlung Zangbo River and the Lhasa River, especially around the Lhasa Airport and Lhasa City, covered with rolling sand dunes are serious in hazard in Tibet. Based on systematic analysis and summarization of the successful experience of air seeding in low altitude regions, feasibility study was carried out of air seeding in the alpine aeolian sandy land in Tibet from the aspects of precipitation, temperature, sunshine, landform, and wind regime. The advantage conditions of simultaneity of rain and heat, and matching of light, temperature and water, greatly favored the growth of plants. Meanwhile, frequent change of wind direction during the early sowing period from May to July helps cover the seeds with sand. Thus, selection of seeds of native plant species, adaptable to the particular habitat of the alpine aeolian sandy land, and solution to the problem of relocation of sown seeds are the two keys to the success of the experiment on air seeding.

(7) Soil moisture content is one of the limiting factors for natural vegetation succession in alpine river valleys on the Tibetan plateau. The soil moisture contents at different depths all showed strong temporal variability, with the mean soil moisture ranging from 4% to 6% in

spring, from 6% to 14% in summer and from 9% to 12% in autumn. The soil moisture content over the upper 60 cm was the key factor that restricted the seed germination and seedling growth, and it affected vegetation coverage and density. The precipitation, variations of river water level, elevation as well as landform types were the main factors determining the variations of soil moisture content in different seasons. The study of spatio-temporal variability of soil moisture and its effect on vegetation in aeolian sandy land have important implications for the ongoing vegetation restoration.

(8) The soil of aeolian sandy land in the middle reaches of Yarlung Zangbo River was neutral, alkaline or strong alkaline, and soil organic matter and total nitrogen content were rather low, whereas total phosphorus and total potassium were very high. The correlation between different soil nutrients and the content of clay, silt, very fine sand, fine sand was strong, whereas the correlation was negative or weak between different soil nutrients and the content of medium sand, coarse sand, very coarse sand. The clay and fine sand content made larger contribution to the soil nutrients content. The aeolian sand movement, which caused the continuous swing of moving sand dunes and the migration and loss of the finer sand particles, affected the soil nutrients content and their redistribution process for different aeolian sandy land types greatly.

(9) The plant height and plant size growth of northern China's psammophyte species were larger than that of native psammophyte species in the field artificial seeding trial, and the species such as *A. sphaerocephala*, *Hedysarum scoparium*, *Calligonum mongolicum*, *H. fruticosum* var. *mongolicum* and *S. moorcroftiana* all exhibited good adaptability to moving sand land. So far as the status of reproduction of the testing species, *A. sphaerocephala* began to flower and seed in the second year, while *H. scoparium* and *C. mongolicum* began to flower and seed in the third year, it was the most important finding that *A. sphaerocephala*, *H. scoparium* and *C. mongolicum* were all able to complete the life cycle in the alpine valley under the special climate zone on the Tibetan plateau, however, the reproducibility of *A. sphaerocephala* was weak, but *H. scoparium* and *C. mongolicum* both showed strong reproducibility. The morphological characteristics and different parts of sand dunes influenced the trial results of field artificial seeding greatly, and the vegetation coverage varied from 5% to 40% on different sand dune types. The approach which sowed seeds into footprints trampled on slope sand land by feet following the contours of mountain artificially proved to be a good measure to improve the results of field artificial seeding trial.

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