Landwirtschaft

Photogrammetric techniques for the functional assessment of tree and forest resources in Khorezm, Uzbekistan

Inaugural-Dissertation
zur
Erlangung des Grades
Doktor der Agrarwissenschaften
(Dr. agr.)

der Hohen Landwirtschaftlichen Fakultät
der
Rheinischen Friedrich-Wilhelms-Universität
zu Bonn

vorgelegt am 9. Dezember 2009

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Tag der Promotion: 23.03.2010

Erscheinungsjahr: 2010

Diese Dissertation ist auf dem Hochschulschriftenserver der ULB Bonn
http://hss.ulb.uni-bonn.de/diss_online elektronisch publiziert

ABSTRACT

A system for inventorying and monitoring forests and tree plantings is indispensable for a proper management of this perennial vegetation. In the mid 1990s, the Government of Uzbekistan (GoU) launched various nationwide tree growing programs. Owing to limited funds and lack of a suitable methodology, the Main Forestry Department (MFD) has not been able to conduct a reliable and comprehensive forest inventory since 1991. On the other hand, photogrammetry combined with GIS-based tools has shown its value and accuracy for assisting in forest inventories worldwide. Given that aerial photographs 1:20,000 are taken in the leafless season every five years by the Land and Geodesy Cadastre Center of Uzbekistan for actualizing topographic maps, the intention of this study is (i) to examine to what extent these photographs can be used for the inventory of forests and tree plantations, and develop a standard methodology with photogrammetry for the MFD, and (ii) to map and perform a functional assessment of tree plantings and forests (e.g., the windbreak function of hedgerows or the spatial extent of tree plantations) and forests (the spatial extent and condition of natural floodplain forests (*tugai*)) in the region of Khorezm in Uzbekistan.

The selected study area in two transects (NS and WE) covers virtually all typical land uses and vegetation formations in an area comprising about 10% of the Khorezm region. An analytical stereo plotter and GIS-based tools were applied. The key results of interpretation and measurements of the aerial photographs are summarized as follows. First, detailed and accurate information on the extent of tree plantations and forests in developed thematic classes could be extracted. Also, windbreak design criteria, such as orientation to the prevailing winds, mean stand height, length (reaching the edges of the related field) and crown closure (as a proxy of porosity) could be determined. Second, species composition, vitality and age classes of tree plantations and forests, as well width (number of rows) of hedgerows/windbreaks could not be extracted with photogrammetry and would require field surveys.

The inventory shows that most of the hedgerows in Khorezm did not meet principal windbreak design criteria and, consequently, are not effective for reducing soil erosion or improving microclimatic conditions. In particular, this is due to the small extent (<1.5%) in irrigated fields, low height (<5 m) and insufficient length (in ca. 50% of the hedgerows) of dominating single species such as white mulberry, willows and hybrid poplars, which were all concurrently used for production purposes. In contrast, orientation to the prevailing winds, crown closure, width and vitality were fair. The area of other tree plantations was ca. 1% of the agricultural land in Khorezm and was dominated by apple and apricot. The vitality of these plantations was satisfactory. Substantiated by the generally young age, it seems that the tree plantation programs of the GoU have been successful to a certain degree with respect to orchards, while hedgerows and wood plantations need to be extended. In this respect, photogrammetry would allow the GoU to closely monitor the implementation dynamics of the programs. Finally, the findings indicate a low forest cover (<1%) in Khorezm and reduction by 60% of the *tugai* forests in 1990-2003, of which ca. 40% could be reversed into forests. With the applied methodology, the MFD should be able to develop better site-specific recommendations for protecting and improving the *tugai* forest ecosystem.

Photogrammetrische Techniken zur funktionellen Beurteilung von Baum- und Waldressourcen in Khorezm, Usbekistan

KURZFASSUNG

Für ein sachgerechtes Management von Wäldern und Baumpflanzungen ist ein System zu deren Inventur und Monitoring essentiell. Mitte der 90er Jahre führte die usbekische Regierung (GoU) verschiedene landesweite Baumpflanzungsprogramme ein. Aufgrund limitierter Mittel sowie fehlender geeigneter Methoden konnte die oberste Forstbehörde (MFD) aber seit 1991 keine verlässliche und umfassende Forstinventur durchführen. Photogrammetrische Methoden kombiniert mit Werkzeugen Geografischer Informationssysteme (GIS) haben ihren Wert und Genauigkeit zur Unterstützung von Forstinventuren weltweit bewiesen. Das Land- und Geodäsie-Katasterzentrum Usbekistans erstellt alle fünf Jahre in der unbelaubten Saison Luftbilder im Maßstab 1:20.000, um die topografischen Karten zur aktualisieren. Das Ziel dieser Arbeit ist daher (i) zu untersuchen, inwieweit diese Luftbilder zur Inventur von Forst- und Baumpflanzungen verwendet werden können und gleichzeitig eine photogrammetrische Standardmethode für das MFD zu entwickeln; (ii) eine Kartierung und funktionelle Beurteilung der Baumpflanzungen (z.B. die Windschutzfunktion der Heckenpflanzungen oder die räumliche Ausdehnung der Pflanzungen) und Wälder (die räumliche Ausdehnung und der Zustand des natürlichen Auenwalds *tugai*) in Khorezm, Usbekistan, durchzuführen.

Das Untersuchungsgebiet liegt innerhalb von zwei Transekten (NS und WO) und deckt nahezu alle typischen Landnutzungsarten und Vegetationsformen und ca. 10% der Fläche Khorezms ab. Ein analytischer Stereoplotter sowie GIS-basierte Werkzeuge wurden angewendet. Die wichtigsten Resultate können wie folgt zusammengefasst werden: Erstens wurden detaillierte Informationen über die Ausdehnung der Baumpflanzungen und Wälder in Form von thematischen Klassen gewonnen. Kriterien zur Anlage von Windschutzpflanzungen (WSP) wie die Orientierung zur vorherrschenden Windrichtung, die mittlere Bestandshöhe, die Gehölzlänge und der Kronenschluss konnten festgelegt werden. Zweitens: Daten über die Artenzusammensetzung, die Vitalität und die Altersklassen der Baumpflanzungen und Wälder sowie die Anzahl der Reihen der WSP konnten nicht mit photogrammetrischen Methoden erhoben werden; hier ist Feldforschung notwendig.

Die Inventur hat gezeigt, dass die meisten Heckenpflanzungen die prinzipiellen Kriterien zur Anlage einer WSP nicht erfüllen und somit auch nicht zur Reduzierung von Bodenerosion oder zur Verbesserung des Mikroklimas beitragen. Dies liegt an dem niedrigen Anteil von WSP auf bewässerten Feldern (<1,5%) sowie an der geringen Höhe (<5 m) und Gehölzlänge (ca. 50% der Fälle) der dominierenden Arten. Die Orientierung zur vorherrschenden Windrichtung, der Kronenschluss, die Breite und die Vitalität waren hingegen ausreichend. Die Fläche anderer Baumplantagen in Khorezm beträgt weniger als 1% und wird von Apfel und Aprikose mit zufriedenstellender Vitalität dominiert. Für die relativ jungen Obstplantagen scheint das Baumpflanzungsprogramm der GoU recht erfolgreich zu sein, bedarf jedoch der Erweiterung bei den Hecken- und Baumpflanzungen. Die Anwendung von Photogrammetrie würde der GoU erlauben, die Dynamik der Umsetzung ihres Programms zu überwachen. Abschließend zeigen die Ergebnisse eine Reduzierung der *tugai* um 60% zwischen 1990-2003, wovon 40% wieder in Wälder umgewandelt werden könnten. Mit den vorgestellten Methoden könnte die MFD bessere standortspezifische Empfehlungen zum Schutz und zur Verbesserung des Ökosystems *tugai* entwickeln.

Фотограмметрическая техника для функциональной оценки древесно-кустарниковых насаждений и лесов в Хорезме, Узбекистан

АННОТАЦИЯ

Система инвентаризации гослесфонда и древесно-кустарниковых насаждений вне него является необходимой при осуществлении мероприятий, направленных на сохранение и развитие лесных ресурсов, в соответствии, с законодательной и нормативно-правовой базой. Из-за, отсутствия доступной методики вопрос проведения полноценной инвентаризации лесов Главным управлением лесного хозяйства (ГУЛХ) остается открытым. С другой стороны, фотограмметрия в сочетании ГИС технологиями во всем мире доказала свое значение и точность для инвентаризации лесов. Учитывая, что аэрофотосъемка производится в масштабе 1:20 000 в безлиственный период раз в 5 лет для актуализации топографических карт Госкомитетом «Ергеодезкадастр», цель этого исследования была: (а) проверить какую информацию и ее качество можно получить с имеющихся аэрофотоснимков для инвентаризации гослесфонда и насаждений вне него, и при этом разработать соответствующую методологию для ГУЛХ; и (б) провести картирование и функциональную оценку древесно-кустарниковых насаждений (напр., ветрозащитная функция линейных лесных насаждений (ЛЛН) на орошаемой пашне) и гослесфонда (леса тугайной зоны) в Хорезмском вилояте.

Исследуемая площадь в пределах двух трансект (СЮ и ЗВ) виртуально охватывала все типичные классы землепользования и растительных формаций, что составило почти 10% площади Хорезма. Использовались аналитический стерео плоттер и ГИС средства. Дешифрирование аэрофотоснимков позволяет сделать два заключения. Первое, детальная и точная информация может быть получена о пространственном распространении земель гослесфонда и насаждений вне него в форме разработанных тематических классов. Кроме того, критерии дизайна ЛЛН, включая их расположение относительно господствующих ветров, средняя высота, длина (достижение ЛЛН краев, связанного с ним поля) и горизонтальная сомкнутость крон, могут быть достоверно определены. Второе, ширина (число рядов ЛЛН), а также породный состав, классы возраста и подверженность лесов и насаждений вредителям и болезням не могут быть определены с помощью фотограмметрии и требуют наземного обследования по выборке.

Инвентаризация показала, что большинство ЛЛН в Хорезме не соответствуют основным критериям дизайна ветрозащиты и, следовательно, они не могут быть достаточно эффективными для снижения эрозии почв и улучшения микроклиматических условий. В частности, недостаточная площадь на орошаемой пашне (<1,5%), низкая высота (<5 м) и ограниченная длина (около 50% случаев) не смешанных ЛЛН в основном шелковицы белой, ив и гибридных тополей, все из которых одновременно используются в хозяйственных целях. Однако, расположение этих ЛЛН относительно господствующих ветров, горизонтальная сомкнутость крон и ширина были, в целом, в удовлетворительном состоянии. Площадь других насаждений в Хорезме составила около 1%, где значительно преобладали сады (яблоня и абрикос). Доминирование молодых и средневозрастных насаждений свидетельствует, что осуществляемые мероприятия в определенной степени успешны для садов, а площади ЛЛН, плантации тополя и шелковицы следует увеличить. Здесь фотограмметрия позволит проводить мониторинг за осуществлением мероприятий, направленных на развитие этих насаждений. Наконец, результаты исследования свидетельствуют о низкой лесистости тугайной зоны (<1%) в Хорезме и сокращении площади покрытых лесом земель гослесфонда на 60% в 1990-2003гг., из них 40% перешли в категорию «непокрытые лесом». С помощью применяемой методики, лесхозы будут способны более точно определять участки, нуждающиеся в лесовосстановлении для сохранения и улучшения уникальной экосистемы тугайного леса.

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ACRONYMS AND ABBREVIATIONS

asl	Above sea level
Ergeodezkadastr	Land and Geodesy Cadastre Center of Uzbekistan
Dekhqan farm	Small private holdings
FRA 2005	Forest Resources Assessment 2005 by FAO
GIS	Geographic Information System
Goskomles	State Committee on Forestry
GPS	Global Positioning System
Kolkhozes	Collective farms
Leskhozes	State forestry enterprises (e.g., Khorezm Forestry Enterprise)
MAWR	Ministry for Agriculture and Water Resources of Uzbekistan
MFD	Main Forestry Department at MAWR (former *Goskomles*)
Oblast	Region
SPOT	Satellite Pour l'Observation de la Terre
Shirkats	Private shareholder farms
Sovkhozes	State farms
SU	Former Soviet Union
Uchkhozes	Research farms of Urgench State University
Uzgiprourmonloyiha	Design and Survey Forestry Enterprise of MFD
V-CAP	Data management and orientation software
Viloyat	Region
WGS84	World Geodetic System with the latest revision in 1984

LIST OF SPECIES MENTIONED IN THIS STUDY*

Scientific name	English name	Russian name	Uzbek name
	Plants		
Acer ginnala var. *semenovii* (Regel & Herder) Pax	Maple	Клен	*Zarang*
Ammodendron conollyi Bunge	–	Песчаная акация	*Quyon suyak*
Apocynum scabrum L.	Dogbane	Кендырь	*Kendir*
Artemisia L.	Wormwood	Полынь	*Achchiq shuvoq*
Astragalus L.	Milkvetch	Астрагал	*Oq shatai*
Biota orientalis (L.) Franco	Chinese cedar	Туя восточная	*Tuya*
Calamagrostis epigeios (L.) *Roth*	Chee reed grass	Вейник наземный	*Bug'doiqamish*
Calligonum caput-medusae Schrenk	–	Кандым	*Qizil qandim*
Cydonia oblonga Mill.	Quince	Айва	*Bekhi*
Elaeagnus angustifolia L.	Russian olive	Лох узколист.	*Jida*
Erianthus ravennae (L.) L.	Ravenna grass	Эриантус	*Qamish*
Fraxinus pennsylvanica Marshall	Swamp ash	Ясень	*Shumtol*
Gleditsia triacanthos L.	*G. triacantos*	Гледичия	*Gleditchia*
Glycyrrhiza glabra L.	Licorice	Солодка	*Shirinmiya*
Gossypium L.	Cotton	Хлопчатник	*Pahta*
Haloxylon ammodendron (C. A. Mey.) Bunge	*Saxaul*	Саксаул черный	*Qora saksovul*
Haloxylon persicum Bunge ex Boiss. & Buhse	*Saxaul*	Саксаул белый	*Oq saksovul*
Hordeum L.	Barley	Ячмень	*Arpa*
Juniperus virginiana L.	Eastern red cedar	Можжевельник восточн.	*Archa*
Maclura pomifera (Raf.) C. K. Schneid.	Osage orange	Маклюра	*Maklyura*
Malus spp.	Apple	Яблоня	*Olma*
Medicago L.	Alfalfa	Люцерна	*Beda*
Morus alba L.	White mulberry	Шелковица белая	*Oq tut*
Oryza L.	Rice	Рис	*Guruch*
Phragmites australis (Cav.) Trin. ex Steud.	Common reed	Тростник обыкновен.	*Oddiy qamish*
Populus euphratica Oliv.	Euphrates poplar	Тополь евфратский	*Turanga*
Populus pruinosa Schrenk	–	Тополь сизый	*Turang'il*
Populus spp.	Hybrid poplars	Гибриды тополя	*Terak*

* *Dendrology of Central Asia, 1980; Forestry Compendium, 2000; IBORA, 2005; ITIS, 2008; KhCGR, 2000; Red Data Book of Uzbekistan, 2008; USDA, 2008*

LIST OF SPECIES MENTIONED IN THIS STUDY (CONT.)*

Scientific name	English name	Russian name	Uzbek name
		Plants	
Prunus armeniaca L.	Apricot	Абрикос	*O'rik*
Prunus cerasus L.	Cherry	Вишня	*Olcha*
Prunus persica (L.) Batsch	Peach	Персик	*Shaftoli*
Pyrus communis L.	Pear	Груша	*Nock*
Robinia pseudoacacia L.	Black locust	Робиния (лжеакация)	*Oq akas*
Saccharum spontaneum L.	Wild sugarcane	Тростник сахарный	*Yovvoiy shakar qamish*
Salix spp.	Willow	Ива	*Tol, majnun tol*
Salsola richteri (Moq.) Karel. ex Litv.	–	Солянка (черкез)	*Tuyaqorin (cherkez)*
Secale L.	Rye	Рожь	*Roj'*
Tamarix androssowii Litv., Sched	Salt cedar	Гребенщик Андросова	*Yulg'un*
Triticum L.	Wheat	Пшеница	*Bug'doi*
Typha laxmannii L.	Slender reed mace	Рогоз ширколистн.	*Qo'g'a (tuzg'oq, luh)*
Ulmus pumila L.	Siberian elm	Вяз приземистый	*Urus gujum (qayrag'och)*
Vitis L.	Grape	Виноград	*Uzum*
Zea L.	Corn	Кукуруза	*Jo'xori*
Ziziphus jujube Mill.	Jujube	Унаби	*Chilonjida*
		Animals	
*Cervus elaphus bactrianu*s Lydekker	Baktrian (Bukhara) deer	Бухарский олень	*Buxoro bug'usi (Xongul)*
Gazella subgutturosa Guld.	Goitered gazelle	Джейран	*Jayron*
Lepus tolai Pallas	*Tolai* hare	Заяц песчаник (толай)	*Tolay quyoni*
Meles meles Linnaeus	Eurasian badger	Барсук	*Evrosie bo'rsiqi*
Panthera tigris virgata Illiger	Caspian (Turan) tiger	Туранский тигр	*Turan yo'lbars*
Phasanicus colchicus chroysomeles	Khiva pheasant	Хивинский фазан	*Xiva qirg'ovuli*
Sus scrofa Linnaeus	Wild boar	Кабан	*Yovvoyi cho'chqa*
Vulpes vulpes Linnaeus	Red fox	Рыжая лисица	*Tulki*

* *Dendrology of Central Asia, 1980; Forestry Compendium, 2000; IBORA, 2005; ITIS, 2008; KhCGR, 2000; Red Data Book of Uzbekistan, 2008; USDA, 2008*

1 GENERAL INTRODUCTION

1.1 Background and problem statement

In the arid area in the lower reaches of the Amu Darya River, in the Khorezm region, an administrative *Oblast* (in Russian) or *Viloyat* (in Uzbek) in the northwest of Uzbekistan, Central Asia, trees and forests occur under two circumstances only: (i) to a larger extent, artificially as tree plantations in irrigated lands and (ii) to a lesser extent, naturally as forests in the floodplains flanking the Amu Darya River. Single (woody) shrubs are found in the adjacent sandy desert areas in the Karakum Desert in the southern parts of the region.

Trees in irrigated lands are integrated in the intensive agricultural land-use systems and mainly consist of white mulberry (*Morus alba* L.), willow (*Salix* spp.) and hybrid poplar (*Populus* spp.) hedgerows along agricultural fields and irrigation networks, which have been planted for multipurpose uses, e.g., as windbreaks with an ecological function and for leaf production of pollarded *M. alba* for sericulture, wicker production of pollarded *Salix* spp. for basketry, and wood production of *Populus* and *Salix* spp. as local construction material (Botman, *personal communication*; Vlek et al., 2001). Khorezm is also characterized by other tree plantations including recently apple (*Malus* spp.), apricot (*Prunus armeniaca* L.) and grape (*Vitis* L.) for home fruit consumption and sale, pollarded *M. alba* for sericulture, and *Populus* spp. for local construction material (Kan et al., 2008). Since tree plantations (hedgerows/windbreaks and other tree plantations) are predominantly under agricultural use, they can be classified as “other land with tree cover” in the FAO assessment of forest resources (Appendix 9.1).

Floodplain forests or *tugai* forests (in Uzbek) (canopy closure >10%) and other wooded land (canopy closure <10%) (Appendix 9.1) in *tugai* forests provide ecological functions, e.g., reduce river bank erosion, improve soil fertility, provide habitats for wildlife, etc. (FAO, 2005a; Treshkin et al., 1998). Woody *tugai* forests mainly of Euphrates poplar (*Populus euphratica* Oliv.) and *turang’il* (*P. pruinosa*), but also Russian olive (*Elaeagnus angustifolia* L.) and *Salix* spp. only survive with regular flooding every one or two years (Kuzmina and Treshkin, 1997; Treshkin, et al., 1998). Single (woody) shrubs or other wooded land (Appendix 9.1) in desert areas include *saxaul* or *qora saksovul* (*Haloxylon ammodendron* (C. A. Mey.) Bunge) and *oq saksovul* (*H. persicum*), *quyon suyak* (*Ammodendron conollyi* Bunge), salt cedar (*Tamarix androssowii* Litv., Sched), *qizil qandim* (*Calligonum caput-medusae* Schrenk) and *cherkez* (*Salsola richteri* (Moq.) Karel. ex Litv.), as well herbs such as wormwood (*Artemisia* L.) and milkvetch (*Astragalus* L.), which are concentrated in the lower areas with access to groundwater (Drobov, 1951; Gintzburger et. al, 2003; Korovin, 1962) and fulfill ecological functions such as stabilizing sand dunes and maintaining desert biodiversity (MFD, 2008).

Forest exploitation in Uzbekistan is restricted due to the low forest cover and the importance of the ecological function of forests, while sanitary and regeneration cuttings are practiced every year (FAO, 2005a; FAO, 2006b). The forest management in Uzbekistan dates from Soviet Union (SU) times, when forests were centrally managed by *Goskomles* (State Committee on Forestry), today the Main Forestry Department (MFD) of the Ministry for Agriculture and Water Resources (MAWR) of Uzbekistan, and regionally today by *leskhozes* (state forestry enterprises), e.g., the Khorezm Forestry Enterprise. Another task of the former *leskhozes* was the planting of hedgerows for ecological purposes such as windbreaks in irrigated agricultural fields (Botman, *personal communication*) according to the recommended schemes (e.g., Minselkhoz, 1972) or experimental plantings, e.g., in the Khiva Research Station at the Center for Landscape Gardening and Forestry of the MFD. Further maintenance of those windbreaks was under the responsibility of *kolkhozes* (collective farms) and *sovkhozes* (state farms), who, however, often lacked knowledge and motivation. Cotton (*Gossypium* L.) monoculture was the main task of the *kolkhozes* and *sovkhozes* in Uzbekistan according to centrally determined production plans, and cotton was transported to central Russia for processing (FAO, 1995); it comprised ca. 70% of cotton production in the SU (UzSSR, 1982). The planners in Moscow defined the share for other products that were in high demand in the SU and were produced in Uzbekistan, e.g., raw silk, which was about 50% of the production in the SU. The SU promoted the development of *M. alba* plantations for leaf production in silkworm rearing (sericulture) on a large scale. Since forests and tree plantations served other functions than wood production, during the SU period Uzbekistan's wood demand was satisfied by a supply from the central and northern parts of Russia and Siberia, while the state budget was used to support an extensive forestation program (FAO, 2006a; FAO 2006b).

Following the break-up of the SU and the proclamation of Uzbekistan as an independent state in 1991, funding for afforestation and reforestation was drastically reduced and became insufficient to support further established institutions and their staff in their management of forests and tree plantations (e.g., FAO, 2006a). Many hedgerows established as windbreaks have been cut down or have perished due to a lack of care, and trees are maintained mostly for production purposes, e.g., pollarding *M. alba* for sericulture, etc. (MFD, 2008), while severe water shortages in 2000-2001 affected the vulnerable *tugai* forests (Treshkin, 2001b). Furthermore, wood imports ceased owing to the high prices mainly due to the transportation costs (FAO, 2006a), while the relatively high population growth (UNFCC, 2001) led to a growing demand for construction wood, as well as for fruits, grapes, silk, etc.

To respond to those challenges, the government of Uzbekistan approved forest legislation emphasizing forest protection, regeneration and many other issues (GoU, 1999), and a national action program to combat desertification (UNCCD, 1999). It also initiated many other nationwide tree growing programs, including *Populus* spp. plantations and other fast-growing species to satisfy the high demand for construction wood and pulp (GoU, 1994), windbreak and shelterbelt plantings for improving environmental conditions (GoU, 2007; MAWR, 2002), reformation of the fruit industry and viticulture (GoU, 2006a), and *M. alba* plantations for sericulture (GoU, 2006b). Proper management is the key element of those programs, and up-to-date, reliable and comprehensive information is essential to support sound decision making. However, a lack of knowledge and inconsistency of data on forests and tree plantations existed among both the forest administration and the farmers in the transition period of the country (FAO 2005a; FAO 2006a; FAO 2006b). Extensive field surveys in *tugai* forests and other wooded land in *tugai* forests and deserts as they were performed in the past (KhFI, 1990) are now beyond reach because they are expensive to be carry out. Also, the extent and functionality of tree plantations in large agricultural areas, e.g., the windbreak function of multipurpose hedgerows, has not been assessed in the past. Thus, the limited functional assessment data on forests and tree plantations affect decision making and management.

While worldwide remote sensing techniques (photogrammetry and satellite imagery) combined with Geographic Information System (GIS)-based tools and field sampling have been developed also for use in inventories of forests and tree plantations, such methodologies have not yet been introduced in the forest research divisions of Uzbekistan, in particular the *Uzgiprourmonloyiha* (the Design and Survey Forestry Enterprise) of the MFD. Consequently, in the study region of Khorezm, as in the whole country, functional assessment data on hedgerows and other tree plantations, as well on *tugai* forests and other wooded land, are very limited.

1.2 Research objectives

The main objectives of this study were the adaptation and verification of array approaches used in inventories of forests and tree plantations for development of an easy-to-use, cheap, quick but comprehensive standard methodology for functional assessment of tree plantations and forests in the region of Khorezm, and data collection for a functional assessment of those plantations and forests. The specific research objectives included:

1. To adapt a methodology for the assessment of (i) the windbreak function of multipurpose hedgerows in irrigated agricultural fields, (ii) other tree plantations, and (iii) *tugai* forests and other wooded land in *tugai* forests and deserts applying photogrammetry combined with GIS-based tools and field sampling as an alternative to the former extensive field surveys;
2. To validate the accuracy of the adapted procedure;
3. To assess the spatial extent and windbreak function of existing multipurpose hedgerows in irrigated agricultural fields;
4. To assess the spatial extent, vitality and age of other tree plantations;
5. To assess the spatial extent, vitality and age classes of *tugai* forests and other wooded land in *tugai* forests and deserts as compared to the last Khorezm forest inventory in 1990;
6. To provide recommendations regarding the assessment methodology for the *Uzgiprourmonloyiha,* and data for decision makers including the Khorezm Forestry Enterprise and local farmers;

7. To prepare regional maps of tree plantations and forests, and to compile a reference database of those resources in the study areas.

1.3 Outline of thesis

The thesis consists of nine chapters. Following this general introduction (Chapter 1), Chapter 2 describes the study region with special regard to the interactions between trees and the environment in the study region in Khorezm. The assessment methodology for tree plantations and forests is detailed in Chapter 3. The next three chapters assess the windbreak function of existing multipurpose hedgerows in irrigated agricultural fields (Chapter 4), other tree plantations (Chapter 5) and *tugai* forests and other wooded land (Chapter 6). Each of these three chapters is headed by a brief introduction followed by methodology, detailed assessment and discussion of the results and conclusions. Finally, Chapter 7 presents the general conclusions, recommendations and outlook. Chapters 8 and 9 include literature references and appendices, respectively.

2 INTERACTIONS BETWEEN TREES AND THE ENVIRONMENT IN THE KHOREZM REGION

2.1 Location and demography

With about 6.1 million ha, Khorezm is among the smallest administrative *Viloyats* of Uzbekistan and is located between 41 and 42°N latitude and 60 and 61°E longitude (GoU, 2008). It is situated in the northwestern part of the country and forms one component of the lower reaches of the Amu Darya River. The river is the main water source for the region of Khorezm (Figure 2.1). The region is bordered by the Karakum Desert to the south and the Kizylkum Desert to the east and is about 225 km south from the remainders of the Aral Sea.

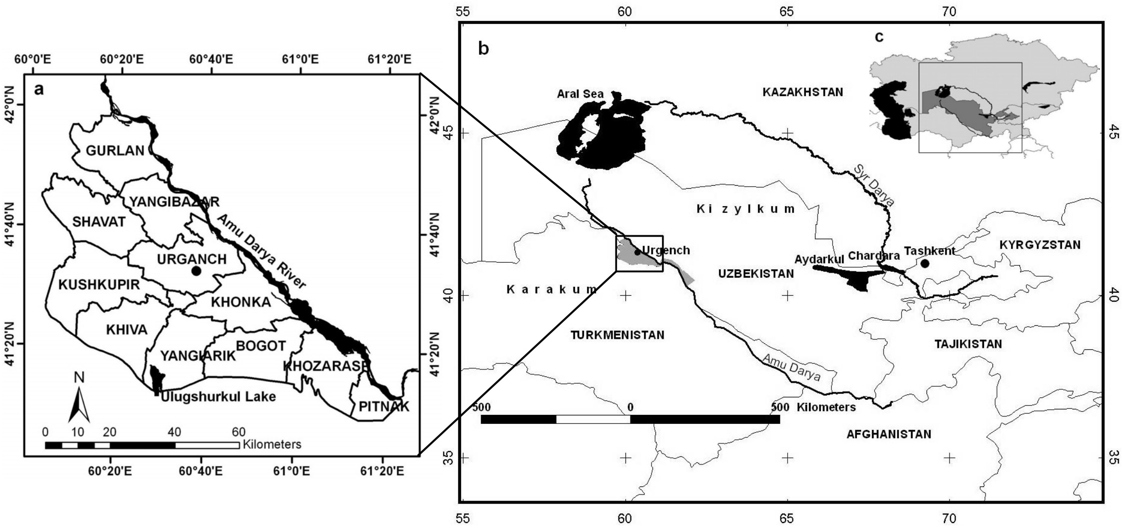

Figure 2.1: Location of the Khorezm region (a), Uzbekistan (b) and Central Asia (c)

Khorezm has some 1.5 million inhabitants, with a population density of almost 250 persons km^{-2} (GoU, 2008) and a high mean population growth of about 2.8% (MMS, 1999). The share of rural inhabitants is high (77%); most people are involved in cotton (*Gossypium* L.), wheat (*Triticum* L.) and rice (*Oryza* L.) production, and in animal husbandry and sericulture (Djalalov et al., 2005).

Owing to the relatively high population growth (UNFCC, 2001), the demand for construction wood, fruits, etc., is increasing (section 1.1). The consumption of fuelwood is also very likely to rise because of the notorious inaccessibility of centrally grid-supplied energy such as natural gas and electricity, and the steadily increasing prices for these resources. Renewable energy resources have not yet been sufficiently considered. Fuelwood can thus be an additional source to reduce the needs in fossil fuel, especially in remote rural areas. Various locally grown tree species, in particular those that are characterized by rapid growth such as Russian olive (*Elaeagnus angustifolia* L.), hybrid poplars (*Populus* spp.) and salt cedar (*Tamarix androssowii* Litv., Sched), show high calorific values, indicating their potential as bio-fuel (Khamzina et al., 2006a).

There is also an urgent need to ease the increasing livestock-feed shortages in Khorezm, since recent research identified the growing importance of this component for household security (Mueller, 2006). Leaves of various trees and shrubs such as Russian olive (*E. angustifolia*), white mulberry (*Morus alba* L.) and Siberian elm (*Ulmus pumila* L.) contain substantial amounts of crude protein that are higher than in alfalfa (*Medicago* L.) hay, which is considered to be a high quality local feed. Recently, it was suggested that these features offer possibilities for the use of tree leaves as supplementary fodder to the low-quality roughages such as the wheat stalks usually used in Khorezm outside the growing season (Khamzina et al., 2006a).

2.2 Climate

As a part of the Central Asian semi-desert zone, Khorezm has an extremely continental climate (Glazirin et al., 1999). The mean annual temperature is about 13°C (Figure 2.2a), while the mean temperature during the coldest month January is approximately -2°C and the absolute daily minimum can be as low as -28°C. Summers are quite hot with mean monthly temperatures in July reaching about 30°C, but daily extremes as high as 47°C have been recorded. From early December till late January, mean monthly temperatures may be below the freezing point (Figure 2.2a).

An analysis of long-term data shows mean daily air temperatures above 10°C between mid April and mid October, which determine the window for vegetation growth and cropping (Chub, 2000).

The long-term annual precipitation is about 100 mm year^{-1} (Figure 2.2a), but in some years amounts were as low as 30-40 mm (Chub, 2000; Glazirin et al., 1999). Most precipitation falls between November and March. Due to the climatic conditions, the local evapotranspiration potential is as high as 1500 mm (Figure 2.2b). A mean wind speed of 3.5 m s^{-1} in the period 1982-2000 with a prevailing NE direction throughout the year was observed for the region (Glavgidromet, 2003).

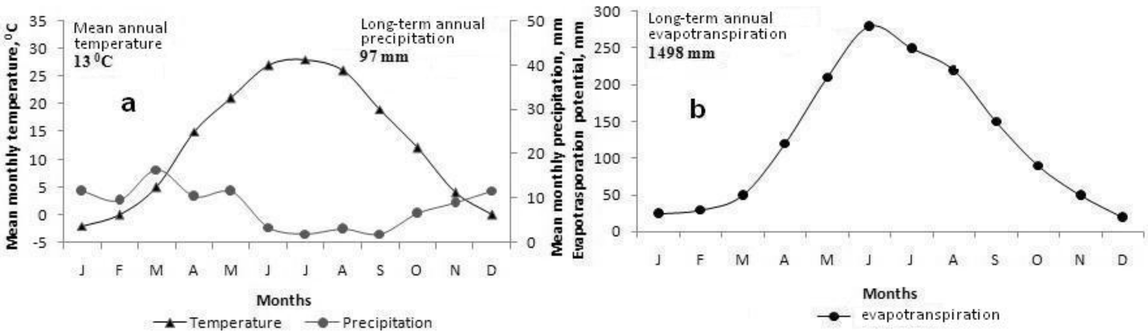

Figure 2.2: Climate in Khorezm: (a) period 1980-2000, Urgench meteorological station (Glavgidromet, 2003); (b) period 1970-1980, Khiva meteorological station (Mukhammadiev, 1982)

The harsh climatic conditions substantially influence the extent and diversity of tree plantations and forests in the region. Tree plantations occur mostly in the irrigated lands, including multipurpose hedgerows, e.g., *M. alba*, willows (*Salix* spp.), etc., and other tree plantations with apple (*Malus* spp.) and *Populus* spp., etc. (section 1.1). Relatively sparse, unevenly distributed, low-diversity, natural woody vegetation is restricted to floodplain *tugai* forests and other wooded land in *tugai* forests consisting mostly of Euphrates poplar (*Populus euphratica* Oliv.) and *turang'il* (*P. pruinosa*), and to single and small (woody) shrubs, e.g., *saxaul* or *qora saksovul* (*Haloxylon ammodendron* (C.A. Mey) Bunge), *oq saksovul* (*H. persicum*), etc., and herbs such as wormwood (*Artemisia* L.) and milkvetch (*Astragalus* L.) in the areas adjacent to the sand Karakum desert or other wooded land in deserts (section 1.1).

2.3 Relief and soils

The relief of Khorezm is mostly flat with insignificant slopes of less than 1% in the west-northwest and towards the southwest, while elevations vary between 128 m above sea level (asl) in the Khazarasp district and 112 m asl in the Khiva district (Katz, 1976). Most of Khorezm is covered with alluvial sediments from the meandering Amu Darya River. However, decades of irrigation-water application have caused additional sedimentation as evidenced in the youngest soil layers. The differences in alluvial deposits thus vary between a few centimeters and 30-40 m, which are also heterogeneously stratified (Fayzullaev, 1980; Nurmanov, 1966). The underlying layers consist of sand, in contrast to the heavy-textured loamy and clay top layers. The thickness of the top layers increases with distance from the ancient to current riverbeds and hence are found in the eastern periphery of Khorezm. According to the FAO classification, the soils in Khorezm belong to five groups: 1) arenosols, gleyic and calcaric (sodic), 2) arenosol and aridic, 3) cambisol and calcaric, 4) fluvisol, gleyic, and humis, and 5) solonchak, takyric and arenosols (Ibrakhimov, 2004), which all are potentially suitable for growing trees and shrubs.

2.4 Irrigation network

The importance of water in Khorezm is well exemplified in the Uzbek proverb, “where water ends, there ends the land”, since the irrigated areas of Khorezm are surrounded by deserts, near-deserts, and steppes, and would be unproductive drylands if not irrigated. In Khorezm, water from the Tuyamuyun Reservoir and the Amu Darya River is channeled to agricultural fields by gravity through a hierarchically arranged irrigation network. In the Soviet literature, the distribution network is split into *inter-farm* and *on-farm canals*. The inter-farm network delivers water from the *main* canals down to the former state farm borders. The *on-farm canals* deliver water to the field application network, which consists of temporary canals. Smaller temporary canals bring water to the field-level furrows. Drainage water is conveyed via hierarchically constructed collectors from the irrigated fields into numerous small lakes and depressions outside the irrigated area. The main depression is the Sarykamish Depression, which was formerly connected with the Aral Sea (see also Ibrakhimov, 2004).

Khorezm has a long history of irrigated agriculture. However, since the mid 1930s and the extension of the irrigation and drainage network over the entire Khorezm region, the groundwater level has drastically risen, predominantly in the medium and heavy soil textures (Ibrakhimov, 2004). Moreover, throughout the main vegetation period April-October, the groundwater tables fluctuate between 1.2 and 1.5 m below the soil surface due to the refill of the groundwater caused by leaching and irrigation events (Ibrakhimov, 2004). Continuous monitoring of the groundwater also revealed average salt contents varying between 2.8 dS m^{-1} in April and 2.6 dS m^{-1} in October. The shallow groundwater tables combined with the high evaporation rates usually provoke a capillary rise of the groundwater and consequently secondary soil salinization (Forkutsa, 2006).

Tree species that are less adapted to salt and water stress and, therefore, require an adequate water supply are, for example, *M. alba*, *Malus spp.*, apricot (*Prunus armeniaca* L.), peach (*P. persica)*, *Populus* and *Salix* spp., and swamp ash (*Fraxinus pennsylvanica* Marshall) (Makhno, 1962). The majority of the tree species found in Khorezm was introduced either a longer time ago (e.g., *M. alba*) at the beginning of the Soviet rule (e.g., *U. pumila*), or very recently, as in the case of fast-growing *Populus* spp. used for construction wood (Worbes et al., 2006). However, only a limited number of tree species such as *E. angustifolia*, *U. pumila* and *P. euphratica* are able to survive in environments characterized by rising groundwater tables and high soil and groundwater salinity (Khamzina et al., 2006a). These salt-tolerant species also are appreciated for their bio-drainage characteristics due to their high transpiration rates, and can be considered in an integrated drainage design (Khamzina et al., 2006b).

2.5 Farming systems

Djanibekov (2006) reported in detail on the characteristics of the various farm production units. However, there is insufficient data on the role and significance of trees in these farming systems. Recent findings revealed close links between crops and trees in the Khorezm region (Worbes et al., 2006). Moreover, in-depth research showed that the trees are used in the state forestry or agroforestry systems on private land for protection of crops from wind erosion, thus increasing crop yields, for sericulture, for the production of construction wood and fuelwood, and for the prevention of desertification on the borders of the Khorezm Oasis (Kan et al., 2008). Such direct and indirect effects have been previously reported in detail (Figure 2.3).

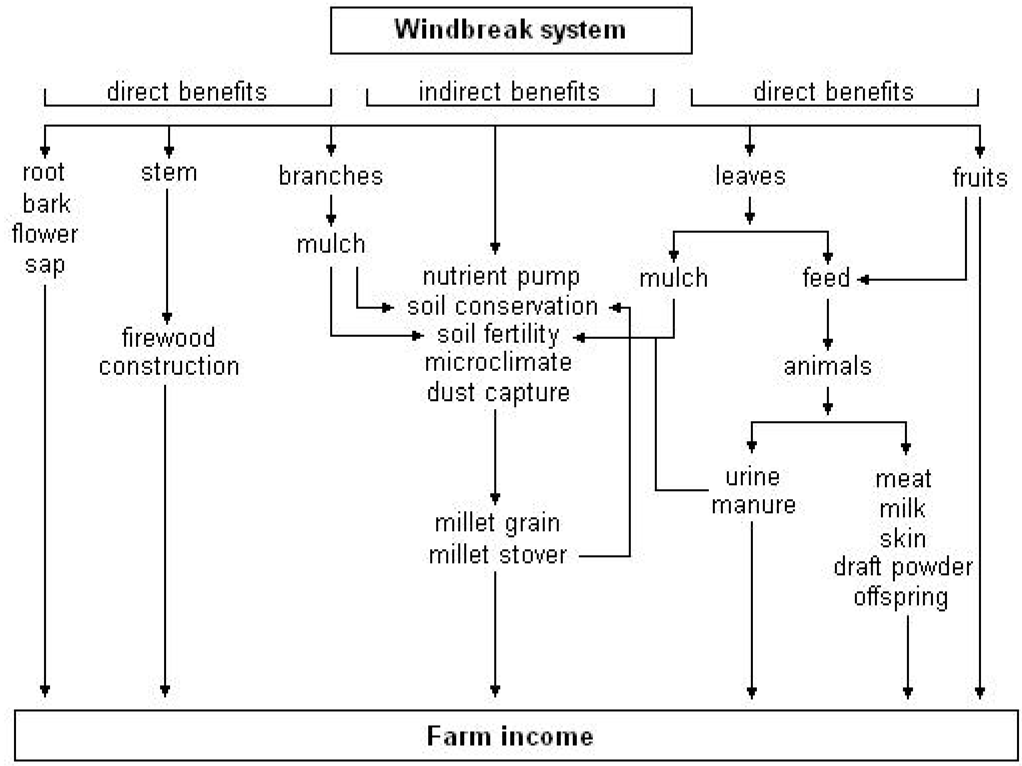

Figure 2.3: Direct and indirect benefits of a windbreak system on farm income (Lamers, 1995)

When tree plantations and forests are classified according to their main function (FAO, 2006b), two major groups emerge in Khorezm:

- Ecological or protection function: (i) During the SU period, about 40,000 ha of field windbreaks and shelterbelts were planted in Uzbekistan (MAWR, 2005). However, in Khorezm they consisted of multipurpose hedgerows bordering agricultural fields and irrigation networks, and were used mainly for production purposes (see below), while their ecological function was neglected. Although worldwide experience evidenced broader usage of windbreak by-products with proper harvesting techniques (e.g., Rocheleau et al., 1988), such practice has not yet been considered in Uzbekistan. (ii) Floodplain *tugai* forests and other wooded land in *tugai* forests reduce river bank erosion, improve soil fertility and provide habitats for wildlife (FAO, 2005a; Treshkin et al., 1998). (iii) Other wooded land in deserts stabilizes sand dunes and maintain desert biodiversity (MFD, 2008);
- Farm or home use: (i) Multipurpose hedgerows (see above), including pollarded *M. alba* for leaf production in silkworm rearing (sericulture), pollarded *Salix* spp. for artisan work, and *Poplus* and *Salix* spp. for construction wood supply, (ii) about

13,000 ha of plantations for fruit supply mainly *Malus* spp., *P. armeniaca* and to a lesser extent *P. persica*, cherry (*P. cerasus*), pear (*Pyrus communis* L.), quince (*Cydonia oblonga* Mill.) and jujube (*Ziziphus jujube* Mill.) as well about 1500 ha of grapes (*Vitis* L.) (Kan et al., 2008; KhCGR, 2000), (iii) pollarded *M. alba* plantations for sericulture, desert shrubs such as *cherkez* (*Salsola richteri* Karel), *T. androsowii*, etc., roamed by goats and sheep, and promising tree species with high contents of nutritive substances in leaves such as *E. angustifolia* and *U. pumila* (Khamzina et al., 2006a), (iv) *Populus* spp. plantations, which are exclusively used for construction wood supply (Worbes et al., 2006), and (v) fuelwood, which can be harvested from any tree species, but then differs in quality (Khamzina et al., 2006b).

2.6 Natural vegetation

Uzbekistan can be classified as a country with a low forest cover (<10%) by Lund's definition (1999). Khorezm covers 610,000 ha (ca. 1%) of Uzbekistan's 44.7 million ha land area, and contributed 60,000 ha (ca. 2%) to the country's 3.3 million ha of forest and other wooded land in 2005 (Table 2.1). The forest cover is decreasing. The Khorezm Forest Service estimated about 39,000 ha of forest in 2005 compared to 47,000 ha in 1990. Although the forest area covers 7% of the Khorezm region, which is higher than the national average of 5%, only 0.03 ha of forest was available for each Khorezm inhabitant (Table 2.1), a value that is close to the 0.02 ha in the very densely populated Netherlands (European Forest Institute, 2005). Forest and other wooded land is subdivided into a large desert (sand) zone (98%) and small plain lowland zone with *tugai* floodplain forests (2%) (KhFE, 2005 reclassified by FAO, 2005a; FAO, 2005b), while in whole Uzbekistan, three zones were classified: desert (90%), mountain (9%) and plain lowlands including *tugai* forests and irrigated valleys (ca. 1%) (MFD, 2008).

Single (woody) shrubs, e.g., *H. ammodendron*, *H. persicum*, etc., and herbs such as *Artemisia* L. and *Astragalus* L., etc., can only be found in the desert zone. Woody shrubs reach an average height of 4 m although their root systems may penetrate down to more than 6 m to reach the groundwater (Breckle, 2002). The standing volume of those shrubs in the desert zone is generally very low, ranging from 2.5 m^3 ha^{-1} in the Tuyamuyun forest territory (management unit) to 3.3 m^3 ha^{-1} in the Khiva forest territory for mature trees (KhFI, 1990), which makes an economical timber production virtually impossible. These desert shrubs cannot be defined as "forest" in the classical view of foresters or botanists. Therefore, such shrubs mainly have ecological functions such as stabilizing sand dunes and maintaining biodiversity at higher levels.

Table 2.1: Forest area in Khorezm and Uzbekistan (Goskomles, 1993*; GoU, 2008; KhFE, 2005*; KhFI, 1990*; MAWR, 2005*; US Census Bureau, 2008)

Regional and country statistics	Khorezm 1990	Uzbekistan 1993	Khorezm 2005	Uzbekistan 2005
Total land area (1000 ha)	610	44,740	610	44,740
Total population (1000)	1018	22,128	1287	26,540
Population density (persons/km^{-2})	170	50	210	60
Total forest land (incl. inland water and other land, e.g., deserts, swamps etc., in forest land) (1000 ha)	94	8077	69	8051
Forest and other wooded land (1000 ha)	79	3383	60	3295
Forest (1000) ha	47	1913	39	2391
Other wooded land (1000 ha)	32	1471	21	904
Forest and other wooded land (%)	14.0	7.6	10.8	7.4
Forest and other wooded land (ha/person)	0.08	0.17	0.05	0.12
Forest (%)	8.4	4.3	7.0	5.3
Forest (ha/person)	0.05	0.09	0.03	0.09

** Reclassified by FAO, 2005a*

Tugai forest ecosystems are an important component of the environment in the river valleys of Central Asia (Treshkin et al., 1998; Treshkin, 2001a). They create favorable microclimatic conditions, which enable plants to survive in arid conditions characterized by high solar radiation, high air temperatures and short availability of direct useful precipitation. The *tugai* is a natural habitat for many species and wild animals. About 16% of the total mammal species diversity in the south of the Aral Sea region is found in the *tugai* forests of the lower Amu Darya (Reimov, 1985). The birds include 91 species, of which 39 are nesting, 16 resident, 18 hibernating, and 18 migratory (Biodiversity Conservation, 1998). Some valuable and rare game species include the Bactrian or Bukhara deer (*Cervus elaphus bactrianus* Lydekker), Persian gazelle (*Gazella subgutturosa* Guld.), wild boar (*Sus scrofa* Linnaeus), *tolai* hare (*Lepus tolai* Pallas), Eurasian badger (*Meles meles* Linnaeus), red fox (*Vulpes vulpes* Linnaeus), and Khiva pheasant (*Phasanicus colchicus chroysomeles*). The *tugai* forests play an important role in the landscape, as they reduce erosion on riverbanks, contribute to soil formation, and improve river water conditions (Treshkin, et al., 1998). The natural *tugai* vegetation also affects the mineralization of the groundwater, and serves as a powerful biodrainage system. *Tugai* trees in the delta and floodplains contribute to the improvement of the soil fertility by accumulating river alluvium during flooding. In addition, they represent natural barriers against the frequent sand and dust storms in the neighboring degraded areas (Aral Sea region).

Since the last century, the *tugai* forests have been used in a variety of ways. The trees are used for construction and fuel wood, while the undergrowth and the leaves of the trees are used as feed for sheep, goats and camels (Novikova et al., 1998; Novikova, 2001; Runge et al. 2001; Treshkin et al., 1998) (see Chapter 6).

2.7 Summary

Although during the SU period, trees in the Khorezm region were introduced for their ecological function and production services, after independence and land reforms, tree planting slumped. The need to stop the advancing land degradation and desertification and increase the current short supply of construction wood, fruit, fodder and fuelwood may encourage the presently insufficient afforestation efforts. However, the expansion of existing tree plantations and natural forests remains doubtful, since there is a lack of funding and suitable methodology, which means that the forest administration cannot conduct the necessary inventories. The ecological conditions determine to a great extent the composition, type, density, growth and development of tree plantations and forests, while the anthropogenic pressure chiefly determines their use. Therefore, it is compulsory to obtain good figures on the present stocks using the most appropriate methods and technologies for the improvement of future management of tree plantations and forests in the Khorezm region in particular, and in the Republic of Uzbekistan as a whole.

3 JUSTIFICATION OF MATERIALS AND METHODS

Both the continuing degradation of forests and a growing demand for tree products in Khorezm require improvement of the present forest and tree management. This is declared in the national forest legislation and mirrored in programs that aim at extending the planting of trees, e.g., windbreaks and shelterbelts, for improving environmental conditions (GoU, 2007; MAWR, 2002), or of hybrid poplar (*Populus* spp.*)* plantations for construction wood and pulp (GOU, 1994). However, updated reliable and comprehensive information is currently not available to decision-makers, including foresters and farmers, since the previously used extensive field surveys for forest and tree inventories are too time and resource demanding, even for the inventory of small and accessible forests such as *tugai* forests and other wooded land in *tugai* forests and deserts (Appendix 9.1). Whereas worldwide, tools using remote sensing (photogrammetry and satellite imagery) combined with Geographic Information Systems (GIS) and field sampling have been developed also for forest and tree inventories, such methodologies have not yet been introduced in Uzbekistan. Therefore, the elaboration of an easy-to-use, cheap, quick but comprehensive standard methodology for the functional assessment of existing tree plantations and forests would bear the potential to provide regularly updated information needed for improved forest management.

In section 3.1, the functional criteria used for the assessment of tree plantations and forests in the study region Khorezm are explained. In section 3.2, the selection of the assessment methodology, i.e., photogrammetry out of an array of approaches used in inventories of forests and plantations, is substantiated. The subsequent sections describe the procedures followed in the selected photogrammetry combined with GIS-based tools and field sampling in consecutive steps: delineation of the study area (section 3.3), specification of the applied photogrammetric equipment with materials and GIS-based tools (section 3.4), stereo photogrammetric techniques and GIS-based measurements to acquire key data (section 3.5), field verifications of the assessment data derived by photogrammetry (section 3.6), and field sampling to collect data not derived by photogrammetry (section 3.7). The final section presents supportive data from secondary sources (section 3.8).

3.1 Functional assessment criteria

The following sections present in-depth explanations of the assessment criteria applied for the windbreak function of multipurpose hedgerows, as well for other tree plantations (apple (*Malus* spp.), apricot (*Prunus armeniaca* L.), grape (*Vitis* L.), white mulberry (*Morus alba* L.) and *Populus* spp.) and forests, in particular the *tugai* forests and other wooded land in *tugai* forests and deserts.

3.1.1 Windbreak function of multipurpose hedgerows

The chief functions of tree windbreaks and shelterbelts, in case windbreaks are designed and structured over a larger area (David and Rhyner, 1999; Wojtkowski, 2004), are to reduce wind speed and hence wind-induced soil erosion. Concurrently, it is intended that they provide shelter and render microclimatic advantages to adjacent crops (Abel et al., 1997; Cleugh, 1998; Rocheleau et al., 1988). A wealth of studies worldwide evidences the effectiveness of windbreaks in reducing wind speed (e.g., Bolin et al., 1987; Cleugh, 2000). Strong winds in Uzbekistan can loose about 50-80% of their velocity when meeting optimally designed line plantings (Molchanova, 1986). The greatest wind speed reductions occur at the leeward side and in particular in the "quiet zone", which is immediately behind a windbreak (Figure 3.1). Consequently, within the quiet zone, the air and soil temperatures may drop by 1-2 and 3-4°C, respectively (Kayimov et al., 1990), while the relative air humidity may increase up to 13% (Botman, 1986). An average increase of 10% in winter wheat (*Triticum* L.) yields was reported from protected irrigated agricultural fields (Dolgilevitch 1983), while Moshaev (1988) concluded that up to 20% yield increases could be reached with an optimal windbreak structure and after the trees in windbreaks have reached their final height.

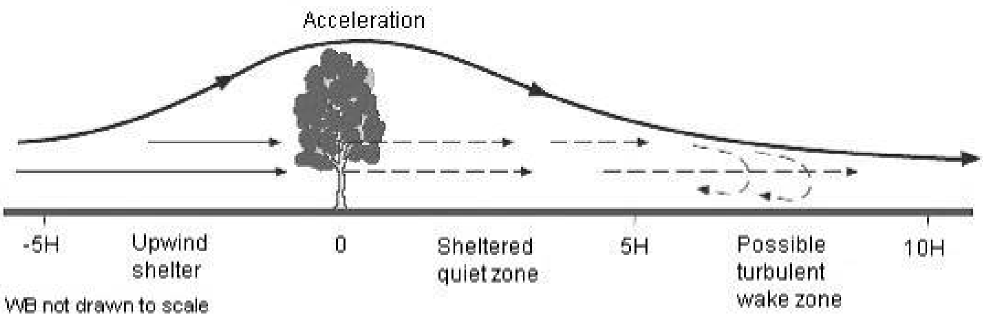

Figure 3.1: Effects of windbreak on airflow (H = height (m)) (Abel et al., 1997)

Several criteria are critical to assess the effectiveness of windbreaks in reducing wind speed with respect to species composition, orientation to the prevailing wind(s), crown closure (as a proxy for porosity), height, length (reaching of the windbreak to the edges of the related field), width (number of rows), vitality (disturbance by pests and diseases) and age classes (e.g., Abel et al., 1997; Bolin et al., 1987; Botman, 1986; Cleugh, 2000; Cornelis and Gabriels, 2005; David and Rhyner, 1999). The spatial extent of existing windbreaks in (irrigated) agricultural fields should also be taken into account (Kayimov, 1993).

The Forest Resources Assessment 2005 (FRA 2005) conducted by FAO (see Appendix 9.1) recommended delineating a minimal area of 0.5 ha for windbreaks in non-agricultural and urban lands. This size was not intended for agricultural lands and is too large for an objective hedgerow or windbreak assessment in the region of Khorezm. This is due mainly to the planting schemes and management practices, e.g., fast-growing tall, but narrow hybrid poplars (*Populus* spp.) or pollarded white mulberry (*Morus alba* L.) trees. Consequently, the minimal area of hedgerows/windbreaks associated with agricultural fields has in this study been reduced to 0.1 ha.

Since the 1980s, long-term studies and practical considerations regarding the establishment of protective vegetative barriers in Uzbekistan have resulted in recommendations to assign 0.5-1.0, 1.5-2.0 and 2.5-3.0% of the irrigated agricultural fields to windbreaks when these fields are affected by weak, moderate and strong winds, respectively (Kayimov, 1993). A minimal share of 1.5% of the fields is recommended to be allocated to tree windbreaks in Khorezm, since moderate winds of 3.5 m s^{-1} on the sandy and loamy soils prevail in the region (sections 2.2 and 2.3). However, it was unclear if the differences in the cropping systems were taken into account in making these blanket recommendations. For example, there are large areas of flooded rice (*Oryza* L.) fields in Khorezm (Figure 3.4), which require a much lower share of windbreaks than, e.g., cotton (*Gossypium* L.) (section 4.4.2). Also, fields adjacent to sand deserts and bare soils (normally at a distance of up to 1 km) would naturally require a much larger share of windbreaks than fields further away. To assess the situation, this study considered three systematic classes of the irrigated agricultural fields: “flooded”, “typical” and “pre-desert”, where a share of <1.5, 1.5-2.0 and >2.0%, respectively, of the fields should to be assigned to windbreaks.

The choice of the tree species can significantly affect the longevity of tree windbreaks (e.g., Bolin et al., 1987; Rocheleau et al., 1988). When long-living species are selected, the need to re-establish plantings periodically is reduced, but such species usually exhibit slow growth. Hence, a mix of slow- and fast-growing species is recommended, which ensures that even during the establishment phase, the desired breaking effect is obtained. A species mix also reduces the danger of infestation by diseases or insects, which have been seen to easily infest and destroy single-species stands. Finally, a mix may provide a wider variety of useful products (Wojtkowski, 2004). Therefore, species composition should be classified by multi- and single-species windbreaks.

An effective windbreak should be oriented within 1-30° of the perpendicular (90°) to the problem winds (Minselkhoz, 1972; Wilkinson and Elevitch, 2000). In such cases, the wind speed can be reduced by 80%. In case the wind blows at an angle of more than 45° or parallel to a windbreak, only 55-20% wind reduction can be expected (Abel et al., 1997; Bolin et al., 1987). Correspondingly, three windbreak orientation classes to the problem winds were used during the analyses of the irrigated fields and the transects: (i) ±1-30° of 90° indicating an "optimal efficiency of shelter", (ii) ±31-45° of 90° showing a "fair efficiency of shelter", and (iii) >±45° of 90° representing a "low efficiency of shelter". When choosing the correct orientation for a windbreak, knowledge about the local wind direction and wind speed is indispensable (section 3.8 and Appendix 9.2). In the case of one prevailing direction, a single windbreak orientation will suffice (Figure 3.2a). In case problem winds occur from different directions or vary among seasons, the option is between a single windbreak orientation providing limited shelter, and a grid of windbreaks or shelterbelts to maximize shelter from several wind directions, for which, however, more land needs to be sacrificed (Figure 3.2b). Therefore, the assessment of the windbreak orientation was conducted for any possible prevailing direction(s) of the problem winds throughout the year.

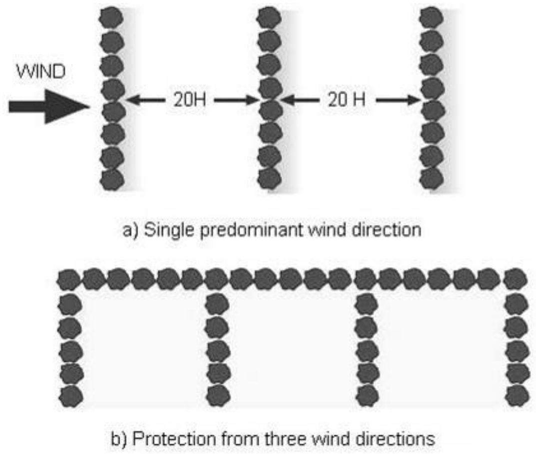

Figure 3.2: a) Choice of windbreak configuration for single wind direction; b) Choice of windbreak configuration for three wind directions (H = height (m)) (Abel et al., 1997)

While the ability of tree windbreaks to reduce wind speed depends also on their porosity or on open spaces, the size of the sheltered area is very similar for both porous and non-porous windbreaks (Figure 3.3a) (Abel et al., 1997; Cleugh, 1998). Thus, the assessment of porosity of windbreaks is considered less important than that of height. Two-dimensional windbreak porosity can be measured using ground-based photographs of a vertical windbreak profile (David and Rhyner, 1999). Alternatively or complementary, the simple field method of visual assessment is suggested to estimate the relative percentage of foliage and gaps while standing in front of and at right angles to a windbreak (Abel et al., 1997). On aerial photographs, the proportion of the area of a forest stand or a windbreak in a horizontal plane that is covered with tree crowns refers to crown closure and is generally stated in terms of decimal values (Figure 3.3b) (Akça, 2000). Since aerial photographs capture only the visible and measurable top level of crown covers of dominant trees (Figure 3.3b), the lower parts of crowns of dominant trees and the larger parts of crowns of intermediate and understory trees are not visible or measurable from aerial photographs (Akça, 2000). Therefore, the crown closure as measured from aerial photographs can only partially characterize the ability of windbreaks to reduce wind speed, as only the top layer of crowns can be seen. Therefore, three assessment classes of crown closure according to the converted porosity values postulated by Abel (1997) were selected: (i) <0.4 where it is assumed that more air flows through the trees, resulting in a smaller reduction in the wind speed downwind and hence in a "low efficiency of shelter", (ii) 0.4-0.6 will provide "fair efficiency", and (iii) >0.6 "optimal efficiency".

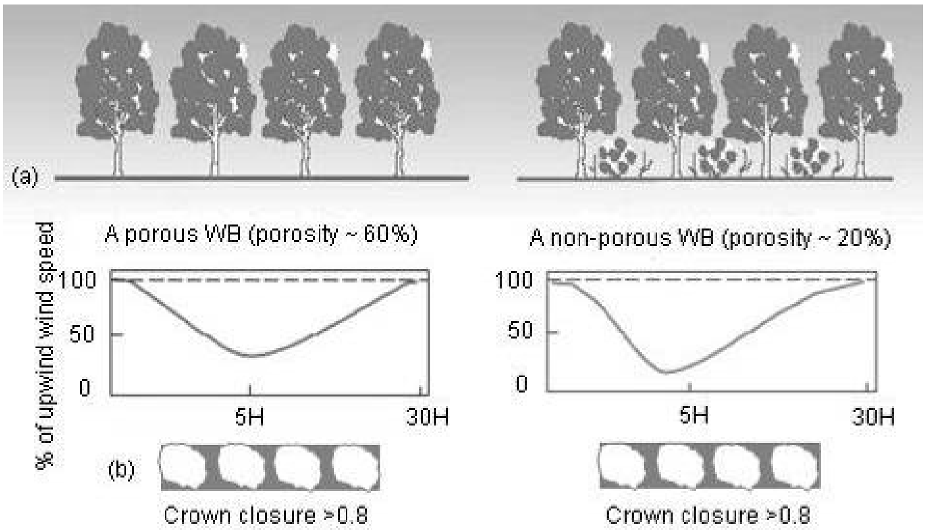

Figure 3.3: (a) Effects of a high- and low-porosity windbreak on wind speed (H = height (m)) (Abel et al., 1997); (b) Crown closure estimated from aerial photographs (Akça, 2000) as seen for the same values of porosity

The size of the sheltered zone at the leeward side of a windbreak chiefly depends on its height. Therefore, shelter effects are expressed in terms of windbreak heights (H) (Figure 3.1). To maximize the area of sheltered land per windbreak unit area, it is recommended to grow relatively narrow and tall tree windbreaks. According to local expert knowledge, the minimal mean stand height for an effective windbreak in Uzbekistan was set at 5 m (Botman, *personal communication*). Consequently, during the assessment, each windbreak was classed into three mean stand height classes according to the extent of shelter: (i) <5 m indicating "little extent", (ii) 5-10 m "fair extent", and (iii) >10 m "large extent".

Several studies concluded that an effective single- or double-row windbreak should be at least 12-20 H (e.g., Abel et al., 1997), while other authors recommended stretching out the windbreak at least along the entire length of the field or, to ensure maximum effect, the windbreak should be extended in both directions beyond the area to be protected, because the flow around the windbreak ends could erode the sheltered zone (Bolin et al., 1987). A compromise criterion whether a windbreak was "reaching" or "not reaching" the edges of the related field was taken to assess the extent of shelter.

Multiple rows of trees bear the potential to maintain a uniform porosity and tree health, and will provide options for proper harvesting (e.g., Abel et al., 1997; Wilkinson and Elevitch, 2000). However, a single row with tree species that have tall, narrow canopies and that are thinner at the top and denser at the lower levels can also be used as a windbreak (e.g., Wojtkowski, 2004). The advantage of single-row windbreaks is obviously the smaller amount of land taken out of production. Nevertheless, regarding the longevity of shelter and options for proper harvesting, at least double-row or better multiple-row windbreaks with several species deem to be most suitable. Therefore, three assessment classes (i) single-row, (ii) double-row and (iii) multiple-row windbreak were used as a proxy for “reduced”, “fair” and “extended” longevity, respectively, of shelter and/or harvesting.

Biotic and abiotic factors may impact tree health and vitality (MacDicken et al., 1991; Appendix 9.1) and therefore reduce the efficiency of the windbreak. Windbreak vitality can be recorded at the level of dominant trees in a windbreak using criteria for rating insect and disease infestations as suggested by Rohrmoser (in MacDicken et al., 1991). This rating was adapted in this study to three vitality classes: (i) “good” - dominance of healthy trees with no infestations (symptoms of disease or insect attack) or optimal efficiency of shelter, (ii) “fair” - dominance of lightly affected trees or fair efficiency of shelter, and (iii) “poor” - dominance of severely affected trees or poor efficiency of shelter.

A division according to age classes was required to estimate the share of young, premature and mature trees constituting the tree windbreaks. Younger trees cannot provide the full range of shelter, since their height and crown size is too small. In contrast, mature trees have a reduced ability to resist adverse site conditions (Wojtkowski, 2004); “young” and “mature” age classes were recommended for cuttings or replacements, respectively, necessary for maintaining existing windbreaks. Hence, it was assumed that premature-age windbreaks will provide an “optimal efficiency” of shelter. Consequently, three age classes (young, premature and mature) were introduced, which were adapted from the local classification and based on the principle species in the region (Table 3.1).

Table 3.1: Distribution of tree age classes by species in Uzbekistan (Botman, *unpublished*)

Principle species	Tree age class (yrs.)		
	Young	Premature	Mature*
Apple (*Malus* spp.)	≤20	21-50	≥51
Apricot (*Prunus armenica* L.)	≤20	21-50	≥51
Cherkez (*Salsola richteri* Karel)	≤3	4-6	≥7
Euphrates poplar (*Populus euphratica* Oliv.)	≤10	11-25	≥26
Grape (*Vitis* L.)	≤5	6-15	≥16
Hybrid poplars (*Populus* spp.)	≤10	11-25	≥26
Qizil qandim (*Calligonum caput-medusea* Schrenk)	≤4	5-9	≥10
Quyen suyak (*Ammodendron conollyi* Bunge)	≤5	6-15	≥16
Russian olive *(Elaeagnus angustifolia* L.)	≤10	11-25	≥26
Salt cedar (*Tamarix androssowii* Litv., Sched)	1	2-3	≥4
Saxaul or *oq saksovul* (*Haloxylon ammodendron* (C. A. Mey.) Bunge) and *qora saksovul* (*Haloxylon persicum* Bunge ex Boiss. & Buhse)	≤10	11-25	≥26
Turang'il (*Populus pruinosa* Schrenk)	≤10	11-25	≥26
White mulberry (*Morus alba* L.)	≤20	21-50	≥51
Willows (*Salix* spp.)	≤10	11-25	≥26

** Cutting or felling age*

To provide an effective windbreak assessment, the necessary supportive data were collected from secondary sources. These included:

1. The area of irrigated agricultural fields and other land in the Khorezm region by Conrad (2006) to assess a share (%) of this land assigned to hedgerows/ windbreaks (section 3.8, Figures 4.1-4.2 and Tables 4.3-4.4).
2. Wind speed and direction obtained from several data log meteorological stations located in Khorezm to assess the windbreak orientation to the prevailing winds in the region (section 3.8 and Appendix 9.2).

Table 3.2 summarizes the selected windbreak assessment criteria and their classes with threshold values.

Table 3.2: Worldwide acknowledged windbreak criteria and classes for assessing existing multipurpose hedgerows in Khorezm

Windbreak criterion		Source	Windbreak criterion class	
Name	Rank		Characteristic	Mark
Share of agricultural fields assigned to windbreaks	Primary	Adopted from Kayimov, 1993	<1.5% (flooded)	Good
			1.5-2.0% (typical)	Good
			>2.0% (pre-desert)	Good
			1.5-2.0% (overall)	Good
Species composition	Primary	Bolin et al., 1987; Rocheleau et al, 1988; Wojtkowski, 2004	Single-species (reduced range of functionality, e.g., longevity)	Poor
			Multi-species (extended range of functionality)	Good
Orientation to prevailing wind direction	Primary	Abel et al., 1997; Bolin et al., 1987; Minselkhoz, 1972	>±45° of 90° (low efficiency of shelter)	Poor
			Range of ±31-45° of 90° (fair efficiency of shelter)	Fair
			Range of ±1-30° of 90° (optimal efficiency of shelter)	Good
Mean stand height	Primary	Botman, *personal communication*	<5 m (little extent of shelter)	Poor
			5-10 m (fair extent of shelter)	Fair
			>10 m (large extent of shelter)	Good
Reaching edges of related field	Primary	Adopted from Bolin et al., 1987	Not reaching (reduced extent of shelter)	Poor
			Reaching (optimal extent of shelter)	Good
Crown closure	Secondary	Adopted from Abel et al., 1997; Akça, 2000; Cleugh, 1998	<0.4 (low efficiency of shelter)	Poor
			0.4-0.6 (fair efficiency of shelter)	Fair
			>0.6 (optimal efficiency of shelter)	Good
Number of rows	Secondary	Adopted from Abel et al., 1997; Wilkinson and Elevitch, 2000	Single-row (reduced longevity of shelter)	Poor
			Double-row (fair longevity of shelter)	Fair
			Multiple-row (extended longevity of shelter)	Good
Vitality	Secondary	MacDicken, 1991	Poor (dominance of severely affected trees or low efficiency)	Poor
			Fair (dominance of lightly affected trees or fair efficiency)	Fair
			Good (dominance of healthy trees or optimal efficiency)	Good
Age class	Secondary	Adopted from Botman, *unpublished*	*Populus* and *Salix* spp. and *E. angustifolia* ≤10 (young) and ≥26 years (mature) and *M. alba* ≤20 (young) and ≥51 years (mature) (reduced efficiency of shelter)	Poor
			Populus and *Salix spp.* and *E. angustifolia* 11-25 years (premature) and *M. alba* 21-50 years (premature) (optimal efficiency of shelter)	Good

3.1.2 Other tree plantations

Other tree plantations in Khorezm consist of (i) *Malus* spp., *P. armeniaca* and *Vitis* L. for local fruit production, (ii) pollarded *M. alba* for leaf production to supply the sericulture industry (silk production), and (iii) *Populus* spp. for construction wood. Information on spatial extent, vitality (disturbance by pests and diseases) and age classes of these plantations is necessary for sound design to develop fruit and wood production and sericulture in the region.

The criteria for selecting a representative assessment area for each of these tree plantations were: a minimum of 0.5 ha and a crown closure of more than 10% of trees able to reach a height of 5 m at maturity (Appendix 9.1). It was assumed that all species of these plantations were able to reach a height of 5 m at maturity unless affected by regular pollarding, which occurs exclusively with *M. alba*.

The vitality included (i) "good", (ii) "fair", and (iii) "poor" classes at the level of the dominant trees used for the assessment of hedgerows/windbreaks (section 3.1.1). Three age classes: (i) "young", (ii) "premature", and (iii) "mature" were elaborated from the local classification and based on the dominant tree species in the region (Table 3.1). During the analyses, several assumptions were made: (i) young trees of *Malus* spp., *P. armeniaca* and *Vitis* L. are non- or low-fruit-bearing trees, (ii) young *M. alba* and *Populus* spp. cannot provide high leaf and wood production, (iii) when corresponding to the recommended cutting or replacement age (Table 3.1) mature *Malus* spp., *P. armeniaca*, *Vitis* L. and *M. alba* species have a reduced fruit bearing and leaf production potential, respectively, (iv) premature *Populus* spp. cannot provide high wood yields, and (vi) only premature *M. alba*, *Malus* spp., *P. armeniaca* and *Vitis* L., and mature *Populus* spp. will give maximum yields.

3.1.3 *Tugai* forests and other wooded land

Information on area, species distribution and vitality (mainly disturbance by pests, diseases and fire; Appendix 9.1) is essential for the protection and regeneration of *tugai* forests and other wooded land in *tugai* forests and deserts. For obtaining this information, different delineations were implemented. A minimal area of 0.5 ha of trees able to reach a height of 5 m in *situ* and a canopy closure of more than 10% (Appendix 9.1) was applied for delineating each *tugai* forest area. A minimal area of 0.5 ha of trees able to reach a height of 5 m in *situ* and a canopy closure of 5-10% or combined cover of shrubs, bushes and trees of more than 10% was defined for delineating “other wooded land” areas in *tugai* forests and deserts. Considering the overall forest cover in the region, the definition of low forest cover by Lund (1999) can be applied for determining either low (<10%) or high (>10%) forest cover.

Changes in the forest area over time are of great interest to foresters. For analyzing the dynamics of the *tugai* over time, the delineated areas of “*tugai* forests” and “other wooded land” in *tugai* forests and deserts were examined also within the local forest management units, the so-called forest compartments. These units had previously been used by the Khorezm Forestry Enterprise for the forest inventories, although the last one dated from 1990 (section 3.8, Tables 6.1-6.2 and Appendix 9.4). For a meaningful comparison with the inventory undertaken in this study, the national classes used in the previous inventories needed to be reclassified to match the categories used in FRA 2005 (Appendix 9.1).

For the inventory, first the dominant species in all delineated areas were identified. It was assumed that vitality (e.g., disturbance pests and diseases) and longevity (e.g., slow- and fast-growing species) of multiple-species forest stands are higher than in their single-species counterparts. Next, the vitality was assessed according to the classes used for the assessment of hedgerows/windbreaks (section 3.1.1): (i) “good”, (ii) “fair”, and (iii) “poor”. Concurrently, three age classes were applied: (i) “young”, (ii) “premature”, and (iii) “mature” (Table 3.1). During the analyses, it was assumed that (i) the appearance of young trees would indicate a certain level of regeneration of *tugai* forests and other wooded land in *tugai* forests and deserts, while (ii) a dominance of mature trees would indicate on-going degeneration, and (iii) a premature class would indicate the optimal age of *tugai* forests and other wooded land.

3.2 Justification and choice of assessment methodology

Since the 19th century, various procedures have been applied worldwide for inventorying forest stocks owing to an increased attention and recognition of this forestry component (e.g., Akça, 2000; Preto, 1992). Each method has advantages and disadvantages (Table 3.3).

Table 3.3: Comparisons of different methods used in forest inventories

Method & Source	Advantage	Disadvantage
1. Extensive field surveys and complete measurements (e.g., Akça, 2000; KhFI, 1990)	Any forest parameter can be measured as compared to methods 3 and 4 Higher accuracy as compared to 3 and 4	More time consuming than methods 2, 3 and 4 More labor intensive than 2, 3 and 4 More expensive than 2, 3 and 4 Large areas cannot be estimated as compared to 2, 3 and 4 Inaccessible areas cannot be estimated as compared to 3 and 4 Some parameters such as forest area and crown closure cannot be accurately nor quickly assessed as compared to 3 and 4
2. Field sampling (Akça, 2000; Preto, 1992; Zagalikis et al., 2005)	Any forest parameter can be measured as compared to 3 and 4 Acceptable accuracy comparable to 1 Less time consuming than 1 Less labor intensive than 1 Much cheaper than 1	Inaccessible areas cannot be estimated as compared to 3 and 4 Some parameters such as forest area and crown closure cannot be accurately and quickly assessed as compared to 3 and 4 Sometimes it may be difficult to find a representative sample for the entire forest population or forest area
3. Photo-grammetry (Akça, 1983 and 2000; Duvenhorst, 1995; Kayitakire, 2002; Kenneweg, 1992; Preto, 1992; Zagalikis et al., 2005; Zagreev et al. 1992)	Quicker than 1 Less labor intensive than 1 Cheaper than 1and 4 Large and inaccessible areas can be estimated as compared to 1 and 2 Accurate assessment of forest area, crown closure etc. as compared to 1 and 2 Higher spatial resolution and hence more forest parameters such as species composition or height can be estimated and with a higher precision as compared to 4	More labor intensive than 4 Less regular frequency of repetitive coverage in contrast to 4 Smaller areas can be estimated compared to 4 Some parameters cannot be objectively and accurately assessed compared to 1 and 2, e.g., vitality, age, growing wood stock, etc.
4. Satellite imagery (Gidske, 1998; Kalensky, 1992; Kayitakire, et al., 2002; Ruecker and Conrad, 2003)	Quicker than 1 and 3 Less labor intensive than 1 and 3; More regular frequency of repetitive coverage as compared to 3, e.g., monthly by 4 vs. yearly by 3 Larger areas can be estimated as compared to 3 Accurate assessment of area as compared to 1 and 2	More expensive than 2 and 3 Lower spectral and spatial resolution and forest parameters such as species composition, height, etc. are measured with a lower precision as compared to 3 Need of more qualified personnel than for 1, 2 and 3

In Uzbekistan, small and accessible forests such as *tugai* forests and other wooded land in *tugai* forests and deserts have been assessed with extensive field surveys (KhFI, 1990). In contrast, tree plantations in large agricultural fields and the windbreak function of multipurpose hedgerows have not yet been assessed. In addition, since 1990, such surveys have no longer been conducted due to poorly funded institutions that are not able to cover labor and time requirements (Table 3.3). This in turn has left a gap that hinders sound decision making and proper management of forests and tree plantations. Hence, this is a classical situation for introducing remote sensing techniques such as photogrammetry and satellite imagery combined with GIS-based tools.

Modern methods in forest inventories intensively use the advantages of satellite imagery and simplified analyses of digital images and their classifications (Kunjappa, 2001; Reese et al., 2002; Remmel et al., 2005). On the other hand, high resolution satellite images such as SPOT images, as well as the software and equipment needed for the analyses, are expensive and out of reach of the budget of the forestry administration in Uzbekistan. This limits the national forest research divisions, in particular *Uzgiprourmonloyiha* (the Design and Survey Forestry Enterprise) of the Main Forestry Department (MFD), in the extraction of relevant data from these sources. Also, due to existing limits in spectral and spatial resolutions of the satellite images, the obtained forest parameters such as stand height, crown dimensions and species composition are questionable (Gidske, 1998). Alternatively, photogrammetry using aerial photographs is a reliable source for such data. These photographs are relatively cheap, are widely available, have a flexible scale, and bear the potential of providing data with an acceptable accuracy of both tree stands and single trees (e.g., Akça, 2000; Duvenhorst, 1995; Kaytakire et al., 2002; Kenneweg, 1992; Zagreev at al., 1992).

Although the use of aerial photographs is highly developed in forest mapping, the application of aerial photographs for forest inventory and mensuration is relatively new (Akça, 2000). Nevertheless, the use of up-to-date stereo photogrammetric equipment including analytical and digital plotters has several advantages over the stereo analogue plotters previously used. This includes, for example, the application of software, the readings by the Global Positioning System (GPS) to set up the stereo model faster and more precisely, the availability of digital results over graphical information, and the possibility to recall and handle stored data using GIS-based tools

(Akça, 2000; Duvenhorst, 1995). Moreover, stereo photogrammetric techniques and equipment are presently used in Uzbekistan, e.g., for the update and actualization of key topographic maps. Hence, aerial photographs are available from national governmental agencies such as *Ergeodezkadastr* (the Land and Geodesy Cadastre Center of Uzbekistan). However, they have not been suggested yet for use in the assessment of tree plantations and forests, although this may have a high potential. Following a comprehensive comparison of the different methodologies applied worldwide, and given the objectives of this study, stereo photogrammetric techniques combined with GIS-based tools were chosen for reaching the overarching objectives (section 1.2). In case the anticipated data cannot be extracted by photogrammetry, field sampling techniques may be needed to complement such methodology.

3.3 Delineation of study area

As a rule of thumb, ca. 5-10% of a total area is the threshold size for obtaining a minimal representation. Therefore, to adequately cover Khorezm in the present study, two transects were delineated in two directions: the north-south (NS) direction covered 32,000 ha between latitudes 42°00′ and 41°20′N, whilst the west-east (WE) transect covered 23,000 ha between longitudes 60°30′ and 61°00′E (Figure 3.4). These transects represent a gradient from the Amu Darya at one end of the transect, over the intensively used agricultural land and settlements, to the Karakum Desert and pre-desert depressions with salt lakes and drainages at the other end. In-depth inventories and analyses of tree plantations and forests were conducted in both transects.

The NS transect included the narrow strips of forests with *tugai* forests and other wooded land in *tugai* forests at the margins of the Amu Darya River, large areas of flooded rice fields, and the town Gurlan in the Gurlan administrative district. It also stretched for about 30 km into the Yangibazar and the Shavat districts, thus including agricultural fields with cotton, rice and winter wheat rotated with rice and fallow, as well as many tree plantations and a few settlements. Next, the transect crossed the Chukurkum Sands and bare soils in the north of the Kushkupir district. In the Kushkupir and Khiva districts, it included various agricultural fields, a few tree plantations, many small lakes and a few settlements. Finally, the transect bordered the margins of the

Karakum Desert and the Druzjba Lake Drainage Collector in the south of the Khiva district (Figure 3.4).

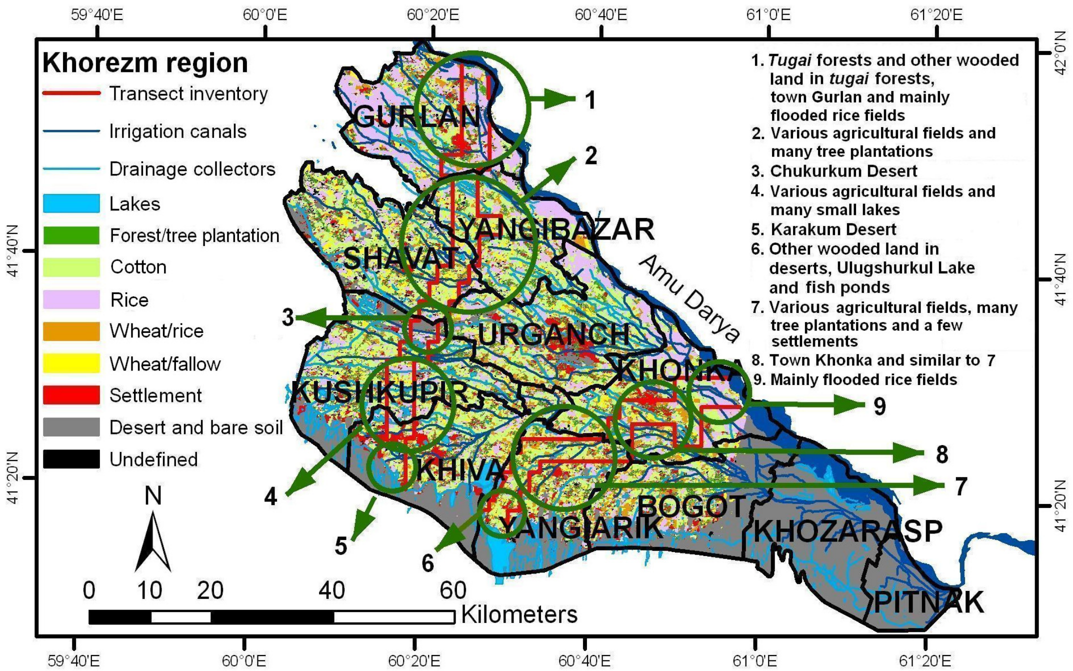

Figure 3.4: Land-use classification and inventory transects in the study region Khorezm (Conrad 2006; GIS-database, 2006; own data)

The WE transect started from "other wooded land" in deserts adjacent to the Ulugshurkul Lake and the large-scale fish ponds at the border of the Khiva-Yangiarik districts, and crossed the entire Yangiarik district with agricultural fields predominantly under cotton and wheat/cotton cultivation, as well many small tree plantations and a few settlements. Next, the transect covered the Khonka district, the town Khonka and various agricultural fields as well many tree plantations and a few settlements along the left bank of the Shavat Canal. The transect ended with flooded rice fields along the right bank of the Shavat towards the margins of the Amu Darya River (Figure 3.4). The total length of the NS and WE transects covered by aerial photographs was 70 and 50 km, respectively.

3.4 Specification of applied photogrammetry with GIS-based tools

Following the selection of the functional assessment criteria (section 3.1), justification and choice of the assessment methodology (section 3.2) and delineation of the study area (section 3.3), a preparation stage was initiated prior to the application of the stereo photogrammetric techniques and GIS-based measurements (section 3.5). This section briefly informs on the applied photogrammetric equipment, GIS-based tools and preparation of aerial photographs in a number of consecutive orientation procedures.

3.4.1 Photogrammetric equipment

A VISOPRET 10-DIG analytical stereo plotter (Figure 3.5) was used for the photogrammetry[1]. The plotter has a medium accuracy for digitizing coordinates and parallaxes on the aerial photographs (Hass, 1995; Poidevin and Tuinivanua, 1994). The optical-mechanical stereo viewer is the main functional component of the plotter. The stereo viewer consists of a binocular viewing system fitted with a zoom lens (zoom up to 3 x 15 times) with floating marks, two stages (up to 240 x 240 mm) for supporting the stereo pair of aerial photographs, control devices for moving the stages with the optical systems, and an illuminating system for aerial photographs (Carl Zeiss Jena Ltd, 1993). The plotter was attached to a P-III computer with a 17” monitor. The software package included V-CAP data management and orientation software and an AutoCAD program to capture, edit and store the obtained data. Finally, the system produced the files, which were later converted into an ESRI ArcGIS-supported format (section 3.4.3).

Figure 3.5: Carl Zeiss Jena VISOPRET 10-DIG analytical stereoplotter

3.4.2 Aerial photographs

The most recent aerial photographs available of the Khorezm region (Table 3.4) were provided by the national authorities (Ergeodezkadastr, 2001). The RC-30 aerial survey camera with a focal length of 153.7 mm and the Kodak Panatomic x 2412 film were

[1] Consultancy and equipment were provided by Altmann & Möllenkamp GbR, Holzerode, Goettingen, Germany

used to capture the photographs at a height of 3070 m. Since the recommended overlap and sidelap of the flight strips were 60 and 30%, respectively (Table 3.4 and Figure 3.6), 70 stereo pairs of aerial photographs (23 x 23 cm) at a scale of 1:20,000 were needed to cover the area of both the NS and WE transects.

Table 3.4: Aerial photograph characteristics (Ergeodezkadastr, 2001; Kodak, 2001; Leica, 1997)

Parameter	Specification*
Camera type	Leica RC-30, wide-angle
Lens focal length	153.7 mm
Film	Kodak Panatomic x 2412, panchromatic, black and-white
Flight management system	Leica ASCOT
GPS station	SR9400, GPS Sensor
Flight height	3070 m
Overlap and sidelap	60 and 30%
Airplane	AN-2
Date	November 25, 2001

**The mention of trade or manufacturer names is for information only and does not imply an endorsement, recommendation, or exclusion by the author*

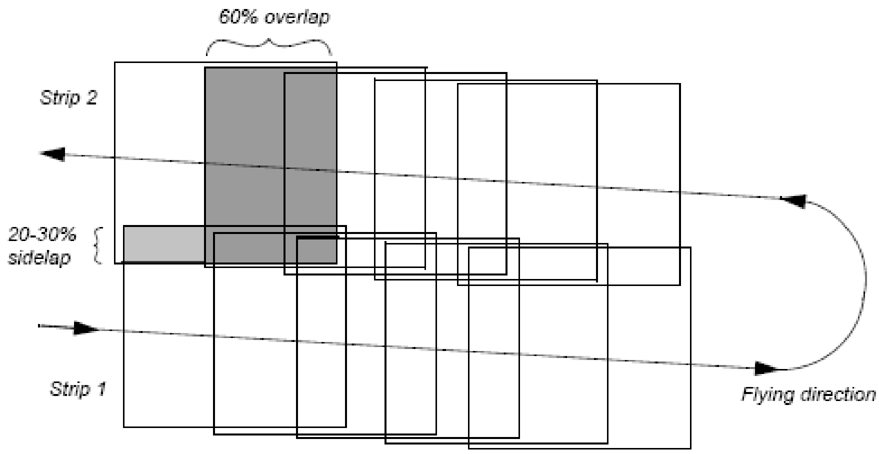

Figure 3.6: Flight strips with 60 overlap and 30% sidelap of aerial photographs (Ergeodezkadastr, 2001)

Prior to the application of the stereo photogrammetric techniques (section 3.5), three orientation procedures were required: (i) interior orientation with formation of the bundles of rays of the aerial photographs, (ii) relative orientation with the correct formation of the stereo module, and (iii) absolute orientation with the orientation of the stereo module. The orientation procedures were carried out relatively fast and accurately by the V-CAP software.

During the interior orientation, the interior perspective of any aerial photograph at the time of photography is determined (Jokinen and Haggren, 1995). The input data for the orientation consisted of a calibrated camera coordinate system derived from the camera calibration certificate supplied by the manufacturer (Leica, 1997). It contains the x and y coordinates (mm) of the principal points calibrated in two forms (auto-collimation and symmetry) and refers to the central cross (FC) on the focal plane frame (Figure 3.7). The x and y (mm) coordinates of the fiducial marks refer also to the central cross. The focal length and the calibrations for lens distortion are included. Once the aerial photographs were mounted on the instrument, the four fiducial marks on the left aerial photograph were measured manually. The same procedure was applied for the right aerial photograph. Measured by the V-CAP, the root means square value of interior orientation was estimated and assessed as acceptable.

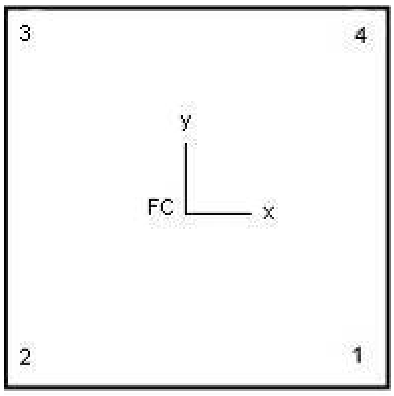

Figure 3.7: Fiducial marks as seen on of the focus plane frame of the camera (Leica, 1997)

The initial relationship between two overlapping aerial photographs is arbitrary, so that the stereo pair or stereo module (regarding the analytical techniques) may not be correctly formed (Photo Mapping, 2003). In the procedure of the relative orientation, the conjugate points need to be observed in both (left and right) aerial photographs to intersect the bundles of rays of the aerial photographs (Jokinen and Haggren, 1995). At least six points at the corners (four) and the center (two) of the photo of each stereo module by *von Gruber* point set (Figure 3.8) were chosen (Photo Mapping, 2003). The areas with bodies or featureless terrains were excluded as points of relative orientation. The position and number of the points were controlled by V-CAP.

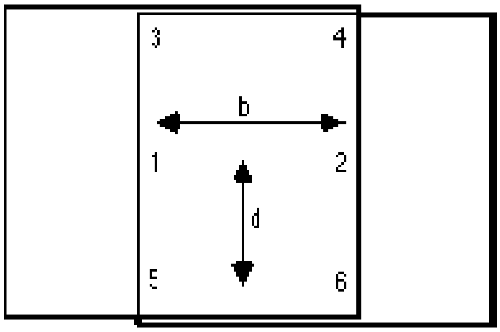

Figure 3.8: Points for measurements of relative orientation by *von Gruber* point set (Photo Mapping, 2003)

Once the relative orientation had determined the true shape of the stereo module, the absolute orientation established its scale, position and tilts with respect to the desired terrain as a final stage (Photo Mapping, 2003). The absolute orientation depended on ground control points, which were the most important inputs to orient the modules for the coordinate system and accuracy (Misra, 2005). At least five points (minimum three, with x, y and z coordinates, fourth and fifth are accessory, with the z coordinate only to check the quality of the absolute orientation) for each stereoscopic pair at the corner edges or within the overlapping area of aerial photographs (Figure 3.9) were needed by V-CAP. Easily identifiable locations such as intersections of roads and agricultural plots, bridges, etc., on the photographs were selected to establish each ground control point (Imagine Orthobase, 2001).

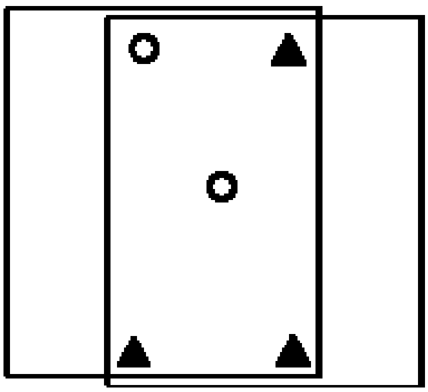

Figure 3.9: Points (triangles show required x, y and z coordinates; circles show required z coordinate only) for measurements of ground control points in absolute orientation (Photo Mapping, 2003)

A Garmin 11 GPS receiver was used for recording all field coordinates of the ground control points, which were referenced to the World Geodetic System with the latest revision dating from 1984 (WGS84) (Garmin, 1999). The coordinates of the ground control points were entered into V-CAP, where the x, y, z values for each ground control point were assigned a unique identification number. The reading error of 5-15 m was corrected and equally distributed among the ground control points of each stereo module by V-CAP within a root mean square of 1 m. Following the absolute orientation process, the stereo model was ready for data extraction and map production.

3.4.3 GIS-based tools

The ESRI ArcGIS 9.0 software package supports map generation and visualization after the application of photogrammetric techniques (section 3.5.2). Also, XTools Pro Table operators (ESRI ArcGIS extension tool) was applied (i) to calculate the area of the generated polygons (section 3.5.2), and (ii) to measure the distances between the points in the segments of hedgerows/windbreaks, which were used to measure the position of those points in field verifications of mean stand height of hedgerows/windbreaks (section 3.6). Finally, Strike.avx (ESRI ArcView 3.2 extension) was applied to measure the hedgerow/windbreak orientation angle of those hedgerow/windbreak poly-lines that were converted from the hedgerow/windbreak polygons, again with XTools Pro Table operators (section 3.5.2).

3.5 Stereo photogrammetric techniques and GIS-based measurements

The applied photogrammetric techniques included photo interpretation, which was trained in the field before the application (section 3.5.1) and measurements with an analytical stereo plotter (section 3.4.1), as well as measurements with GIS-based tools (section 3.4.3) according to the selected functional assessment criteria (sections 3.1.1-3.1.3).

3.5.1 Field training areas

The interpretation of the aerial photographs depends on the photographic indicators of the objects such as color, shape and texture, and also on the specific and contextual knowledge of the interpreter (Schmitt-Fürntratt, 1992). The quality and the scale of the aerial photographs must be adequate to distinguish those elements. A thorough knowledge of site conditions benefits photo interpretation (Spurr, 1948).

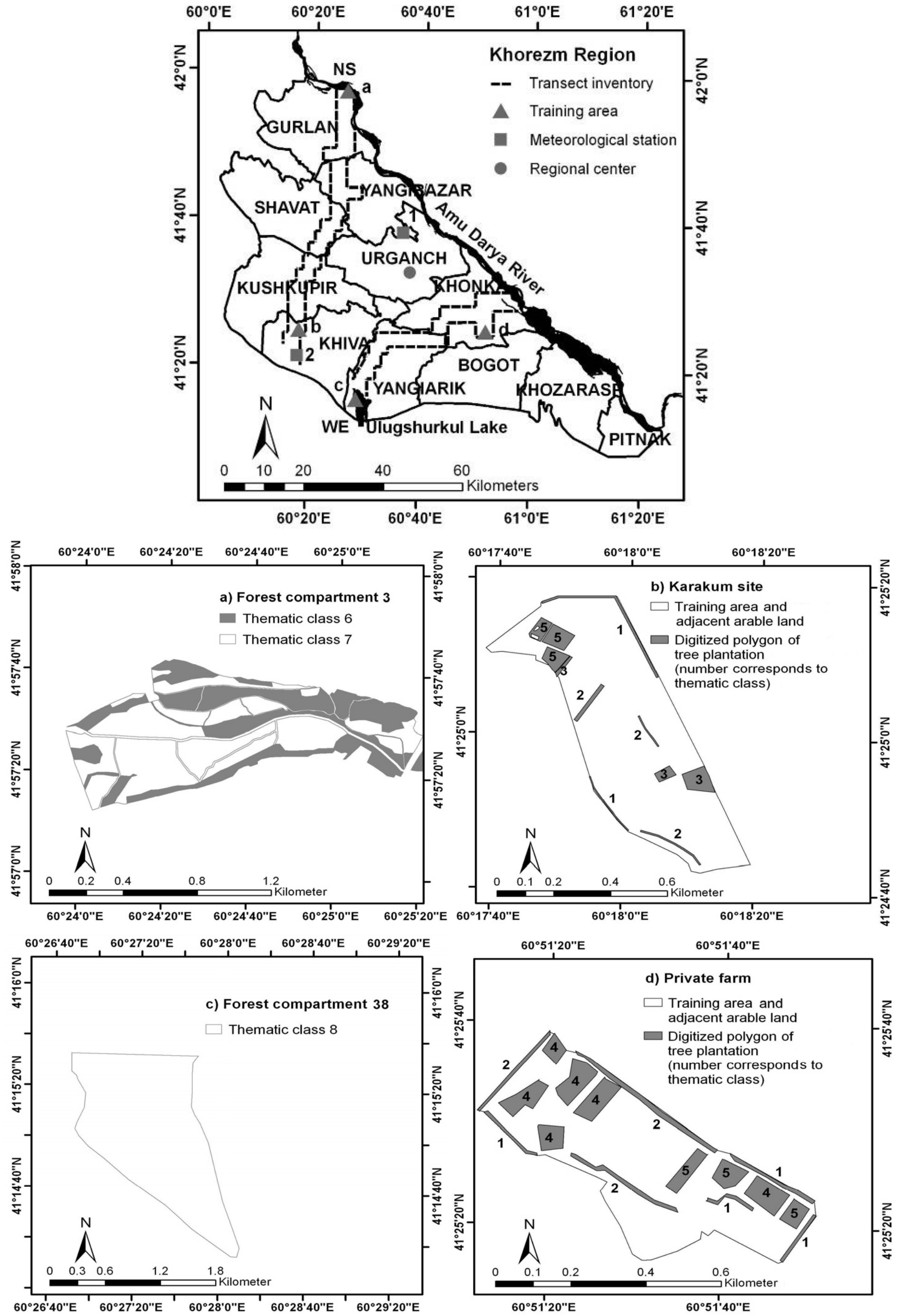

Figure 3.10: Established field training areas in the inventory transects, Khorezm: (a) forest compartment 3 in Gurlan; (b) Karakum site in Khiva; (c) forest compartment 38 in Yangiarik; (d) private farm in Khonka with thematic classes (Table 3.7) and meteorological stations of the ZEF/UNESCO Khorezm Project in *Uchkhozes* (research farms) of Urgench University: (1) in Khiva and (2) Yangibazar (section 3.8)

To develop the photo-interpretation skills, four field training areas in tree plantations and forests in Khorezm were established: (i) the forest compartment 3 (*tugai* forests and other wooded land in *tugai* forests) in Gurlan (41°57´N latitude, 60°24´E longitude, 89 m asl) of the Khorezm Forestry Enterprise of the MFD (Figure 3.10a), (ii) the Karakum site (hedgerows/windbreaks and other tree plantations) in Khiva (41°25´N latitude, 60°18´E longitude and 101 m asl) of the Khiva Research Station at the Center for Landscape Gardening and Forestry of the MFD (Figure 3.10b), (iii) the forest compartment 38 (other wooded land in deserts) in Yangiarik (41°15´N latitude, 60°27´E longitude, 98 m asl) of the Khorezm Forestry Enterprise of the MFD (Figure 3.10c), and (iv) a private farm (hedgerows/windbreaks and other tree plantations) in the Khonka district (41°25´N latitude, 60°51´E longitude and 102 m asl) (Figure 3.10d).

3.5.2 Photo interpretation, and photogrammetric and GIS-based measurements

According to the observed planting schemes (Table 3.5) and the patterns of natural vegetation (Table 3.6), the shape and texture of the visible (horizontal) crown projections, the length and texture of the crown shadow profiles and the site conditions were used as photographic indicators of tree plantations (hedgerows/windbreaks and other tree plantations) and forests (*tugai* forests and other wooded land in *tugai* forests and deserts) distinguished in the given scale on the aerial photographs and assigned to the corresponding thematic classes (Table 3.7). Also, a minimal area and a minimal crown closure (sections 3.1.1-3.1.3) were applied to delineate those thematic classes.

Ocular photo interpretation of each tree plantation or forest was completed with the analytical stereo plotter according to the defined thematic classes (Table 3.7). The minimal area (to the nearest 0.01 ha) was controlled by the AutoCAD software of the plotter (section 3.4.1). The minimal crown closure (to the closest 0.1-0.2 coefficient) was ocularly estimated with the plotter and roughly checked with the graphical crown density scale (Figure 3.11). The shape of each delineated horizontal crown projection (classes 1-2 and 6-8, Table 3.7) and the overall shape to simplify the joined horizontal crown projections and spaces between the projections corresponding to the clusters (class 3) or rows (classes 4-5) were plotted, and an output file with digitized polygons was produced with AutoCAD. The resulting polygons were transformed from AutoCAD to the commonly used ESRI ArcGIS software to compute the area of the polygons (to the nearest 0.01 ha) with XTools Pro Table operators (section 3.4.3) and to produce map layers (Figure 3.10a-d). Next, the delineated tree plantations and forests were ready for an assessment based on the selected criteria (see 3.1.1-3.1.3). To validate the results of the thematic classes during delineation of hedgerows/windbreaks, other tree plantations, *tugai* forests and other wooded land, field surveys were conducted (section 3.6).

Table 3.5: Observed planting schemes by existing tree plantation type, species and management practice in field training areas

Species	General detail	Cluster		Row		
		Number of clusters	Distance between clusters (m)	Number of rows	Distance between rows (m)	Distance between trees (m)
Hedgerows/windbreaks						
Populus and *Salix* spp., *E. angustifolia* and pollarded* *M. alba*, and *Salix* spp.	Row(s) in a line-shaped area	−	−	Single, double or triple rows	1.0-2.0	0.5-1.5
Other tree plantations						
Populus spp.	Rows in line-shaped clusters in a square- or rectangular-shaped area	Minimal 2	3.0-5.0	Triple to sextuple rows	1.0	0.5-1.0
Vitis L. and pollarded *M. alba*	Rows in a square- or rectangular-shaped area	−	−	Multiple rows	2.0-3.0	1.5-2.0
Malus spp., and *P. armeniaca*	Rows in a square- or rectangular-shaped area	−	−	Multiple rows	4.0-6.0	4.0-5.0

* *Defined as regularly pollarded species. This classification is due to an observed specifically low height of pollarded species, not exceeding 2.5 m; − = Not applied*

Table 3.6: Patterns of natural vegetation by defined classes in the field training areas

Forest class	Pattern*
Tugai forests (*P. euphratica* and *pruinosa*, etc.)	Forest stand with high to medium crown closure (≥0.1) in an irregularly shaped area (≥0.5 ha) in floodplains on the margins of the Amu Darya River
Other wooded land in *tugai* forests (*P. euphratica* and *pruinosa*, etc.)	Low crown closure (<0.1) of single trees in an irregularly shaped area (≥0.5 ha) in floodplains on the margins of the Amu Darya River
Other wooded land in deserts (*H. ammodendron* and *persicum*, etc.)	Low crown closure (<0.1) of single woody shrubs or shrubs in an irregularly shaped area (≥0.5 ha) in sandy desert areas adjacent to the Karakum Desert

** According to FRA 2005 (Appendix 9.1)*

To identify the orientation angle of the hedgerow/windbreak polygons for the full stand (Table 3.8), these were converted to poly-lines with the XTools Pro Table operator, and the angle of each poly-line (to the closest 1°) was computed with Strike.avx (section 3.4.3).

Ocular estimates of hedgerow/windbreak crown closure for the full stand (Table 3.8) were carried out (to 0.05 coefficient) with the plotter and the transparent dot grid device (Figure 3.12). The ratio of the number of dots falling on the visible open (empty) spaces in the horizontal crown projection to the total number of dots in that projection allowed measurement of the crown closure.

Prior to measurements of mean hedgerow/windbreak height at individual tree level (Table 3.8), two 2.5% representative segments (to the nearest 0.01 ha controlled by AutoCAD) were selected, based on the “best” and “worst” appearance of crown closure (to the nearest 0.05 coefficient ocularly estimated with the plotter and the dot grid device) in each hedgerow/windbreak polygon. Tree height was measured at three randomly selected representative points in each delineated segment. In the stereo-module of the plotter, the assumed tree top in the horizontal crown projection and the visible ground point right next to that tree top were used. These were digitally measured by the coordinates (x and y) and elevation (z), and the tree height (to the closest 0.5-1.0 m) was automatically computed with AutoCAD. It was assumed further that the weighted mean of three points or trees in each of the two segments would be more suitable to represent the mean stand height as compared to the more time-consuming measurements of many sample points or the subjective selection of an average representative segment for each hedgerow/windbreak.

Table 3.7: Thematic classes in Khorezm (each class confirmed in a few replications)

Thematic class	Photographic indicator			Site condition	Other criterion*	
		Crown shadow profile				
	Horizontal crown projection	At edge of projection	Between projections (tree plantations) or in projection (forests)		Minimal area (ha)	Minimal crown closure (coefficient)
Hedgerows/windbreaks						
1 (Pollarded *M. alba* and *Salix* spp.)	Line-shaped and clumped projection (individual crowns or rows cannot be indentified) corresponding to single, double or triple rows in a line-shaped area	Poorly visible profile due to short length	–	Along irrigation networks and bordering agricultural fields	≥0.1	–
2 (*Populus* and *Salix* spp. and *E. angustifolia*)	Similar to thematic class 1	Visible long and clumped profile (individual crowns/rows cannot be identified)	–	Similar to thematic class 1	Similar to thematic class 1	–
Other tree plantations						
3 (*Populus* spp.)	Line-shaped and clumped projection (individual crowns/ rows cannot be identified) corresponding to triple to sextuple rows in a line-shaped cluster. There are several clusters or projections in a square- or rectangular-shaped area and where spaces between the projections are not visible due to a crown shadow profile exceeding those spaces	Similar to thematic class 2	Long, but not visible profile due to the not visible spaces	Any space in agricultural fields	≥0.5	≥0.1

* *According to FRA 2005 (Appendix 9.1); – = Not applied*

Table 3.7: (cont.)

Thematic class	Photographic indicator				Other criterion*	
	Horizontal crown projection	Crown shadow profile		Site condition	Minimal area (ha)	Minimal crown closure (coefficient)
		At edge of projection	Between projections (tree plantations) or in projection (forests)			
Other tree plantations						
4 (*Vitis* L. and pollarded *M. alba*)	Line-shaped and clumped projection (individual crowns cannot be identified) corresponding to each row in square- or rectangular-shaped area and where spaces between the projections are visible due to a crown shadow profile not exceeding those spaces	Similar to thematic class 1	Similar to thematic class 1 "at edge of projection"	Similar to thematic class 3	Similar to thematic class 3	Similar to thematic class 3
5 (*Malus* spp. and *P. armeniaca*)	Similar to thematic class 4, but an un-clumped projection (individual crowns cannot be identified)	Similar to thematic class 2, but un-clumped profile (individual crowns can be indentified)	Similar to thematic class 2 "at edge of projection", but un-clumped profile (individual crowns can be identified)	Similar to thematic class 3	Similar to thematic class 3	Similar to thematic class 3

* *According to FRA 2005 (Appendix 9.1)*

Table 3.7: (cont.)

Thematic class	Photographic indicator				Other criterion*	
	Horizontal crown projection	Crown shadow profile		Site condition	Minimal area (ha)	Minimal crown closure (coefficient)
		At edge of projection	Between projections (tree plantations) or in projection (forests)			
***Tugai* forests and other wooded land in *tugai* forests and deserts**						
6 (*Tugai* forests (*P. euphratica* and *pruinosa*, etc.))	Various-shaped and clumped projection (individual crowns cannot be identified) corresponding to a forest stand in an irregularly shaped area	Similar to thematic class 2	Long, but not visible profile due to the clumped projection	Floodplains along margins of the Amu Darya River	Similar to thematic class 3	Similar to thematic class 3
7 (Other wooded land in *tugai* forests (*P. Euphratica* and *pruinosa,* etc.))	Single-tree projection corresponding to single trees in an irregularly shaped area	Similar to thematic class 1 (young trees) and 5 (mature trees)	Similar to thematic classes 1 "at edge of projection" (young trees) and 5 (mature trees)	Similar to thematic class 6	Similar to thematic class 3	<0.1
8 (Other wooded land in deserts (*H. ammodendron* and *persicum*, etc.))	Similar to thematic class 7	Similar to thematic class 1 (mature woody shrubs/ shrubs)	Similar to thematic class 1 "at edge of projection" (mature woody shrubs/shrubs)	Sandy desert areas adjacent to the Karakum Desert	Similar to thematic class 3	<0.1

* *According to FRA 2005 (Appendix 9.1)*

Table 3.8: Application of photogrammetric techniques and GIS-based tools for selected assessment criteria

Assessment criterion	Assessment technique	Assessment size
	Hedgerows/windbreaks	
Thematic class	Ocular photo interpretation	Stand
Area and number	GIS	Stand
Species composition	–	–
Orientation to prevailing wind direction	GIS	Stand
Crown closure	Ocular estimate with dot grid device	Stand
Mean stand height	Analytical photogrammetric measurement	Individual tree (weighted mean of three randomly selected representative points/trees in each of two 2.5% representative segments based on “best” and “worst” appearance of crown closure in each hedgerow/windbreak)
Reaching edges of related field	Ocular photo-interpretation	Stand
Number of rows	–	–
Vitality	–	–
Age class	–	–
	Other tree plantations	
Thematic class	Ocular photo-interpretation	Stand
Area and number	GIS	Stand
Species composition	–	–
Vitality	–	–
Age class	–	–
	***Tugai* forests and other wooded land in *tugai* forests and deserts**	
Thematic classes	Ocular photo-interpretation	Stand
Area and number	GIS	Stand
Species distribution	–	–
Vitality	–	–
Age class	–	–

– = Not applied (the criterion was assessed directly in the field (section 3.7))

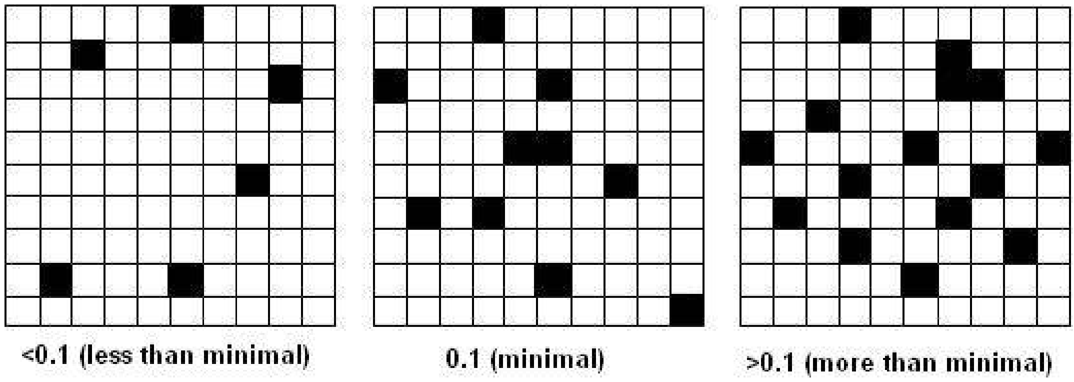

Figure 3.11: Graphical crown density scale (squares with black patterns represent different arrangements of crown closure coefficient)

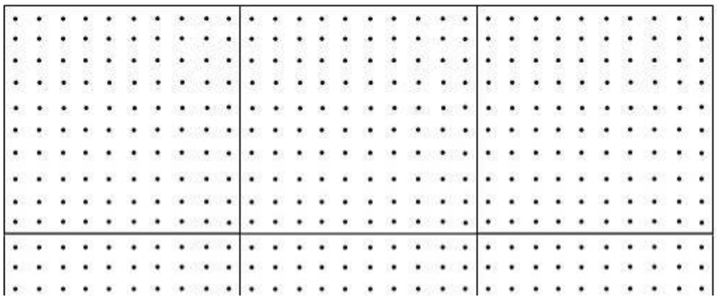

Figure 3.12: Transparent dot grid device

For the full stand, the edges of the hedgerow/windbreak crown projection and the edges of the related field were compared with respect to whether the hedgerow/windbreak reached the edges of the related field (Table 3.8).

Although the thematic classes were used to delineate hedgerows/windbreaks, other tree plantations and *tugai* forests and other wooded land in *tugai* forests and deserts, identification of species composition in most of the thematic classes, e.g., 1-2, 4, etc. was limited (Table 3.7). Therefore, species in the delineated thematic classes were identified during field surveys (section 3.7).

Since it was difficult to determine number of rows in the clumped crown projection of the hedgerows/windbreaks (Table 3.7), this criterion was assessed directly in the field (section 3.7).

The vitality of hedgerows/windbreaks, other tree plantations and *tugai* forests and other wooded land in *tugai* forests and deserts could not be assessed with photogrammetry due to the subjectivity of such assessment, as the lower parts (leaves, branches and stem) of dominant trees and the larger parts of intermediate and understory trees are not visible and recognizable on aerial photographs (Akça, 2000).

Given the above limits, tree and forest vitality was observed through field surveys (section 3.7).

Finally, the age classes of hedgerows/windbreaks, other tree plantations and *tugai* forests and other wooded land in *tugai* forests and deserts could not be objectively assessed on the aerial photographs. The unusual appearance of pollarded crowns of *M. alba* and *Salix* spp., which does not differentiate much in shape, size and shadow in young and/or pre- and mature age classes, substantially limits identification of age classes from aerial photographs. Also, there was a minimal difference of horizontal crown projections and crown shadow profiles between the young and premature age classes of fast-growing *Populus* spp. Taking these phenomena into consideration, age classes were assessed directly in the field (section 3.7).

3.6 Field verification of assessment data derived by photogrammetry

Data derived by photogrammetry were verified in the field (Table 3.9) using a reliable representation of the entire assessment size, similar to that of a 5-10% population fraction or sample in forest statistical techniques as suggested by Akça (2000) or Zagreev et al. (1991). Field positioning of the digitized polygons (to the closest 10-20 m) was controlled by a Garmin 11 GPS receiver (Garmin, 1999). In a large number of the delineated hedgerows/windbreaks, a 10% random sample was applied for visual identification of the hedgerow/windbreak thematic class (Table 3.9). The full stand was used for a small number of other tree plantations and *tugai* forests and other wooded land in *tugai* forests and deserts.

Field verification of the measured area by GIS-based tools (Table 3.9) was not needed, since the use of aerial photographs in forest mapping and GIS digitizing procedures has been proven to be accurate and efficient and has become a standard procedure (e.g., Kleinn et al. 2005; Zihlavnik et al., 2007). Also, measurement of the orientation angle of hedgerows/windbreaks (to the nearest 1°) with GIS-based tools is more objective, precise and quicker compared to visual assessments during field surveys. Therefore, field verification of the hedgerow/windbreak orientations was excluded.

Table 3.9: Field verification of data derived by photogrammetry

Assessment criterion	Verification method	Verification size*
Hedgerows/windbreaks		
Thematic class	Visual recognition	10% random sample
Area and number	±	±
Species composition	−	−
Orientation to prevailing wind direction	±	±
Crown closure	Visual assessment	10% random sample
Mean stand height	Measurements with an optical height meter and a telescoping measuring rod	10% random sample, individual tree level (weighted mean of points/trees measured in three photogrammetrically measured points/trees in each of two 2.5% representative segments based on “best” and “worst” appearance of crown closure in each hedgerow/windbreak)
Reaching edges of related field	Visual assessment	10% random sample
Number of rows	−	−
Vitality	−	−
Age class	−	−
Other tree plantations		
Thematic class	Visual recognition	Stand
Area and number	±	±
Species composition	−	−
Vitality	−	−
Age class	−	−
***Tugai* forests and other wooded land in *tugai* forests and deserts**		
Thematic class	Visual recognition	Stand
Area and number	±	±
Species distribution	−	−
Vitality	−	−
Age class	−	−

** Regarding the assessment size in Table 3.8; ± = Not applied (field verification for the given criterion was not required); − = Not applied (the criterion was assessed directly in the field (section 3.7))*

Crown closure of hedgerows/windbreaks (to the nearest 0.1-0.3 coefficient) was visually assessed in the field applying a 10% random sample (Table 3.9). This was achieved by standing in front of and at right angles to the hedgerow/windbreak and by estimating the coefficient or relative percentage of foliage and gaps as recommended for assessing windbreak porosity (Abel et al., 1997). However, only the top layer of crowns needs to be assessed in the field, since only this part of crowns is visible in the horizontal plane on the aerial photographs (section 3.1.1).

Field verification of mean hedgerow/windbreak height was completed applying a 10% random sample at individual tree level and by estimating the weighted mean of the points or trees measured in the three photogrammetrically measured representative points/trees in each of two representative 2.5% segments of each hedgerow/windbreak (Table 3.9). First, the distances between the points and segments in each hedgerow/windbreak polygon (to the nearest 1.0 m) were measured with XTools Pro Table operators (section 3.4.3). Next, the approximate location of those points in the hedgerows/windbreaks in the field (to the nearest 1.0 m) was measured with a measuring tape. A tree height below 5 m (to the closest 0.1 m) was measured with a telescoping aluminum rod of 5-m height placed right next to the tree. Trees above 5 m (to the closest 0.1-0.3 m) were measured with the Suunto PM-5/1520 optical height meter (Suunto, 2002a).

Whether the hedgerow/windbreak reached the edges of the related field or not was visually verified in the field applying a 10% random sample, comparing the edges of the hedgerow/windbreak to the edges of the related field (Table 3.9).

Assessment criteria such as species composition of hedgerows/windbreaks, other tree plantations, *tugai* forests and other wooded land in *tugai* forests and deserts, number of rows in hedgerows/windbreaks, etc. (Table 3.9) should be assessed directly in the field, applying appropriate methods and sample sizes (section 3.7).

3.7 Field sampling of assessment data not derived by photogrammetry

Due to the limitations regarding assessment of some criteria with photogrammetric techniques and GIS-based tools (section 3.5.2), those criteria were assessed by field surveys taking into account the sample size of each method (Table 3.10). The results of the field sampling were projected to the entire number of hedgerows/windbreaks, tree plantations and forests.

In a large number of the delineated hedgerows/windbreaks, a 10% random sample was applied for assessing hedgerow/windbreak criteria. For a small number of other tree plantations and *tugai* forests and other wooded land in *tugai* forests and deserts, the full stand was used.

Table 3.10: Field sampling of assessment data not derived by photogrammetry for the selected assessment criteria

Assessment criterion	Sample method	Sample size*
Hedgerows/windbreaks		
Thematic classes	–	–
Area and number	–	–
Species composition	Visual identification	10% random sample
Orientation to prevailing wind direction	–	–
Crown closure	–	–
Mean stand height	–	–
Reaching edges of related field	–	–
Number of rows	Visual identification	10% random sample
Vitality	Visual assessment	10% random sample, individual tree level (dominant trees in each of two 2.5% representative segments based on "best" and "worst" appearance of crown closure in each hedgerow/ windbreak)
Age class	Assessment with tree increment borer	10% random sample, individual tree level (weighted mean of randomly selected tree in each of two 2.5% representative segments based on "best" and "worst" appearance of crown closure in each hedgerow/ windbreak)
Other tree plantations		
Thematic classes	–	–
Area and number	–	–
Species composition	Visual identification	Stand
Vitality	Visual assessment	Individual tree level (dominant trees in randomly selected plots of 0.01-0.1 ha in 5% representative area in each tree plantation; number and size of plots depending on size of plantation area)
Age class	Assessment with tree increment borer	Individual tree level (weighted mean of randomly selected tree in randomly selected plots of 0.01-0.1 ha in 5% representative area in each tree plantation; number and size of plots depending on size of plantation area)

* *Verification sample depended on the assessment size in Table 3.8; − = Not applied (the criterion was assessed with photogrammetry and GIS-based tools (section 3.5))*

Table 3.10: (cont.)

Assessment criterion	Sample method	Sample size*
***Tugai* forests and other wooded land in *tugai* forests and deserts**		
Thematic classes	−	−
Area and number	−	−
Species distribution	Visual identification	Individual tree level; dominant species in randomly selected plots of 0.01-0.1 ha in 5% representative area in each forest, including forest compartment subdivision; number and size of plots depending on size of forest area)
Vitality	Visual assessment	Individual tree level (dominant trees in randomly selected plots of 0.01-0.1 ha in 5% representative area in each forest, including forest compartment subdivision; number and size of plots depending on size of forest area)
Age class	Assessment with tree increment borer	Individual tree level (weighted mean of three randomly selected trees in randomly selected plots of 0.01- 0.1 ha in 5% representative area in each forest, including forest compartment subdivision; number and size of plots depending on size of forest area)

* *Verification sample depended on the assessment size in Table 3.8; − = Not applied (the criterion was assessed with photogrammetry and GIS-based tools (section 3.5))*

Visual identification revealed the species composition and number of rows in a 10% random sample of hedgerows/windbreaks, as well as in the full stand of other tree plantations (Table 3.10). In *tugai* forests and other wooded land in *tugai* forests and deserts, species were identified at the individual tree level. Dominant species in randomly selected plots of 0.01-0.1 ha in representative areas (total area 5%) in each forest patch/forest compartment, were identified. Number and size of the plots depend on the size of the forest area.

Vitality (disturbance by pests, diseases and fire) was visually assessed at the individual tree level (Table 3.10). Dominant trees in two representative segments (2.5% of the hedgerow/windbreak area) based on the "best" and "worst" appearance of crown closure in each hedgerow/windbreak were used for the assessment. In other tree plantations and *tugai* forests and other wooded land in *tugai* forests and deserts, dominant trees were selected in randomly selected plots of 0.01-0.1 ha in the 5% representative area.

Age classes (to the nearest year) were measured with the Suunto 300-mm tree increment borer (Suunto, 2002b) in the same sampled areas as were used for assessing vitality (Table 3.10). In even-aged hedgerows/windbreaks and other tree plantations, one tree was randomly selected for the estimation of the weighted mean in the segments and plots. Three trees were selected in the plots in uneven-aged *tugai* forests and other wooded land in *tugai* forests and deserts.

3.8 Supportive data from secondary sources

Additional information on the area of irrigated agricultural fields and other land in the Khorezm region (Figures 4.1-4.2 and Tables 4.3-4.4) was needed to assess the hedgerows/windbreaks. This was taken from Conrad (2006) and secondary sources.

While assessing hedgerow/windbreak orientation (section 3.1.1), data on wind speed and direction (Appendix 9.2) were collected at two meteorological stations of the ZEF/UNESCO Khorezm project installed in Yangibazar (41°65′N latitude and 60°62′E longitude) and Khiva (41°36′N latitude and 60°31′E longitude) (Figure 3.10). Wind speed and direction were measured at 2-m height with a cup anemometer and anemoscope (Eijkelkamp, 2002). The meteorological station used solar energy for the data logger (Micromec Multisens 5.0, Technetics-Messwerterfassungssysteme, Freiburg, Germany), which recorded micro-meteorological data in 30-min intervals.

Finally, for assessing the former extent of the *tugai* forests, the hardcopy dataset of the Khorezm forest inventory conducted in 1990 (KhFI, 1990) (Appendix 9.4) provided by the Khorezm Forestry Enterprise was used in this study.

4 THE WINDBREAK FUNCTION OF MULTIPURPOSE HEDGEROWS

In the intensive agricultural land-use systems in the Khorezm region, numerous tree hedgerows along agricultural fields, irrigation networks and roads have been planted for rendering ecological services such as reducing wind erosion and improving microclimatic conditions, but also for production purposes. In particular, the leaf production of white mulberry (*Morus alba* L.) for the sericulture industry and the wicker production of willows (*Salix* spp.) for basketry used to be widespread in the region. Unfortunately, there is only little information available on the extent and windbreak function of the hedgerows. This is due mainly to the lack of a suitable assessment methodology. The first part of this chapter elaborates and crosschecks a routine methodology for the assessment of the windbreak function of existing hedgerows. Secondly, based on this methodology, the hedgerows are evaluated from a quantitative and qualitative point of view while considering worldwide recognized standards of windbreak technologies and design. The spatial extent of the hedgerows and general windbreak design were evaluated using remote sensing, in particular, photogrammetry combined with Geographic Information System (GIS)-based tools. The data that could not be derived directly through remote sensing such as tree vitality and age classes were collected through field sampling.

4.1 Introduction

Wind erosion persists as a problem for agriculture in many regions of the world, including Uzbekistan, Central Asia (Gintzburger et al., 2003; Kayimov, 1993; UNCCD, 2005). In Uzbekistan, about 2.4 million ha (56%) of irrigated land suffer from wind erosion, of which ca. 1 million ha are affected to average and strong degrees (UNCCD, 1999). The strong winds affect agriculture also by decreasing air and soil humidity, scattering weed seeds, sandblasting fields, and filling the numerous irrigation canals and drainage collectors with soil particles (Abel et al., 1997; Kayimov, 1993). One option to protect agricultural land from wind and air-blown soil particles and to improve microclimatic conditions for crops is to plant windbreaks or shelterbelts. These have been proven to be effective worldwide (Cleugh, 2000; Rocheleau et al., 1988; Wojtkowski, 2004) including in Uzbekistan (e.g., Kayimov, 1986). This is exemplified also in the region of Khorezm, a 610,000 ha administrative district located in northwestern Uzbekistan, which is located in the lower reaches of the Amu Darya River and in the ecological disaster zone in the Aral Sea Basin (FAO, 2003a).

Historical and anecdotal evidence indicate that people in Central Asia planted hedgerows around their households to buffer the extreme temperatures that occur during the cold winters and hot summers (Veselovsky, 1877), which are typical for the continental climate of the Central Asian semi-desert zone. The first reported attempts in Uzbekistan to establish tree windbreaks for combating soil erosion date from 1919 (MFD, 2008; Molchanova, 1980). By 1937 about 1000 ha of windbreaks had been established on agricultural land. In the period 1960-1970, large-scale windbreak planting schemes were implemented along agricultural fields throughout the country to protect croplands and reduce desertification, particularly at the edges of the irrigated fields (Khanazarov and Kayimov, 1993; Molchanova, 1980). In 1966-1992, about 40,000 ha windbreak and shelterbelt systems were established on agricultural lands (MAWR, 2005). Also, the shelterbelt systems were planted on about 1.4 million ha of steppe to protect pasture land (Musabekov, *unpublished* 2003). After the break up of the Soviet Union in 1991, these practices ceased, due to the reorganization of the collective (*kolkhozes*) and state farms (*sovkhozes*) into *shirkats* (private shareholder farms) and *dekhqan* farms (small private holdings). Many hedgerows established as windbreaks and shelterbelts have been cut down or have perished due to a lack of care (MAWR, 2005; MFD, 2008).

Various studies have reported on the effects of the windbreak and shelterbelt systems in Uzbekistan, especially underlying the importance of their structure. An average increase of 10% in cotton yield was reported by Dolgilevitch (1983), while Moshaev (1988) claimed that a 20% increase was feasible with an optimal structure of windbreaks and once the trees had reached their maximum height. In the 1980s, it became a declared policy in Uzbekistan that 0.5-1.0, 1.5-2.0 and 2.5-3.0% of the agricultural land in those regions affected by weak, moderate and strong winds, respectively, must be protected by tree windbreaks or shelterbelts (Kayimov, 1993). Research to date has focused chiefly on the impact of windbreak structures such as height and porosity on crop yields, but has ignored other key aspects of windbreaks regarding, e.g., multi-species composition, length (reaching of the windbreak to the edges of the related field), etc. In addition, research on windbreaks has not been conducted in Khorezm or neighboring regions such as Bukhara and Karakalpakstan, and the spatial extent and efficiency of windbreaks is still unexplored.

In the study region Khorezm, with moderate winds of 1-6 m s^{-1} (Glavgidromet, 2003), a minimal share of 1.5% of windbreak systems should be allocated to the agricultural land given the declaration in the 1980s. Also, recent studies and available wind data reveal that, due to the vegetation (crop) pattern that covers the soil virtually throughout the year (Conrad, 2006) as well as the prevailing moderate wind speeds, the potential for wind-induced erosion seems to be low. This was also confirmed in the report of UNCCD (1999), where it has been stated that although ca. 90% of irrigated lands in Khorezm are subjected to wind erosion, only 5% of this area is affected to average and strong degrees. On the other hand, the region has an extreme continental climate (Glazirin et al., 1999), where even slight changes in the microclimate such as increasing air humidity or decreasing air and soil temperatures through tree windbreaks would improve growing conditions for the adjacent crops. This in turn could increase crop yields as compared to open fields (Botman, 1986).

During the Soviet epoch, Uzbekistan became specialized in the production of cotton, and thus became an agrarian country. After independence, the agricultural sector remained the key for the economic development of the country, since it contributed 33% to Uzbekistan's GDP, and about 30% of the able workforce is employed in this sector, which in 2005 generated nearly 40% of the national foreign exchange earnings (Worldbank, 2005), mainly from cotton. The national action program to combat desertification (UNCCD, 1999) and the programs on windbreak and shelterbelt plantings for improving environmental conditions (GoU, 2007; MAWR, 2002) promoted the inclusion of tree windbreaks and shelterbelts as a means to combat land degradation and to re-integrate trees in the agricultural landscape. However, the research findings on previous windbreak plantings in Uzbekistan are in fact insufficient to justify such large-scale investments in mitigating measures with doubtful remediation effects.

The presently available windbreak data are not only unreliable but also too incomplete for an objective decision making with regard to the establishment and maintenance of windbreaks. Although prior to independence forest inventories were regularly conducted, they failed to assess the functioning of the tree windbreaks as a whole, but instead mainly just provided forest stocks (Botman, *unpublished*). Moreover, not a single inventory has been conducted since independence. The lack of a suitable methodology still is a chief obstacle to obtaining accurate and reliable information on the established windbreaks and in particular on the surrounding agricultural fields. The monitoring of a few forested areas is not adequate for assessing windbreaks that span large areas of the irrigated landscape.

Although Uzbekistan is fairly well endowed with qualified manpower, the previous extensive field surveys were not only based on an outdated and conservative approach, they were also both resource demanding and time consuming compared to the worldwide used remote sensing techniques photogrammetry and satellite imagery (e.g., Akça, 2000; Reese et al., 2002). Nonetheless, field sampling is needed to complement such approaches in case the anticipated data cannot be extracted by photogrammetry (Akça, 2000) or in case the spectral and spatial resolutions of satellite imagery limit a comprehensive analysis (Gidske, 1998). The use of more updated techniques such as satellite imagery for the assessment of windbreaks is feasible also in Uzbekistan, but is currently hampered due to the high prices for the satellite images, software, and equipment, as well as by the lack of a skilled and motivated work force. The development of a method for assessing the spatial extent and windbreak function of existing hedgerows that is reliable, quick, comprehensive, not labor intensive and reasonable in price is, therefore, greatly needed, not only in Uzbekistan but in entire Central Asia.

Meantime, compared to other techniques (Table 3.3), photogrammetry combined with GIS-based tools can be a reliable tool to assess tree plantings, including hedgerows/windbreaks. Remarkably, Uzbekistan conducts aerial surveys at regular intervals applying aerial photographs and stereo photogrammetric equipment to update and actualize key topographic maps (Ergeodezkadastr, 2001), which could be used for conducting forest inventories and assessing windbreaks. However, until today the national forest research communities have not seized this opportunity, which is partly because they are not aware of the efficiency of this approach or of whether the findings are sufficiently accurate. Therefore, the objectives of this part of the study were (i) to verify if the stereo photogrammetric techniques combined with GIS-based tools and field sampling represent a technologically suitable and financially feasible approach for forest research divisions of Uzbekistan, (ii) to assess the spatial extent and windbreak function of existing hedgerows, and (iii) to map hedgerows/windbreaks and create an adequate database for decision makers such as foresters and/or farmers for the pilot region Khorezm.

4.2 Materials and methods

Several criteria with classes developed according to recommendations were used for assessing the windbreak function of existing hedgerows (section 3.3.1). The criteria included species composition, orientation to the prevailing winds, crown closure (as a proxy for porosity), height, length (reaching of the windbreak to the edges of the related field), width (number of rows), vitality (disturbance by pests and diseases) and age classes. The spatial extent of the hedgerows/windbreaks was assessed in three systematic classes of the irrigated agricultural fields (section 3.1.1) and two delineated transects (section 3.3).

Out of an array of approaches used worldwide for inventories of forests and tree plantations, the photogrammetric technique was selected as the most suitable (section 3.2). Two arbitrarily selected transects which covered ca. 10% (ca. 55,000 ha) of the Khorezm area were delineated as the study area (Figure 3.4). Crossing the region in NS (320 km^2) and WE (230 km^2) directions, these transects included all typical landscapes in the study region. Hedgerows/windbreaks with a minimal area of 0.1 ha in the irrigated agricultural fields were delineated (section 3.1.1). The applied photogrammetric equipment consisted of a VISOPRET 10-DIG analytical stereo plotter and AutoCAD software (section 3.4.1). Prior to the analyses, 70 stereo pairs of aerial photographs were prepared in the consecutive procedures interior, relative and absolute orientations (section 3.4.2). Also, ESRI ArcGIS 9.0 and ESRI ArcView 3.2 software and their extensions were used as GIS-based tools (section 3.4.3). In case the anticipated data could not be extracted by photogrammetry, field sampling was conducted (section 3.7).

The photogrammetric techniques included ocular photo interpretation with the plotter to identify hedgerows/windbreaks and their species according to two thematic classes (i) pollarded *M. alba* and *Salix* spp., and (ii) hybrid poplar (*Populus* spp.), *Salix* spp. and Russian olive (*Elaeagnus angustifolia* L.) species (Table 3.7). These were developed in two training areas established in Khorezm (Figure 3.10b and d), while the final species identification and distribution was done directly in the field (section 3.7). The minimal area of hedgerows/windbreaks (to the nearest 0.01 ha) was controlled by the AutoCAD software of the plotter (section 3.5.2).

Once each hedgerow/windbreak was identified, its polygon was plotted and an output file (digitized polygons) produced (Figure 3.10). The application of corresponding GIS-based tools allowed computing the area (to the nearest 0.01 ha) of the digitized polygons and their orientation angles (to the closest 1°) (section 3.5.2).

Ocular estimates of hedgerow/windbreak crown closure (to the nearest 0.05 coefficient) were carried out with the plotter and transparent dot-grid device (Figure 3.12). The stereoscopic photogrammetric measurements with the plotter provided the mean hedgerow/windbreak height (to the closest 0.5-1.0 m), which was determined for three randomly selected representative points or trees in each of two 2.5% segments based on “best” and “worst” appearance of crown closure in each hedgerow/windbreak (section 3.5.2). This procedure was more favorable compared to a subjective selection of an “average” representative segment for each hedgerow/windbreak or time- and resource-consuming measurements of many sample points. Finally, the borders of each hedgerow/windbreak horizontal crown projection and those of the related field were compared in the aerials photographs with respect to whether the hedgerow/windbreak reached the edges of the field.

Photogrammetrically derived hedgerow/windbreak assessment data were next verified on the randomly selected 10% sample of hedgerows/windbreaks (section 3.6). Field positioning of the digitized polygons (to the closest 10-20 m) was checked by a Garmin 11 GPS receiver (Garmin, 1999). Hedgerow/windbreak thematic classes were visually determined in the field. Criteria of crown closure and reaching of the hedgerow/windbreak to the edges of the related were also visually verified in the field (section 3.6). Mean hedgerow/windbreak height was verified for the same representative points or trees and the segments measured by photogrammetry using a 5-m telescopic aluminum rod and a Suunto PM-5/1520 optical height meter for trees below and above 5 m, respectively (section 3.6). The field verification of the area and orientation angles of hedgerows/windbreaks as calculated with GIS-based tools was not required because of the accuracy of the information extracted by photogrammetry (section 3.6).

Windbreak assessment data that could not be derived by photogrammetry, such as species composition, number of rows, etc., were collected directly in the field according to the selected classes (Table 3.1) and applying the appropriate method and sample size (section 3.7). The results of the sampling were projected to the entire number of hedgerows/windbreaks. Additional data to delineate the agricultural fields by class and analyze local wind data for assessing the orientation of hedgerows/windbreaks to the prevailing winds were collected from secondary sources (section 3.8.2).

4.3 Results

First, the verification of the photogrammetrically derived hedgerow/windbreak data is presented. This is followed by the assessment of the present situation in the Khorezm region with regard to hedgerow/windbreak area, species, orientation, etc.

4.3.1 Verification of assessment data derived by photogrammetry

The recognition of hedgerows/windbreaks with respect to their thematic class by photo interpretation was quite satisfactory as evidenced by an overall accuracy of 85% (Table 4.1). The pollarded "*M. alba* and *Salix* spp." class can be distinguished from the class of "*Populus* and *Salix* spp. and *E. angustifolia*". The accuracy of both classes with respect to whether the hedgerow/windbreak reached to the edges of the related field was acceptable.

Table 4.1: Verification of photo interpretation of hedgerow/windbreak assessment criteria and classes

Criterion/class	Accuracy (%)
Thematic class*	
1 (Pollarded *M. alba* and *Salix* spp.)	80
2 (*Populus* and *Salix* spp. and *E. angustifolia*)	90
Overall	85
Reaching edges of related field	
Reaching	95
Not reaching	85
Overall	90

** Table 3.7*

The photogrammetric measurements of mean hedgerow/windbreak height appeared to be overestimated compared to the field-verified height with an overall difference of 11% between the two values (Table 4.2). In contrast, crown closure was underestimated by 11%. The height and crown closure class marks "fair" showed peak differences compared to the field survey values of up to +15 and -14%, respectively. However, the differences in absolute values (m) between photogrammetry and field surveys were in all cases relatively small.

Table 4.2: Verification of stereo photogrammetric measurements for hedgerow/windbreak assessment criteria and classes

Criterion and class*	100% photo-interpreted mean (n=2323)	10% sample estimates (n=232)							
		n	Photo interpreted		Field verified		Difference	
			mean ±standard deviation	CV** (%)	mean ±standard deviation	CV (%)	absolute	%
Mean stand height (m)								
<5 (poor)	3.6	163	3.7±0.9	25	3.3±0.8	25	+0.4	+11
5-10 (fair)	8.3	36	8.1±1.1	14	6.9±1.1	16	+1.2	+15
>10 (good)	11.7	33	11.7±0.7	6	11.0±0.5	5	+0.7	+6
Overall	7.9	232	7.8±0.9	15	7.1±0.8	15	+0.8	+11
Crown closure (coefficient)								
<0.4 (poor)	0.28	67	0.29±0.09	13	0.32±0.09	13	-0.03	-4
0.4-0.6 (fair)	0.61	144	0.58±0.09	20	0.64±0.06	17	-0.06	-14
>0.6 (good)	0.81	21	0.80±0.05	24	0.83±0.04	24	-0.03	-15
Overall	0.57	232	0.56±0.08	19	0.60±0.06	18	-0.04	-11

**Selected classes and marks (Table 3.2); Coefficient of variation*

Measurement of assessment criteria such as hedgerow/windbreak area and orientation to the prevailing winds with GIS is more objective, easy and faster than direct field measurements. Therefore, field verification of those criteria was not conducted. In contrast, species composition, number of rows, vitality and age classes cannot be reasonably estimated with photogrammetry and, therefore, field sampling is needed (section 3.7).

4.3.2 Windbreak assessment

In the two transects (Figure 4.1), more than 2,300 hedgerows/windbreaks and a share of 1.2% agricultural fields assigned to hedgerows/windbreaks were found (Table 4.3). The share of those fields in both the NS and WE transect was similar. However, a low share was observed in the "pre-desert" and "flooded" classes, while the "typical" class had a high share in both transects (Table 4.4).

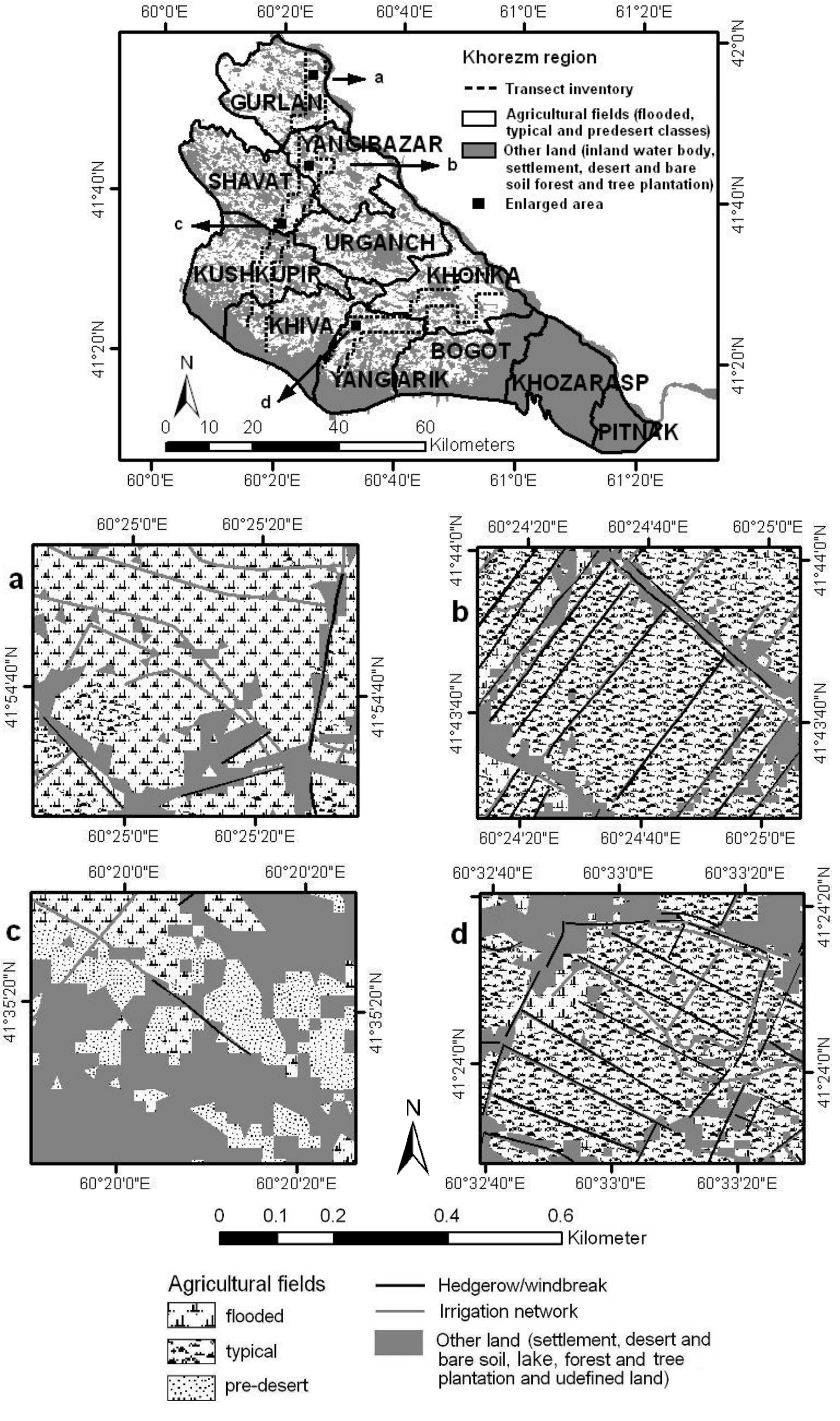

Figure 4.1: Photo-interpreted hedgerows/windbreaks in classes of agricultural fields (section 3.1.1) in inventory transects, Khorezm (Conrad, 2006; GIS-database, 2006; own data)

Table 4.3: Overall distribution of hedgerows/windbreaks in NS and WE transects, Khorezm

Transect statistics	NS transect	WE transect	Total
Transect area (ha)	32,020	23,020	55,040
Agricultural fields (ha)	22,292	17,059	39,351
Number of hedgerows/windbreaks (n)	1374	949	2323
Hedgerows/windbreaks (ha)	270	181	451
Share of agricultural fields assigned to hedgerows/windbreaks (%)	1.2*	1.1*	1.2*

** Corresponded to "poor" in "overall" class (Table 3.2)*

Table 4.4: Distribution of hedgerows/windbreaks by agricultural field class in NS and WE transects, Khorezm

Class of agricultural fields*	Agricultural fields (ha)	Number of hedgerows/ windbreaks (n)	Hedgerows/ windbreaks (ha)	Share of agricultural fields assigned to hedgerows/windbreaks (%)	Mark**
NS transect					
Flooded	1790	17	10	0.6	Good
Typical	16,251	1259	238	1.5	Good
Pre-desert	4251	98	22	0.5	Poor
NS total	22,292	1374	270	1.2	Poor
WE transect					
Flooded	3026	17	3	0.1	Good
Typical	14,033	932	178	1.3	Poor
Pre-desert	–	–	–	–	–
WE total	17,059	949	181	1.1	Poor
Total	39,351	2323	451	1.2	Poor

** Section 3.1.1; ** Table 3.2*

Multi-species or mixed hedgerows/windbreaks were not identified in the inventoried transects. Single-species hedgerows/windbreaks with pollarded *M. alba* and *Salix* spp., *Populus* and *Salix* spp. and *E. angustifolia* dominated (Figure 4.2). Other tree species such as Euphrates poplar (*Populus euphratica* Oliv.), Siberian elm (*Ulmus pumila* L.), swamp ash (*Fraxinus pennsylvanica* Marshall), honey locust (*Gleditsia triacanthos* L.), osage orange (*Maclura pomifera* (Raf.) C. K. Schneid.), black locust (*Robinia pseudoacacia* L.) and maple (*Acer ginnala* var. *semenovii* (Regel & Herder) Pax) were also included, but their shares were rather small. Spatial distribution of tree species was similar in both NS and WE transects.

The analysis according to other criteria of the windbreak function of existing hedgerows is presented in Table 4.5. Although some assessment criteria were "good" or "fair" for the largest share of the hedgerows/windbreaks, e.g., orientation to the prevailing wind direction, crown closure, etc., the most important criterion of mean stand height was "poor".

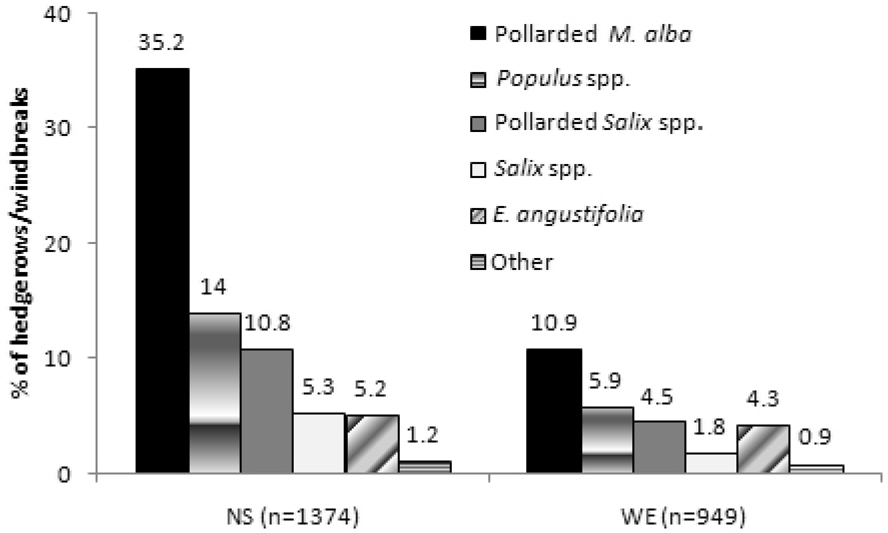

Figure 4.2: Species composition of hedgerows/windbreaks in NS and WE transects, Khorezm

Table 4.5: Windbreak function of hedgerows/windbreaks in NS and WE transects, Khorezm

Windbreak criterion*		Distribution of hedgerows/ windbreaks by class mark*				Note
name	rank	Poor	fair	good	total	
Orientation to prevailing wind direction	Primary	488 21%	256 11%	1579 68%	2323 100%	SE+NW and N+S were most suitable orientations in the south to intercept the prevailing NE and W winds; any orientation was suitable in the north (Appendix 9.2)
Mean stand height	Primary	1696 73%	418 18%	209 9%	2323 100%	Mean stand height by class mark: 3.6 m (poor), 8.3 m (fair) and 11.7 m (good); mean stand height by tree species: 2.7 and 3.0 m (pollarded *M. alba* and *Salix* spp.), 5.7 m (*Salix* spp.), 7.8 m (*Populus* spp.) and 4.6 m (*E. angustifolia*)
Reaching edges of related field	Primary	1092 47%	–	1231 53%	2323 100%	–
Crown closure	Secondary	209 9%	1440 62%	674 29%	2323 100%	–
Number of rows	Secondary	720 31%	1487 64%	116 5%	2323 100%	–

** Table 3.2*

Table 4.5: (cont.)

Windbreak criterion*		Distribution of hedgerows/ windbreaks by class mark*				Note
name	rank	poor	fair	good	total	
Vitality	Secondary	209 9%	511 22%	1603 69%	2323 100%	Tree species by vitality class mark (poor, fair and good): *M. alba* (5, 10 and 85%), *Salix* spp. (12, 18 and 70%), *Populus* spp. (16, 58 and 26%) and *E. angustifolia* (20, 19 and 61%)
Age class	Secondary	1812 78%	–	511 22%	2323 100%	Tree species by age class mark (poor (young/mature) and good (premature)): *M. alba* (80 (80/–) and 20%), *Salix* spp. (79 (72/7) and 21%), *Populus* spp. (85 (85/–) and 15%) and *E. angustifolia* (53 (32/21) and 47%)

** Table 3.2*

4.4 Discussion

Both the results of the verification of the photogrammetrically derived data and the hedgerow/windbreak assessment data are discussed in the following.

4.4.1 Verification of assessment data derived by photogrammetry

The significance of aerial photographs in estimating different characteristics in forest and tree plantations is unquestioned. An archive of documents substantiates the applicability of aerial photographs in forest management and forest mapping in, e.g., Central Europe (Loetsch and Haller, 1964), North America (Spurr, 1948), Russia (Anuchin, 1982), and several tropical countries (Nyyssönen, 1964). With analytical and digital stereoscopic instruments, corrections in the orientation process and GIS digitizing procedures can be made to accurately transfer the extent of forest and tree units from aerial photographs into base maps. Today, this is a standard and routine procedure (e.g., Akça, 2000; Duvenhorst, 1995; Zihlavnik et al., 2007).

The practical use of aerial photographs in forest inventory and mensuration however is, in contrast to their use in forest mapping, still controversially discussed. Recent findings underline that the use of modern digital evaluation methods such as aerial photographs can provide tree and stand characteristics with nearly the same accuracy as obtained with field surveys, but in less time and at lower costs (Akça, 2000). Ongoing studies have demonstrated the limitations of aerial photographs especially in closed forests of the temperate zone and tropical forests for accurately estimating species composition, and for identifying understory plants in a multi-layered vegetation, and crown size and tree height. This is because these forests are usually characterized by numerous species, dense canopy and with under- and upper-story vegetation close together (e.g., Akça, 2000; Skorobogatko, 2004). However, it is unlikely that the debated disadvantages that can lead to inaccurate identification of species composition and measurements of dendrometric data will also occur in the forests of the arid zones, which are characterized by low tree cover and a limited number of tree species, or in the tree plantations sparsely distributed in the agricultural landscapes, or in hedgerows/windbreaks. However, in the absence of studies conducted in arid regions and thus of compelling evidence, this remains a hypothesis that needs to be verified. Consequently, this study focuses on the verification of the different variables usually employed in photogrammetry.

The period of the year in which the aerial photographs were taken certainly affected the assessment of the hedgerows/windbreaks. Leaf shedding of the deciduous trees in the study region usually starts early October and continues into November (Khamzina et al., 2006a). Nevertheless, on the aerial photographs made available, the horizontal crown projections and crown shadow profiles could be determined based on the outlines of the branches of the trees in the line-shaped and clumped planting schemes of hedgerows/windbreaks (Tables 3.5 and 3.7). This allowed a quite objective identification of hedgerows/windbreaks and assessment of primary windbreak criteria such as orientation to the prevailing wind direction, mean stand height and whether the hedgerow/windbreak reached the edges of the related field (section 3.3.1).

The hedgerow and windbreak classes can be accurately distinguished (Table 4.1). However, identification of species composition in the classes was impossible. This is due to only slight or no differences in the photographic indicators such as the clumped and leafless horizontal crown projections and crown shadow profiles of pollarded *M. alba* vs. pollarded *Salix* spp., and *Populus* spp. vs. *Salix* spp. or *E. angustifolia* (Table 3.7). To assess species composition of the hedgerows/windbreaks, field surveys with simple visual identifications were done. Nevertheless, the bird's-eye view of the aerial photographs would give a potentially better representation of hedgerow/windbreak species over large areas if suitable photographs (e.g., color-infrared, scale ≤1:15,000 and taken in the growing season) were available. The aerial photographs allowed an acceptable accuracy in the assessment of to what extent the hedgerow/windbreak reached the edges of the related field (Table 4.1). The field verifications of the hedgerow/windbreak assessment criteria such as area and orientation angle to the prevailing winds were not required, since measurements of those criteria with GIS-based tools are more accurate and unbiased compared to field survey-based methods as reported in forest area estimations by Kleinn et al. (2005) or Zihlavnik et al. (2007).

The differences between the photogrammetric measurements and field survey data of mean hedgerow/windbreak height and crown closure showed over- and underestimated extremes of about 15% (Table 4.2). Although this may seem an argument against the accuracy of stereo photogrammetry when using 1:20,000-scale photographs, in absolute values the results of the photogrammetry vs. field measurements did not differ that much. A +11% difference, e.g., in the <5 m mean stand height class, indicates an overestimation of about 0.4 m for the weighted mean in a sample of 163 hedgerows/windbreaks (Table 4.2) and for three randomly selected representative points or trees in each of two 2.5% representative segments of each hedgerow/windbreak (Table 3.8). This is of minor importance, since this particular parameter on its own is hardly relevant as a windbreak criterion given that a height of 5 m is the minimum recommended threshold value conventionally applied in Khorezm for classification as a functional windbreak (Botman, *personal communication*). Furthermore, when considering the absolute values, a 15% difference in the class 5-10 m indicates a 1.2 m overestimation, which would hardly alter the overall assessment (Table 4.2). Moreover, Akça (1983), Kätsch (1991) and Zagreev et al. (1992) reported a standard error of the photogrammetrically measured mean stand height of ±0.7 to ±0.8 m, which is close to the values determined in this study.

On the other hand, a systematic overestimation of tree height by photogrammetry was expected, since the aerial photographs were taken in November 2001, whereas the field survey was conducted in July-August 2003 when the aerial photographs finally became available. Between the date of the photographs and that of the field survey at least 1.5 years of tree growth had taken place. During this period, some trees in the lower two classes (<5 m and 5-10 m) had outgrown the class depicted in the respective photograph. Particularly at the onset of their growth cycle, species such as *Salix* spp., *E. angustifolia* and *Populus* spp. experience rapid growth (Khamzina, et al., 2006b), and these trees will have shifted from the lower to the higher classes. This is then manifested in a larger number of trees in the lower quartiles of the middle class (5-10 m), whereas concurrently the larger trees in the same middle class will have changed to the higher class, thus resulting in a reduced number of trees in the upper quartiles of the middle class. These combined phenomena explain the differences in the lower overall averages during the field survey (Table 4.2). In addition, previous research has shown that tree species in the study region reach a certain height and that growth ceases after this maximum has been reached (Khamzina et al., 2006b). Consequently, tree height in the highest class had not altered over time. Assuming that no trees will be harvested or die and that no additional trees will be planted, the trees will remain in the upper height class with a certain steady height (Table 4.2). Hence, taking all aspects into consideration, the method developed is able to distinguish different height classes with an acceptable accuracy applying the available aerial photographs.

Meanwhile, the differences between the ocularly estimated and field-monitored values of crown closure were certainly caused by seasonal differences, as the aerial photographs were taken in November, while the field verification was conducted in July-August during a period where the trees have a fully developed crown (Khamzina et. al, 2006a). This provides a good explanation for the differences in crown closure, which was underestimated using the aerial photographs (Table 4.2). Also, the overshadowing of the understory trees had an effect on the ocular estimation of crown closure similar to the frequent underestimations as recorded previously (Akça, 2000). Consequently, although crown closure is of less importance for assessing the functionality of windbreaks and only partly represents porosity (section 3.3.1), the developed methodology for the study region turned out to be sufficiently accurate despite the obvious discrepancies caused by the long period between the aerial photographs and the field survey.

The applied planting schemes of hedgerow/windbreaks with a high density of trees resulted in overshadowing and clumping of the horizontal crown projections where rows of trees could not be indentified in the given scale of 1:20,000. Therefore, the number of rows of hedgerows/windbreaks was assessed directly in the field. Also, it was not possible to extract and count individual tree crowns or measure their size. Those variables are needed if aerial estimations of growing wood stock are of interest (Akça, 2000; Pope, 1962).

Horizontal crown projections on aerial photographs mainly indicate the upper part of crowns of dominant trees, while the lower parts (leaves, branches and stem) of the trees as well as most of the crowns of intermediate and understory trees cannot be identified (Akça, 2000). In vitality assessments, all parts of a tree, i.e., leaves, branches and stem, should be estimated to obtain comprehensive data. Given the limits mentioned above, the vitality of hedgerows/windbreaks thus needs to be estimated through field surveys.

The appearance of pollarded crowns of *M. alba* and *Salix* spp., which does not differentiate much in shape, size and shadow in young and/or pre- and mature age classes, substantially limits identification of age classes of hedgerows/windbreaks from aerial photographs. Also, there was only a minimal difference in horizontal crown projections and crown shadow profiles between young and premature age classes of the fast-growing *Populus* spp. Taking these phenomena into consideration, age classes of hedgerows/windbreaks were assessed directly in the field.

It goes without saying that the optimal time for taking aerial photographs with the purpose of identifying vegetation is during the summer when the foliage is normally fully shaped (Spurr, 1948). In contrast, aerial photographs taken in late autumn are more suitable for other purposes, e.g., for the actualization of topographic maps, since deciduous trees will be less dense and more can be learned about the ground beneath the canopy. On the other hand, taking aerial photographs twice during the vegetation season entails very high costs, which are certainly beyond the scope of the low budget inventory of the current forestry management organizations in Uzbekistan, and which are already hindering the application of innovative and initiative research methods. Hence, one compromise is to exploit the available aerial photographs, as they can serve several functions concurrently. Forest managers should therefore seize this opportunity for stepping up the support for hedgerow/windbreak assessment and use the available aerial photographs even when these have been taken in late November. The aim to obtain at least the anticipated long-term benefits in a situation where no assessment or inventory had been conducted for several decades dictated the choice to conduct field surveys during the summer months, which is the optimal period for verification of vegetation. This would allow conclusions about whether the information derived by photogrammetry is compatible with reality, and if the method thus could also be applied with suboptimal material.

Given that the outcomes were neither too conservative nor too progressive but more in line with the expectations, the generated knowledge and the hard evidence obtained during the validation prevailed over assumptions. Even though the available (November) aerial photographs initially seemed a handicap, the outcomes and the conducted in-depth validation evidenced the applicability and accuracy of the photo interpretations and photogrammetric measurements and thus the potential for assessing the spatial extent and effectiveness of the hedgerows/windbreaks as presented in the following.

4.4.2 Windbreak assessment

Khorezm is a region where century-long anthropogenic activities (Tolstov, 1948), and in particular those associated with irrigated agriculture, have strongly influenced the natural soil formation and hence the present landscape. Notably, the irrigated soils in Khorezm are relatively young formations, since the irrigation practices have altered, e.g., mineralization of organic matter, humus accumulation, clay formation, and microbiological activity (Tursunov, 1981). The results of the past and previously employed land-use practices are mirrored also in the spatial extent of the hedgerows/windbreaks in the region.

For the flooded agricultural fields with rice (*Oryza* L.), in particular at the margins of the Amu Darya River in the far north and east of Khorezm, the findings show a low share of hedgerows/windbreaks. For this, there are several explanations. This class of agricultural fields means limited opportunities to plant trees inside rice fields as compared to typical agricultural fields. Obviously, only a very limited number of tree species withstand permanent waterlogged conditions, as this leads to a lack of oxygen in the root zone and hence to the disappearance of vegetation other than rice (Bouman and Tuong 2001; Valkov 1986). On the other hand, the need for windbreaks to combat wind erosion, e.g., inside or around flooded rice fields, is restricted, since these areas are more in need of protection against irrigation-water-induced erosion than against wind erosion. Consequently, instead of the recommended minimal share of 1.5% of agricultural fields assigned to hedgerows/windbreaks, a share of <1.5% would provide the necessary wind shelter in flooded fields, irrespective of wind and soil conditions.

Different crops are affected differently by windbreaks (Kort, 1988). Although findings showed that most hedgerows/windbreaks bordered typical agricultural fields with cotton (*Gossypium* L.) and winter wheat (*Triticum* L.) rotated with rice and fallow, crops such as winter wheat, barley (*Hordeum* L.) and rye (*Secale* L.) responded better to windbreak protection than spring wheat or corn (*Zea mays* L.) (Kort, 1988). Cotton and wheat yields are also reduced by strong winds (Botman, 1986; Dosakhmedov 1986). Given the dominating state order in Uzbekistan, which prescribes that the majority of the fields have to be planted with the strategic cotton and wheat crops, windbreaks may play a vital role to protect those crops.

The pre-desert agricultural fields are characterized by harsher microclimatic conditions, e.g., sandblasting, compared to other agricultural fields. This, combined with the notoriously low water availability (Conrad, 2006) explains the low share of hedgerows/windbreaks despite a potentially great necessity. Hence, as a key output of the conducted priority analyses, "pre-desert" agricultural fields should have the highest priority, "typical" a medium priority and "flooded" less or no priority with regard to the introduction of windbreaks. The structure and layout of the windbreaks for the protection of those fields must fulfill specific requirements with respect to height, length, orientation and species composition of the windbreaks, since these criteria are of decisive importance for a well-functioning windbreak (e.g., Abel et al., 1997; Cleugh, 2000). Also, the share of windbreaks in pre-desert agricultural fields needs to be extended, as the present share does not meet the standards defined by the national experts (Kayimov, 1986). A substantial effort is therefore needed to introduce more dense and effective windbreaks. To comply with the national recommendation of a minimal share of 1.5% agricultural fields assigned to windbreaks, the selection should take into account the priority classes of <1.5, 1.5-2.0 and >2.0% for flooded, typical and pre-desert agricultural fields, respectively. Especially, targeting an additional 1.6% allotment of agricultural fields to hedgerows/windbreaks in the pre-desert agricultural fields should in particular be recommended to achieve the minimal area (>2.0%) under windbreaks for protection against the moderate winds prevailing in the region.

The dominance of deciduous single-species hedgerows/windbreaks with *M. alba* and *Salix* spp*.,* which are regularly pollarded, and fast-growing *Populus* spp. may substantially reduce the windbreak function in terms of extent and longevity (e.g., Abel et al., 1997). Hence, it is recommended to replace these species with new species, preferably a mix of fast- and slow-growing species planted in at least two rows (e.g., Bolin et al., 1987; Rocheleau, 1988); the species should, of course, be suitable for the region. Recently conducted variety studies underscored that, e.g., *U. pumila, P. euphratica* and *E. angustifolia* could fulfill these criteria (Khamzina et al. 2006a). Coniferous trees are hardly expected to grow in the region given the harsh climatic conditions (Khamzina et al., 2006a). The pre-desert areas (crop fields adjacent to sand deserts or bare soils at a distance of up to 1 km) potentially require more protection against sandblasting of plants and fields, which occurs frequently even during events with lower wind speeds in spring and summer. This is a further argument for multi-species windbreaks in these areas.

An archive of research results underscores that the orientation of the windbreaks to the prevailing problem winds, which in this case are defined as those that could erode soils, must be at right angle to or at angle of not less than 30-45° to the wind (e.g., Minselkhoz, 1972; Wilkinson and Elevitch, 2000). Given that those threshold winds (although they rarely occurred, Appendix 9.2) that lead to soil erosion are in the range of 3-6 m s^{-1} (Molchanova, 1986), and that winds of more than 6 m s^{-1} may lead to strong erosion of the sandy and loamy soils predominating in the Khorezm region, most of the present hedgerows/windbreaks are oriented at a right or near right angle to these winds. From this perspective, the existing hedgerows/windbreaks provide optimal to fair shelter.

However, the analyses of the local wind data (Appendix 9.2) show that there is a high frequency of problem winds in the leafless season, i.e., when the deciduous trees have shed all their leaves, thus leaving very porous tree lines, which are not very effective in breaking winds. Consequently, these lines of trees will not effectively function as windbreaks during the period when the cropland is most exposed to the problem winds. To combat the resulting wind erosion, rows of conifer tree species could be incorporated into existing windbreaks or even replace existing deciduous trees. However, although this seems a plausible approach, the harsh agro-environmental conditions such as high saline groundwater and highly saline soils led to low survival rates of, e.g., eastern red cedar (*Juniperus virginiana* L.) and Chinese cedar (*Biota orientalis* (L.) Franco), which reduced the feasibility of introducing conifers into the region (Fimkin, 1963; Khamzina, et al., 2006a). Although species may exist that could potentially cope with these extremes, they would first need to be screened and tested. Alternatively, a solution could be zero tillage practices (perhaps combined with tree windbreaks) that include the presence of a permanent soil cover or mulching, since a ground cover is known to effectively reduce wind-borne soil erosion in leafless seasons as shown in Sub-Saharan West Africa (Hailu and Runge-Metzger, 1992).

In contrast, throughout the growing season, the deciduous trees bear a full canopy that potentially allows the hedgerows/windbreaks to intercept the wind. Furthermore, due to the prevailing low wind speeds during the growing season, there is no danger of wind erosion, and the vegetation cover of the crops provides additional protection. The most important advantage of the tree lines during the growing season is the improvement of the microclimate, which includes lowering air and soil temperatures and increasing air humidity that in turn may lead to increasing crop yields and water saving (e.g., Abel et al., 1997; Cleugh, 2000; Kayimov et al., 1990). The latter is an important asset in a region that needs to improve water use efficiency (Martius et al. 2004).

The range of crown closure values suggests that existing hedgerows/ windbreaks provide “fair” to “good” wind shelter for the agricultural fields in the region. However, with the photogrammetric technique used, only the upper crown projections are visible on the aerial photographs. Therefore, to accurately capture the vertical profile of hedgerows/windbreaks, photogrammetric estimates should be complemented with ground surveys, where the porosity can be precisely estimated with either ground photos (David and Rhyner, 1999) or with simple visual estimates (Abel et al., 1997).

The differences between the monitored and ocularly estimated findings of crown closure are very likely caused by seasonal differences, as the aerial photographs were taken in November, when the deciduous trees in the study region have usually started shedding their leaves (Khamzina et al., 2006a), while the field verification was conducted in July-August where trees usually have a fully developed crown (Khamzina et al., 2006a). This is likely the explanation for the underestimated crown closure.

The overshadowing of the understory trees also had an effect on the interpretation of the aerial photographs regarding crown closure similar to the frequent underestimations of crown closure as recorded previously (Akça, 2000). Consequently, although porosity is of secondary importance for assessing the functionality of windbreaks (Abel et al., 1997), the employed methodology for estimating crown closure can provide a useful approximation of the porosity of the hedgerows/windbreaks in the study region. It turned out to be sufficiently accurate despite the obvious discrepancies due to the different dates of the photographs and field surveys.

The observed low height of the hedgerows/windbreaks in Khorezm is the greatest problem with regard to the extent of shelter of agricultural fields against problem winds. Windbreak height is influenced by the existing species composition (Khamzina et al., 2006a) and management practices of those species, which includes annual pollarding of *M. alba* and *Salix* spp., which are the principle species (46 and 15%, respectively) in the hedgerows/windbreaks. The tallest hedgerows/windbreaks included fast-growing *Populus* spp. that, however, constituted only 20% of all species, the remainder is *E. angustifolia* and *Salix* spp. (ca. 10 and 7%, respectively) and other species (about 2%). The fast-growing species have a short lifetime (Rocheleau et al., 1988). On the other hand, recent household surveys in the study region revealed an interest of farmers in *Populus* spp. for construction purposes and other domestic uses (Kan et al., 2008) but not primarily as windbreaks, which explains also the early harvest of this species. Although many hedgerows/windbreaks were planted in the desirable orientation to the prevailing winds, the shelter of the agricultural lands was poor due to the low height of the trees.

Worldwide experience suggests application of proper harvesting techniques to maintain the windbreak function (Rocheleau et al., 1988; Wilkinson and Elevitch, 2000), e.g., every fourth tree (a 25% harvest) or every tree in the interior row, thus avoiding gaps for permanent protection (a 50% harvest) for leaf harvesting of pollarded *M. alba* and *Salix* spp. or wood harvesting of fast-growing *Populus* spp. Alternatively, those pollarded species can be replaced, e.g., by suitable species on marginal lands such as *U. pumila*, *P. euphratica* and *E. angustifolia* (Khamzina et al., 2006a).

Many studies concluded that an effective windbreak should stretch along the entire length of the related field or even be extended in both directions beyond the area to be protected to ensure maximal effectiveness (e.g., Bolin et al., 1987; Den Heijer, 1991). Otherwise the wind flow around the windbreak ends would lead to wind eddies that could erode the soil on the adjacent areas of the field and thus beyond the sheltered zone. Since at least 50% of the hedgerows/windbreaks did not stretch along the entire length of the adjacent fields, the efficiency of shelter in those areas can only be sub-optimal. Extending windbreaks with suitable species can easily be introduced to correct the windbreak length. This is, however, resource demanding.

The number of rows in windbreaks usually is considered a secondary-level criterion (Abel al., 1997), although the findings of different studies show that at least double-row and certainly multiple-row windbreaks have the higher longevity of wind shelter over single rows (e.g., Abel et al., 1997; Wilkinson and Elevitch, 2000). The presence of multiple-row and multi-species windbreak is often considered as ideal. Hence, given that double-row hedgerows dominate in the study region, it can be expected that the windbreak function is quite effective. Even if a tree is occasionally missing in a row, a double-row structure has the potential to provide effective shelter. On the other hand, the double-row hedgerows/windbreaks consist mainly of the same species, which indicates that they could be improved.

The dominance of “good” and “fair” marks in “vitality of hedgerows/ windbreaks” indicates generally good condition. However, measures of pest and disease control for the most affected *Populus* spp. should be applied.

Although at present all species in hedgerows/windbreaks are dominated by young trees that indicate recent establishment, in the near future their shelter function will be more efficient as the trees will become “premature”. Nevertheless, the absence of mixed rows with fast- and slow-growing tree species reduces the lifespan of existing hedgerows/windbreaks. This may lead to the need for additional resources for replanting to obtain the potential protection.

4.5 Conclusions

Despite the fact that the aerial photographs used in this study were taken in November when the trees had started to shed their leaves, the in-depth screening and verification of the results show that most key windbreak criteria can be assessed with an acceptably accuracy. For example, the thematic classes of the hedgerows/windbreaks could be indentified with an overall accuracy of 85%. Furthermore, even with the differences between data monitored in the field in summer and photogrammetrically derived from the photographs taken in late autumn, an acceptable accuracy could be achieved, e.g., overall 11% over- and underestimation for mean stand height and crown closure, respectively. Finally, a wealth of evidence from worldwide assessments shows the high accuracy of photogrammetry with GIS-based tools in forest mapping and forest management. Consequently, location and area of hedgerows/windbreaks as well as their orientation to the prevailing winds can be accurately estimated with this method. This also excludes the necessity for the validation of those criteria.

The use of the aerial photographs with a scale of 1:20,000 was seen to be not suitable for the identification of species composition in thematic classes of the hedgerows/windbreaks or recognition of their number of rows. A high density of trees usually applied in the planting schemes of the hedgerows/windbreaks in the region resulted in clumping and overshadowing of the horizontal crown projections, thus individual tree crowns and rows are poorly visible. Also, the lower parts of trees are not visible on horizontal crown projections of the aerial photographs, reducing the objectivity in the assessment of the vitality of hedgerows/windbreaks. The appearance of pollarded crowns of *M. alba* and *Salix* spp. and fast-growing *Populus* spp., which does not differentiate much in shape, size and shadow in age classes, substantially limits identification of the age classes with photogrammetry. A lack of variables at an individual tree level may limit aerial estimation of the growing wood stock of hedgerows/windbreaks if such assessment is applied. Consequently, species composition, number of rows, vitality and age classes of the hedgerows/windbreaks need to be measured directly in the field. Hence, with the aerial photographs presently available in Uzbekistan, the *Uzgiprourmonloyiha* (Design and Survey Forestry Enterprise) of the Main Forestry Department (MFD) could benefit from the following procedures for assessing hedgerows/windbreaks. In a first step, the aerial photographs can be used for the identification of hedgerows/windbreaks according to the developed thematic classes, number and area (share), orientation angle to the prevailing winds, crown closure as a proxy for porosity, mean stand height, and whether the hedgerow/windbreak reaches the edges of the related field. In a second step, field surveys need to complement the data gained in the first step by collecting missing data such as species composition, number of rows, vitality and age classes of the hedgerows/windbreaks.

Large-scale aerial photographs (<1:15,000), which ideally are taken during the growing period, could eliminate all potential hindrances. However, this will substantially increase the costs, which cannot be covered by the low forestry budgets. Therefore, the aerial photographs that were available and were tested and verified in this study can be used for assessing hedgerows/windbreaks when photogrammetry is combined with targeted field surveys.

Following the confirmation of the feasibility of the use of the available aerial photographs, the developed methodology assessed the windbreak function of existing hedgerows in the study region Khorezm. The findings show that:

- The overall share of agricultural fields assigned to hedgerows/windbreaks is low. Especially targeting a 1.6% allotment of agricultural fields to hedgerows/windbreaks in the pre-desert agricultural fields should be recommended to achieve the minimal area (>2.0%) under windbreaks for protection against the moderate winds prevailing in the region.
- There are no multi-species hedgerows/windbreaks in Khorezm. The dominant single-species hedgerows/windbreaks consist of pollarded *M. alba* (46%), fast-growing *Populus* spp. (20%) and pollarded *Salix* spp. (15%). A mix of fast- and slow-growing species, e.g., a row of shrubs, a row of medium height and a tall row of trees in hedgerows/windbreaks, is required. Such promising tree species in the region like *U. pumila*, *P. euphratica* and *E. angustifolia* should be included.
- Most of the hedgerows/windbreaks were oriented (ca. 70%) or nearly oriented (ca. 11%) in SE+NW and N+S directions to intercept the prevailing NE and W winds, especially in the southern part of Khorezm.

- About 60 and 30% of existing hedgerows/windbreaks can be classified as having "fair" and "good" crown closure, respectively. About 65% of the hedgerows/windbreak had a double-row structure. However, mean stand height of the hedgerows/windbreaks was "poor" in ca. 70% of the cases, where it did not exceed 5 m for pollarded *M. alba* and *Salix* spp. Only 50% of the hedgerows/windbreaks reached the edges of the related agricultural field. Although the efficiency (crown closure) and longevity (number of rows) of were satisfactory, the extent of wind shelter was low, as expressed by height and length. In this case, improved harvesting techniques, e.g., only 25 or 50% leaf harvesting of the pollarded species, should be applied. Alternatively, they can be replaced with promising species on marginal lands, e.g., *U. pumila*, *E. angustifolia*, etc., and the tree rows extended to reach the edges of the related fields.
- The majority of the hedgerows/windbreaks were in "good" (ca. 70%) and "fair" (ca. 20%) condition regarding vitality. *Populus* spp. was the most affected by pests and diseases. Given the permanent risk, especially with respect to *Populus* spp., pest and disease control is necessary.
- Young trees dominated in all species (ca. 80%) of existing hedgerows/windbreaks. Although presently young trees have reduced wind shelter efficiency, in the near future the optimal efficiency will be obtained as the trees will become "premature". Nevertheless, the lack of mixed rows with fast- and slow-growing tree species leads to a shorter lifespan of the hedgerows/windbreaks and may lead to additional resources needed for replanting.

Wind erosion may not seem a great problem at present in the Khorezm region, but may become one in the long term. Also, the extremely continental climate of Khorezm with high air temperatures and low precipitation in summer may affect the microclimate of agricultural fields, which could lead to reduced crop yields and water use efficiency. Used together with improved farm practices such as contour planting, minimal tillage and crop rotation, tree windbreaks may offer long-term strategies for preventing soil loss, protecting crops and saving water.

5 OTHER TREE PLANTATIONS

This chapter reports on the results of the first regional inventory of tree plantations in the Khorezm region. Some documents of the national and regional agencies contain information on tree plantations, e.g., the area of fruit orchards and vineyards in Khorezm (KhCGR, 2000), but they are frequently sporadic and inconsistent (FAO, 2006a). The lack of an appropriate methodology for mapping tree plantations substantially limits inventories for these resources both in the Khorezm region and on a national level. Therefore, an applicable methodology was developed for supporting plantation inventories, which was then verified. The generated information on the spatial extent and distribution of apple (*Malus* spp.), apricot (*Prunus armeniaca* L.), grape (*Vitis* L.), mulberry (*Morus alba* L.) and hybrid poplar (*Populus* spp.) plantations and their vitality (disturbance by pests and diseases) and age classes was analyzed.

5.1 Introduction

The future growth in wood demand will largely be met by forest plantations (FAO, 2001). Plantations are efficient means for producing forest products on a relatively limited land area, and can thus help to reduce deforestation and degradation of natural forests. However, if forest plantations are poorly planned and managed, and the perception of land uses is not taken into consideration, they can have negative environmental and social impacts (FAO, 2001). For example, the replacement of natural forest with high-yielding, intensively managed, short-rotation tree plantations has caused social problems in South America, Asia and other areas.

The present global trend is towards an increased establishment of tree plantations as a reliable source of industrial wood. The development of forest plantations in some countries has already had a major impact on wood production. In Chile and New Zealand, for example, the establishment of extensive plantations has enabled these countries to meet all their domestic wood needs and in addition to support a significant export industry. In most other countries, the domestic demand is higher, and timber supplies from plantations are not sufficient to meet domestic demand and must be supplemented by imported timber (FAO, 2001).

In Central Asia, the majority of forest plantations has been established for protective purposes, e.g., wind erosion control in plains and deserts and water erosion control in mountains, whilst western Asia has established about 70% of its plantations primarily for production (FAO, 2006a). Harsh growing conditions, in particular aridity, but also technical and financial constraints have limited the scaling up of plantation efforts in Central Asia. Moreover, most of the plantings are government undertakings, and the pace of establishment is highly dependent on governmental priorities and budget allocations. Therefore, commercial plantings and private sector involvement should be promoted.

Since Uzbekistan has a low forest cover, and any logging for industrial purposes is forbidden except for sanitary felling and clearings (FAO, 2006b), the country implemented a state program for establishing plantations with *Populus* spp. and other fast-growing species to satisfy the high national demand for construction wood and pulp (GoU, 1994), which used to be supplied by Russia (FAO, 2006b). A recent evaluation revealed the general failure of this program due to environmental constraints and disturbances affecting tree health, which decreased the initially established area of about 50,000 ha of *Populus* spp. in Uzbekistan, including 7300 ha in Khorezm, by 50% as of 2002 (FAO, 2006b). During the same period, the average amount of annual wood removal in the country amounted to about 30,000 m^{-3}, of which about 30% was industrial wood used mainly for sawn wood and hardboard for producing wooden cases, matches, pulp and paper. Wood is also commonly used as fuel (FAO, 2006b; UNECE, 2005). In Khorezm, the annual wood harvesting was estimated at about 1000 m^{-3}, of which 50% was used as industrial wood. During the past years, wood has generally been supplied by the private sector and consumed by the small-scale wood-processing businesses for manufacturing small furniture (FAO, 2006b).

Similar to wood production, the share of fruit production and consumption worldwide has substantially increased during the last two decades (FAO/WHO, 2004). But the future demand for fruits is likely to increase given the projected population growth (UNCDB, 2005), and attempts have been made to shift from staple foods (cereals, pulses and starchy roots), vegetable oils, sugar and meat to fruit and vegetable consumption (FAO/WHO, 2004). During the Soviet period, Uzbekistan supplied fruit and early-harvested vegetables cultivated on large collective (*kolkhozes*) and state (*sovkhozes*) farms to other Soviet republics, exporting about 30% of its annual production (Olimjanov and Mamarasulov, 2006; Shadibaev and Uralov, 2008). With the collapse of the processing capacity, this market segment deteriorated. Nowadays, fruit and vegetable production has been revitalized to a certain extent by farmers on their newly obtained private plots, although processing facilities are not re-established yet. In 1999, fruits and grapes in Uzbekistan were produced on about 120,000 and 80,000 ha, respectively, with average yields of 4.2 t ha^{-1} (FAOSTAT, 2008). The Khorezm region shared about 5 and 2% of this area, respectively, with average yields of 5.2 and 10.4 t ha^{1} (KhCGR, 2000). Also, in Uzbekistan, about 40% of all fruit orchards in Central Asia were found, and vineyards covered even 50% (FAOSTAT, 2008). The Uzbek government initiated several measures for reforming its fruit industry and viticulture (GoU, 2006a), which included, e.g., exemptions for a period of three years from income and property taxes, as well as from value added tax. Additional incentives were offered to fruit growers and processing enterprises, as it was realized that a reform of this industry is crucial to the decisions on tree planting among the farmers and producers (Kan et al., 2008).

In the past decade, the sericulture industry has experienced an increase in raw silk production. The major share was provided by the largest producer China with an annual growth rate in 1992-2002 of about 10%, while other countries such as South Korea, Japan and Uzbekistan faced significant reductions of about 40, 20 and 10%, respectively (FAO, 2003b). The sericulture commodity chain is labor intensive, and includes the cultivation of silkworm feed, silkworm rearing, silk reeling, and other post-cocoon processes such as twisting, dyeing, etc. (GoI, 2006). Previously, Uzbekistan produced about 50% of all raw silk in the former Soviet Union (SU) (UzSSR, 1982). Today, many factors limit the re-development of the country's sericulture, including the lack of *M. alba* plantations for feeding silkworms, insufficient credits and subsides for silkworm producers and for pest and disease control for *M. alba* plantations (GoU, 2006b). To counterbalance this situation, various measures were initiated aiming at re-stimulating the development of this industry. These included the establishment of many new *M. alba* plantations in the irrigated agricultural lands, replanting of the older plantations, provision of planting materials and of pest and disease control options (GoU, 2006b).

In general, the poor information about the size and status of the tree plantations calls for caution when interpreting the plantation area estimates (FAO, 2006a). This in turn substantially reduces the awareness of forest and agricultural specialists to monitor the implementation of the national support programs to stimulate the development of tree plantations including private tree plantings. Also, since the land reforms in 2003, the plantations have become privately owned. However, the new owners are too inexperienced to successfully manage these plantations as a source of income (Kan et al., 2008). The lack of a methodology for assessing tree plantations and, based on these assessments, cost-efficient and resource-effective recommendations, hampers the further development of this sector.

Tree plantations in the agricultural areas can no longer be assessed with the previously used procedures such as comprehensive plantation surveys. In this regard, remote sensing techniques with satellite images or aerial photographs combined with GIS-based tools deem a suitable approach, since they have proven their value worldwide (e.g., Akça, 2000; Preto, 1992; Remmel et al., 2005). Different state organizations in Uzbekistan regularly conduct detailed topographical surveys based on aerial photographs in each region in 5-year intervals (Ergeodezkadastr, 2001), but these have not been used for extracting data on tree plantations. The objectives of this research component was thus to (i) adapt a method based on photogrammetry and GIS-based tools for the identification of tree plantations including *Malus* spp., *P. armeniaca*, *Vitis* L., *M. alba* and *Populus* spp., as well as for assessing the spatial extent, vitality and age of those plantations, (ii) validate the accuracy of this procedure and to explore the options to apply this method beyond the Khorezm region, and (iii) provide an updated plantation map and information that allow monitoring over time the spatial extent and distribution of tree plantations in the study region Khorezm.

5.2 Materials and methods

Given the availability and applicability of the aerial photographs, photogrammetry was the most obvious option compared to the other approaches used worldwide for taking stock of forest and tree plantations (section 3.2). A total of 70 stereo pairs of aerial photographs taken in late autumn (November, 2001) at a scale of 1:20,000 was sufficient to capture the area of the tree plantations and to study the variety of the tree plantations in two study transects delineated in NS and WE directions in Khorezm (section 3.3). With a VISOPRET 10-DIG analytical stereo plotter and AutoCAD software, the necessary photogrammetric techniques were applied (section 3.4.1). The commonly used orientation steps interior, relative and absolute orientations were completed (section 3.4.2).

Prior to the delineation of tree plantations, two training areas were established (Figure 3.10 b and d) to develop thematic classes of tree plantations. A minimal area of 0.5 ha of trees with a crown closure of more than 10% was selected (section 3.1.2 and Appendix 9.1). Although the FRA 2005 by FAO suggested a minimal tree height of 5 m at maturity for the delineation of tree plantations (Appendix 9.1), for this criterion it was assumed that all trees would be able to reach the height of 5 m unless affected by regular pollarding, which occurs exclusively with *M. alba*.

Ocular photo interpretation and delineation of each tree plantation was completed with the analytical stereo plotter according to the thematic classes (section 3.5.2), while the minimal plantation area (to the nearest 0.01 ha) was controlled by AutoCAD (section 3.4.1). Ocular estimates of crown closure (to the closest 0.1-0.2 coefficient) were carried out with the AutoCAD plotter and roughly checked with the graphical crown density scale (Figure 3.11). The resulting polygons were transformed with the AutoCAD to the commonly used ESRI ArcGIS 9.0 software, which formed the basis for computing the area of the polygons (section 3.4.3) and to generate the map layers (Figure 3.10 b and d).

To cross-check the accuracy of the delineated tree plantations in the thematic classes such as "*Populus* spp.", "*Vitis* L. and pollarded *M. alba*", and "*Malus* spp. and *P. armeniaca*", field verification was conducted. This addressed verification of all tree plantations examined by photogrammetry (Table 3.9). The location in the field of each tree plantation was recorded with a GPS (accuracy ±10-20 m) (section 3.6). Verification of the measured tree plantation area by GIS-based tools was not performed, since the use of aerial photographs in forest mapping and GIS digitizing procedures have proven their accuracy and efficiency on numerous occasions and thus have already become a standard procedure (e.g., Zihlavnik et al., 2007).

That part of the information that could not be accurately extracted from the aerial photographs included species composition, vitality and age of tree plantations.

Consequently, these were estimated directly in the field according to the selected classes (section 3.1.2), applying the appropriate method and sample size (section 3.7). The results of the sampling were projected to the entire area of other tree plantations.

5.3 Results

The aerial photographs made available for this study were taken in late autumn, a period characterized by leaf shedding of deciduous trees. This could have rendered the identification of various tree parameters difficult, but this was not the case for identifying the horizontal crown projections and crown shadow profiles, which could be distinguished on the aerial photographs by the branches in the specific planting schemes of the species. For example, *Malus* spp. and *P. armeniaca* had a line-shaped and un-clumped crown projection in square- or rectangular-shaped areas where branches of individual trees were visible and recognizable due to the applied planting schemes for fruit trees with large distances between trees and rows (Table 3.7). In contrast, a separation between *Malus* spp. and *P. armeniaca* was not feasible, because both species had less or no leaves at all in late autumn. *Populus* spp. could be identified in all cases due to its unique pattern, i.e., a clumped crown projection between trees, rows and clusters due to the very dense planting schemes (Table 3.7), even with less or no leaves. *Vitis* L. and pollarded *M. alba* both had clumped crown projection between trees in dense planting schemes, while rows were visible due to the low heights of the trees making the crown shadow profile shorter, i.e., it did not exceed the spaces between the rows. Based on the field verification, the three thematic classes "*Populus* spp.", "*Vitis* L. and pollarded *M. alba*", and "*Malus* spp. and *P. armeniaca*" could be accurately identified from aerial photographs (Table 5.1) even though these were taken in late autumn and only available at a 1:20,000 scale. *Populus* spp. plantations could be distinguished from other spp., while *Vitis* L. and pollarded *M. alba* as well as *Malus* spp. and *P. armeniaca* could be identified only in the corresponding classes.

Table 5.1: Verification of photo interpretation of tree plantation thematic classes

Thematic class*	Accuracy (%)
3 (*Populus* spp.)	100
4 (*Vitis* L. and pollarded *M. alba*)	90
5 (*Malus* spp. and *P. armeniaca*)	95
Overall	95

** Table 3.7*

The size of the plantations could readily be identified with the aerial photographs. The combined standing plantation resource comprised 663 ha or 1.2% of the transect area (Table 5.2). *Malus* spp. and *P. armeniaca* orchards dominated in Khorezm. The area of *M. alba*, *Vitis* L. and *Populus* spp. plantations was low. Other fruit species such as peach (*Prunus persica* (L.) Batsch), pear (*Pyrus communis* L.) and cherry (*Prunus cerasus* L.) occurred sporadically. This pattern was similar in both transects.

Table 5.2: Spatial extent of tree plantations in the study transects

Transect	Transect area (ha)	Tree plantations (ha)							
				Orchards					
		Populus spp.	*M. alba*	*Malus* spp.	*P. armeniaca*	Other spp.	Total	*Vitis* L.	Total
NS	32,020	11 <0.1%*	48 0.2%	178 0.6%	93 0.3%	17 <0.1%	288 0.9%	30 0.1%	377 1.2%
WE	23,020	6 <0.1%	54 0.2%	136 0.6%	55 0.2%	11 <0.1%	202 0.9%	24 0.1%	286 1.2%
Total	55,040	17 <0.1%	102 0.2%	314 0.6%	148 0.3%	28 <0.1%	490 0.9%	54 0.1%	663 1.2%

** Ratio to the transect area*

The assessment revealed that the largest area of tree plantations showed "good" and "fair" vitality (Figure 5.1). The area of the "poor" class was small, and no significant differences existed between the species. In contrast, in the class "fair", *Populus* spp. dominated. *Malus* spp., *M. alba, P. armeniaca* and *Vitis* L. showed the highest values in the "good" class.

The "young" age class dominated in the tree plantations (Figure 5.2), which corresponds to reduced fruit, leaf and wood production (section 3.1.2). No *Populus* spp. and *M. alba* were in the "mature" age class. The "premature" age class showed a low number of all species except for *Vitis* L., where an almost equal share of "premature" and "young" age classes was observed.

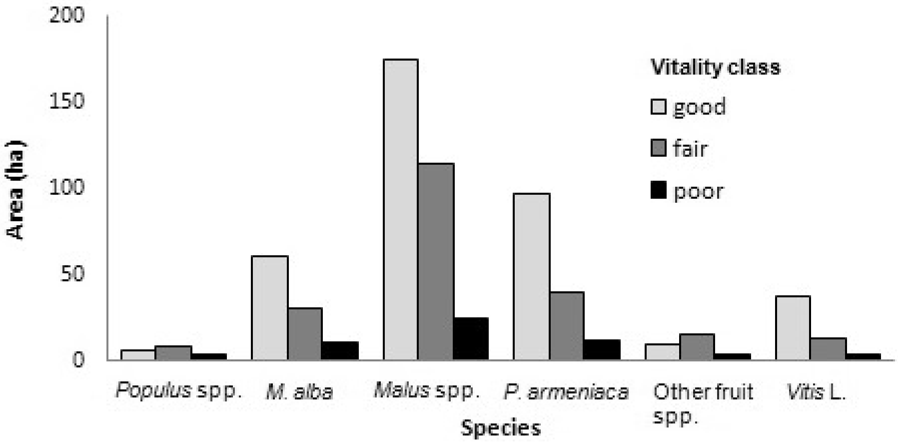

Figure 5.1: Distribution of area by vitality classes of tree plantation species

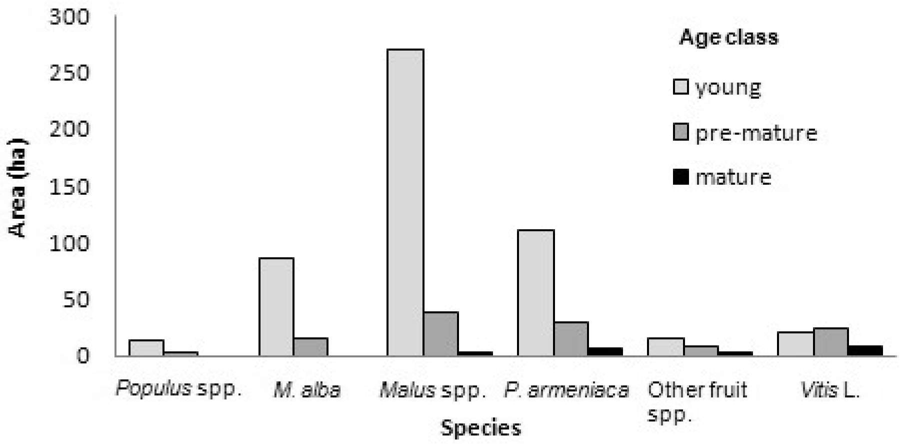

Figure 5.2: Distribution of area by age classes of tree plantation species

5.4 Discussion

The use of aerial photogrammetry in forest mapping and forest management has been well developed since the 1950s and is nowadays used for various forest types (e.g., Anuchin, 1982; Nyyssönen, 1964; Spurr, 1948). In combination with GIS-based tools and analytical stereoscopic instruments, spatial extent and distribution of trees can be accurately extracted from aerial photographs and converted into GIS map formats with a high precision (Akça, 2000).

Although the available photographs were taken in late autumn (November, 2001) when leaf shedding of most of the deciduous trees occurs in the study region (Khamzina et al., 2006a), the horizontal crown projections and crown shadow profiles still could be distinguished on the aerial photographs through the appearance of branches and the species-specific planting schemes, e.g., *Malus* spp. and *P. armeniaca* with large distances between trees and rows. The three thematic classes, namely "*Malus* spp. and *P. armeniaca*", "*Vitis* L. and pollarded *M. alba*", and "*Populus* spp." could be separated, although a further separation of species in the classes was not always feasible. In case a detailed species distribution is of interest, either aerial photographs with a larger scale (<1:15,000), and taken in summer (by default with high resolution or quality) are needed, or with the available photographs, the photogrammetric procedures have to be complemented with field surveys. Also, with suitable large-scale photographs, individual crowns can be recognized and measured. Those variables will be needed in aerial estimation of growing wood stock as suggested previously (e.g., Akça, 2000; Pope, 1962), in particular tree plantations grown for construction wood, e.g., *Populus* spp. In contrast, estimation of leaf and fruit yields from aerial photographs is at present still not possible with photogrammetric techniques due to purely technical limitations.

The aerial photographs with a scale of 1:20,000 turned out to be not very suitable for the identification of vitality and age classes of the tree plantations, however for different reasons. In the case of vitality, only the upper layer of the crown can be assessed, whereas the lower layers and stem remain out of reach (Akça, 2000). Age classes cannot be differentiated, especially for the appearance of the pollarded crowns of *M. alba* and the crowns of fast-growing *Populus* spp., where the horizontal crown projection showed no difference between young and or/premature and mature age classes, since the shape, size and shadow of the crowns were similar. Since the vitality, age classes and production values of the different fractions (fruit, leaves, wood, etc.) of tree plantations often are a key interest of owners, at present only field surveys can be recommended. When applying the correct method and considering the criteria for the determination of the size of the samples, these parameters can be determined with a high accuracy.

Despite the fundamental limitations of photogrammetry, the available aerial photographs can be used for forest managers and agricultural specialists for delineating the spatial extent of tree plantings for fruit production (*Malus* spp., *P. armeniaca* and *Vitis* L.), construction wood (*Populus* spp.), or sericulture (pollarded *M. alba*). This will support those specialists, as they have no funds for expensive and time-consuming inventory methods in the extensive agricultural areas. However, for determining the extent of all tree plantations in these areas, it is likely that a larger number of aerial photographs will be required. However, the costs for these are still relatively low compared to those for satellite images (roughly three times cheaper for the area of Khorezm, Vakhidov, *personal communication*), and regular time series of aerial photographs of the area are available for every five years (Ergeodezkadastr, 2001). Funds and resources should be made available to forest and agriculture specialists, in particular since different legislation acts in Uzbekistan have been passed aiming at the revitalization of tree plantations for satisfying the domestic demand for fruits and grapes (GoU, 2006a), sericulture (GoU, 2006b) and construction wood and pulp (GoU, 1994). Given the increasing interest of the national and regional administration in monitoring the impact of these legislative measures, the developed method based on the available aerial photographs can be recommended. On the other hand, in case production data are also desired, field surveys with the appropriate sampling techniques have to be applied.

The inventory showed that with 1.2% only a very low percentage of the total area was under tree plantations in the Khorezm region. Although in the past the region had much larger forest stands stretching for hundreds of kilometers along the Amu Darya River, these have been sacrificed for the development of the agricultural sector. Due to the intensively managed irrigated agricultural system, there are fewer trees in the river oases. The trees are grown mainly for their supporting functions, e.g., home consumption of fruits and fuelwood, whereas the bulk of the arable land is dedicated to cotton monoculture and other crops such wheat and rice (Djanibekov, 2008).

The inventory revealed a high share of fruit orchards, and to a minor extent of *Populus* spp. for construction wood. This is very much in line with recent conclusions from a comprehensive farm survey in the Khorezm region (Kan et al., 2008) and confirms the preference of the local population for fruit trees such as *Malus* spp. and *P. armeniaca* over *Populus* spp. or *M. alba*. Even though fruits are consumed domestically or sold at local markets (Bobojonov and Lamers, 2007), the high demand for apples and apricots seems to be mostly driven by the export opportunities to the Russian Federation and other countries due to higher market prices (e.g., Shadibaev and Uralov, 2008). Also, non-wood forest products such as leaves, bark, flowers, roots, etc., are of importance to the local population (Kan et al., 2008) and represent an additional incentive for land users to plant specific tree species.

Populus spp. occurred only sporadically despite the fact that wood production seems to be economically reasonable (Worbes et al., 2006). Nevertheless, the use of this softwood species is limited to light constructions only (Forestry Compendium, 2000). To satisfy the domestic demand, Uzbekistan imports coniferous wood for construction purposes mainly from Russia (Worbes et al., 2006). Given the growing need for construction wood by the local population, the extension of appropriate tree plantations could be an attractive option in the near future. In that case, it seems judicious to plant not only softwood species such as *Populus* spp. but also other species such as *Ulmus pumila* L. (Khamzina, 2006a).

The findings indicate a significant share of young trees among all species. This has been explained as a result of the land privatization process that gained momentum after 1996 (Kan et al., 2008). During this land privatization, fruit orchards could be purchased. The legislation according to which land planted with trees would be automatically exempted for several years from the state order system seems to have motivated many farmers to take up this challenge (Kan et al., 2008). Hence, farmers opted in the first place to plant highly profitable fruit trees both in their gardens and on rented lands (former *shirkats*). It is estimated that the largest area of plantations consists of fruit trees planted on rented lands. Even though the land remains the property of the state, it can be rented for farming purposes.

The field surveys revealed that the vitality of tree plantations was mainly "good" or "fair", but some tree species were more susceptible to pest and disease infestations than others, in particular *Populus* spp. showed higher infestation rates. This confirms earlier findings in a region-wide detailed survey for tree pests and diseases in 2003 (Ruzmetov, *unpublished*) and underlines the necessity for increasing the phyto-sanitarian services to avoid a further spread of these infestations.

5.5 Conclusions

Aerial photogrammetry with GIS-based tools can be easily applied for assessing the spatial extent of tree plantations in large agricultural fields in the region of Khorezm. Although a large number of photographs are required, these are still cheaper than satellite images, since they are available from national governmental agencies, e.g., *Ergeodezkadastr*. Although taken in the late autumn when the trees have started to shed their leaves, the aerial photographs still can be used for separating thematic classes of tree plantations. To render a species distribution in these classes feasible, the scale of the aerial photograph should be at least 1:15,000 and when possible taken during the growing period. With the available scale of 1:20,000, the photogrammetry procedures have to be complemented with field surveys.

The presently available aerial photographs are sufficiently useful for forest and agricultural managers for delineating the spatial extent of tree plantings for fruit production (*Malus* spp. and *P. armeniaca*) and construction wood (*Populus* spp.), or sericulture and viticulture. Given the increasing interest of the national and regional administration in monitoring the impact of national legislative measures, the method using the available aerial photographs is suitable.

The aerial photographs were not applicable for the assessment of vitality, age classes and production (fruits, leaves and wood) of tree plantations. There were different reasons, e.g., the subjectivity of vitality assessments from aerial photographs when only the upper layer of the crowns can be assessed while the lower layers and stems are not visible. Simple technical limitations occurred in the case of leaf and fruit yields. Since the vitality, age classes and production of different fractions of tree plantations are a key interest of tree growers, field surveys are recommended.

Aerial photographs are a reliable option for a wide-scale tree plantation inventory, and the results of the analyses represent both a first approximation of the present tree plantation resources and a reference for the future.

Trees were found on ca. 1.2% of the area, which is still quite a low share despite a variety of governmental decisions to re-vitalize tree plantations for satisfying the local demand for fruit, wood and sericulture. On the other hand, the dominance of young and pre-mature orchards indicates that farmers recently started growing fruit trees, particularly in pursuit of higher market prices abroad.

The share of wood plantations, in particular *Populus* spp., was very low, indicating a failure of the incentives provided by the state-supported programs sinse 1994. This may, on the one hand, have been caused by water deficiencies, and poor pest and disease control (FAO, 2006b), but also by a low awareness about the value and scope of wood yields (Worbes et al., 2006). The extension of tree plantations for the production of construction wood could become an attractive option in the near future due to a growing local demand and an increased dependency on imported timber. From this perspective, the growing of both softwood (e.g., *Populus* spp.) and hardwood species (e.g., *U. pumila*) would be beneficial (Khamzina, 2006a). Moreover, Khamzina (2006 a) showed that the promotion of pure timber production with long-term profit prospects seems less feasible than the growth of tree species that, during their life cycle, also offer by-products that can ensure annual cash flows.

6 *TUGAI* FORESTS AND OTHER WOODED LAND

The few studies on the *tugai* forests, reporting mainly on their extent and physiology in Central Asia and Uzbekistan, addressed in particular the right bank of the Amy Darya River, the Republic of Karakalpakstan, and areas flanking the Syr Darya and Zaravshan rivers. In contrast, no updated forest inventory exists for the left bank of the Amu Darya River in the Khorezm region, despite the urgent need for reliable data to adequately manage this unique biosphere. The lack of a suitable methodology that is cheap, comprehensive and affordable is a major limiting factor for the forest research division and forest managers to obtain such inventories in Uzbekistan. Therefore, first a suitable methodology for an inventory was elaborated and verified. Second, spatial extent and distribution of the *tugai* forests were assessed with aerial photographs taken in late autumn 2001, while vitality (disturbance by pests, diseases and fire) and age of the *tugai* forests were assessed during field surveys in summer 2003. The comparison of the data set 2001-2003 and information of the last Khorezm forest inventory (KhFI, 1990) allowed estimation of the recent changes in the area of the *tugai* forests in the region.

6.1 Introduction

The excessive diversion of river water for irrigation and the construction of high-capacity hydro-power plants in the Central Asian countries during a relatively short period of time (1960-1995) were impressive, but these measures triggered an environmental degradation of which the drying up of the Aral Sea is just one example. The irrigation-water-induced desertification of the surrounding areas has also had serious social and economical consequences (UNCCD, 1999). It is repeatedly stated that one devastating impact of the Aral Sea crisis is the degradation of the unique Amu Darya River eco-system, which specially is manifested in its delta. The lowering of the Aral Sea water level and the regulation of the Amu Darya river flow owing to the construction of dams, watersheds and hydro-networks caused considerable changes in the vegetation (Treshkin, 2001a). Subsequently, water and sediment input were reduced, which changed the groundwater level, whilst also the salinity of river and surface waters increased (Abdullaev, 2002). Although the ensuing environmental changes affected the various vegetation types differently, a most significant change was postulated for the *tugai* forests[2].

The *tugai* or riparian forest is typical for river valleys and deltas in arid regions (Treshkin et al., 1998), where it occupies sand banks, islands and low terraces, and thus is regularly flooded (Kuzmina and Treshkin, 1997). Narrow belts of *tugai* forest span from a few hundred meters up to several kilometers and typically flank the river reaches and canals. *Tugai* forests manifest in three main groups[3]: tree *tugai* (ligneous), bush *tugai*, and grass *tugai* (Kuzmina and Treshkin, 1997; Treshkin et. al., 1998). At the beginning of the 20th century, the narrow belts of *tugai* forest stretched along rivers for hundreds of kilometers. They covered about 600,000 ha in the floodplains of the Amu Darya alone, including 300,000 ha in its lower reaches and delta (Appendix 9.3). Nowadays, this area is less than 30,000 ha in the delta (Treshkin, 2001a), which is a reduction of the total area of *tugai* forests by more than 90% in the past 60 years. Also, many plant species are endangered, including wild sugarcane (*Saccharum spontaneum* L.), ravenna grass (*Erianthus ravennae* L.), slender reed mace (*Typha laxmannii* L.) and many others (Treskin, et al., 1998). The endemic species of the *tugai*, the Caspian or Turan tiger (*Panthera tigris virgata* Illiger), disappeared in the 1950s (ITIS, 2008).

The repeatedly cited reduction of the forest area, loss in biodiversity, simplification of the forest structure, and invasion of desert plants into the *tugai* ecosystem (see e.g., Treshkin 2001a) are alarming and can be assessed in the long run but hardly in the short and medium term. Also, it is often stated that the main reasons for the degradation of the *tugai* forests are related to indirect and direct anthropogenic factors. The lowering of the groundwater table and increasing soil salinity are the main reasons for the disappearance of the *tugai* forests (Kuzmina and Treshkin, 1997; Treshkin, 2001b). Anthropogenic factors also impacted the *tugai* dynamics, including an uncontrolled tree cutting and overgrazing that transformed the tree-shrub

[2] The term "*tugai*" is mainly used for the floodplains and river deltas in the former Central Asian Soviet Republics, e.g., those around the Amu Darya, Syr Darya, Zeravshan, Vaksh rivers (Treshkin, 2001a). *Tugai* forests also exist in northern China (Xinjiang) (Thomas, 2004) and other regions with an arid or semi-arid climate (Appendix 9.3).

[3] Poplar species such as Euphrates poplar (*Populus euphratica* L) and *turang'il* (*P. pruinosa*), but also Russian olive (*Elaeagnus angustifolia* L.) and willow (*Salix* spp.) species characterize the woody *tugai*. The tree *tugai* includes bushes and tall grasses, such as salt cedar (*Tamarix androssowii* Litv., Sched), common reed (*Phragmites australis* (Cav.) Trin. ex Steud), chee reed grass (*Calamagrostis epigeios* (L.) Roth) and herbs such as cultivated licorice (*Glycyrrhiza glabra* L.) and dogbane (*Apocynum scabrum* L.).

communities into pasture ecosystems, fires, and tillage activities to prepare these lands for crop production (Treshkin, et al 1998). However, a closer look at the data that are at the roots of these conclusions show that these reports are limited to parts of the right bank of the Amu Darya River delta in the Republic of Karakalpakstan. Moreover, they are based on results of fieldwork, and thus the extent and scope of the data collection is limited, as well as on secondary data from sporadic forest inventories aiming to estimate the dynamics of *tugai* forests and their species diversity (Novikova, 2001; Treshkin 2001a). Extrapolations and assumptions have next been made with respect to the forest areas, although clear evidence from these areas is missing owing to a lack of regular inventories, for example, the forest inventory data in the region of Khorezm have not been updated since the early 1990s.

In the aftermath of independence, the availability of a suitable methodology has become a critically limiting factor in the procurement of accurate and reliable information on the existing patches of *tugai* forests. In the past, small and accessible tracts of *tugai* forests were monitored with extensive field surveys. However, today such conservative approach cannot be applied, because it is time and resource demanding and only low funds are foreseen in the annual budgets. On the other hand, photogrammetry and satellite imagery have successively been used in forest mapping and inventory in many regions of the world (e.g., Akça, 2000; Remmel et al., 2005). Moreover, for updating and actualization of the topographic maps in Uzbekistan, aerial photographs are taken every five years (Ergeodezkadastr, 2001). Yet these photographs have not been suggested for use in forestry. The lack of knowledge regarding suitable options of the forest specialists, who were educated during the former Soviet system, is certainly caused by a lack of an updated, professional education. These specialists are still unaware of new technologies and procedures on, for example, forest area estimates by the use of photogrammetry. The objectives of this study therefore are (i) to elaborate a method based on photogrammetry and GIS for assessing the spatial extent and distribution of *tugai* forests, (ii) to validate the accuracy of this procedure and to explore the options to apply this method beyond Khorezm, and (iii) to provide an updated forest map and information that allows monitoring the dynamics of the *tugai* forest over time in the region.

6.2 Materials and methods

Two datasets were used in this study: (i) the raw data from the Khorezm forest inventory conducted in 1990 (KhFI, 1990) provided by the Khorezm Forestry Enterprise, and (ii) aerial photographs taken in November 2001 by the Land and Geodesy Cadastre Center of Uzbekistan (Ergeodezkadastr, 2001) and field verified in summer 2003.

6.2.1 Khorezm forest inventory 1990

The original forest inventory data were entered in Excel, cross-checked for errors, cleaned and prepared for a reclassification to match the forest categories used in the latest Forest Resources Assessment 2005 (FRA) as proposed by FAO (Appendix 9.1). The classes of the spatial extent of forests and crown closures used in the original and national datasets were converted to the FRA 2005 categories, which include forest area and other wooded land (details in Appendix 9.4). The requirements for delineating the forest areas, e.g., a minimal area of 0.5 ha, crown closure of more than 10%, and tree height of 5 m or trees able to reach this height in *situ* (Appendix 9.1) were taken into account. Moreover, since the original data were generated according to the framework of the local forest management units, i.e., the large “forest territories” and small “forest compartments” of the Khorezm Forest Enterprise, the data according to FAO categories (FRA, 2005) were compared in selected forest compartments of a single forest territory in delineated transects (section 3.3).

6.2.2 Aerial photography 2001 and field verification 2003

Five stereo pairs of aerial photographs out of a total of 70 at a scale of 1:20,000 were needed to capture the area of *tugai* forest in two study transects delineated in NS and WE directions in Khorezm, and to study the extent of this ecosystem in the Khorezm region (section 3.4.2). With a VISOPRET 10-DIG analytical stereo plotter and the AutoCAD software, the necessary photogrammetric techniques could be completed (section 3.4.1). Prior to the application of these procedures, the orientation steps interior, relative and absolute orientations were applied (section 3.4.2). Prior to the delineation of the *tugai* forest areas, training areas were established in the forest compartments (Figure 3.10a and c). At the same time, the parameters for delineating the *tugai* thematic class were developed, e.g., a minimal area of 0.5 ha with trees having a canopy cover of more than 10%, or trees able to reach these thresholds in *situ* for the *tugai* class (Table 3.7 and Appendix 9.1).

Ocular photo interpretation and delineation of each *tugai* forest patch were completed with the analytical stereo plotter according to the thematic *tugai* forest class (section 3.5.2), while the minimal forest area (to the nearest 0.01 ha) was controlled by AutoCAD (section 3.4.1). Ocular estimates of crown closure (to the closest 0.1-0.2 coefficient) were carried out with the AutoCAD plotter and roughly checked with the graphical crown density scale (Figure 3.11). The resulting polygons were transformed with AutoCAD and entered into the commonly used ESRI ArcGIS software, which was used for computing the area of the polygons (Section 3.4.3) and for generating the map layers (Figure 3.10a and c).

Field verification was used to cross-check the accuracy of the delineated forest patches in the thematic classes "*tugai* forests" and "other wooded land" in the *tugai* area (section 3.6). The verification of the measured forested area by GIS-based tools was not conducted, as the use of aerial photographs in forest mapping and GIS digitizing procedures had proven the accuracy and efficiency of this method on numerous occasions, and it has thus become a standard procedure (e.g., Kleinn et al., 2005).

Species distribution, vitality and age classes of *tugai* forests and other wooded land in *tugai* forests and deserts were assessed directly in the field according to the selected classes (section 3.1.3) and applying the appropriate method and sample size (section 3.7). The results of the sampling were projected to the entire area of the forests.

6.3 Results

6.3.1 Khorezm forest inventory 1990

The inventory showed that natural forests in Khorezm were located in three forest territories: Kokralin, Khiva and Tuyamuyun (Figure 6.1). The narrow patches of *tugai* forests were located in the Kokralin territory, including the Gurlan, Yangibazar and Urganch administrative districts. Single woody shrubs in desert zone occurred in the Khiva and Tuyamuyun territories. The Khiva forest territory comprised the area of the Khiva, Yangiarik, Bogot and Khozarasp districts. The Tuyamuyun territory was located in the Pitnak administrative district. The administrative districts Shavat, Kushkupir and Khonka were outside the forest management units (Figure 6.1).

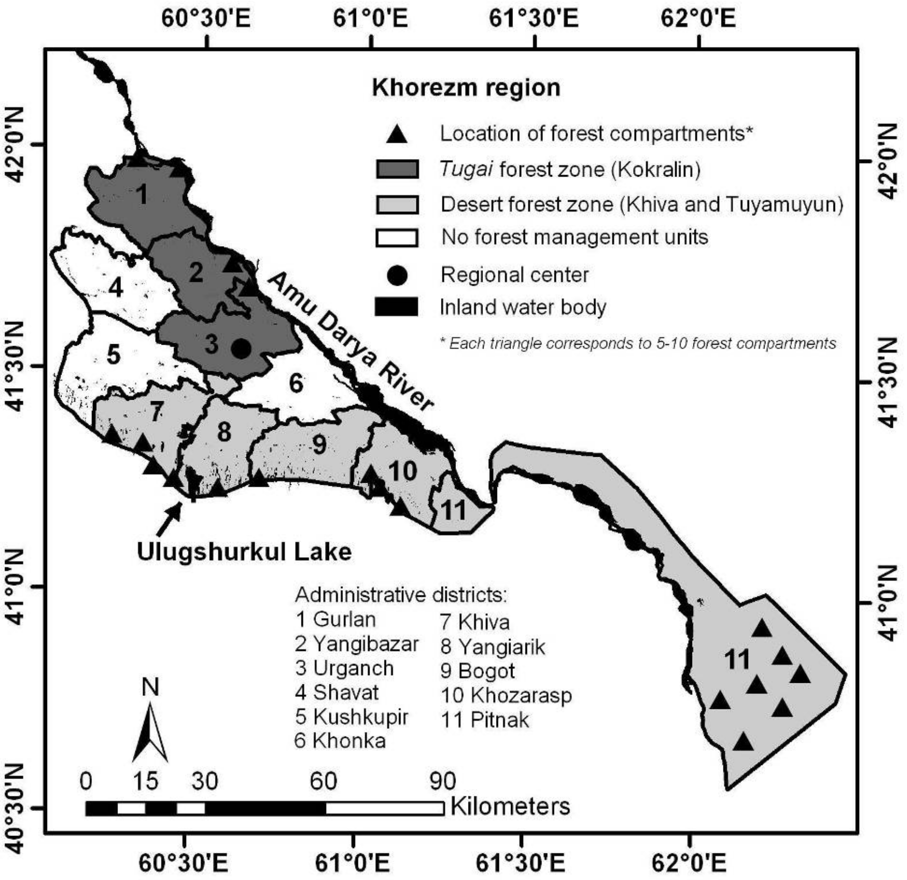

Figure 6.1: Extent of forest management units in Khorezm (KhFI, 1990)

In total, 137 forest compartments were unequally distributed over the three forest territories (KhFI, 1990). The largest number of the compartments was established in the Tuyamuyun (71) and Khiva (51) forest territories located in the southern and southeastern parts of Khorezm. These compartments were found mainly in depressions and in regions with numerous lakes (incl. the largest Lake Ulugshurkul) and surrounded by sandy deserts. 15 *tugai* forest compartments were on the narrow patches and strips of *tugai* along the Amu Darya riverbanks in the northern-eastern part of Khorezm (Kokralin territory).

The extent of forest territories by national classes (KhFI, 1990) and categories FRA 2005 (Appendices 9.1 and 9.4) are presented in Tables 6.1 and 6.2, respectively.

Table 6.1: Forest area by national classes in Khorezm in 1990 (KhFI, 1990)

Forest territory	Forest land class (ha)									
	Forest land						Non-forest land			Total forest land class
	Closed forest*		Open forest plantation	Forest nursery	Treeless					
	total	including forest plantation			sparse forest stand	not covered by forest	water body	garden	other land	
Kokralin (*tugai*)	820	18	56	16	25	118	92	14	287	1428
Khiva (desert)	9968	3105	202	0	604	491	3261	0	2018	16,544
Tuyamuyun (desert)	36,067	141	0	0	31,000	7094	4	0	1326	75,491
Total forest territory	46,855	3264	258	16	31,629	7703	3357	14	3631	93,463

* *Appendix 9.4*

Table 6.2: Reclassification of inventory data into FRA 2005 (FAO, 2005a)

Forest territory	Forest land by FRA 2005 categories (ha)					
	Forest	Other wooded land	Other land		Inland water body	Total category
			total	incl. tree cover		
Kokralin (*tugai*)	836	25	475	70	92	1428
Khiva (desert)	9968 (0)*	604 (10,572)	2711	202	3261	16,544
Tuyamuyun (desert)	36,067 (0)	31,000 (67,067)	8420	0	4	75,491
Total forest territory	46,871 (836)	31,629 (77,664)	11,606	272	3357	93,463

* *Between brackets, values of "forest" in desert zones moved to "other wooded land"*

The largest share of forest territories was found in deserts (Tuyamuyun and Khiva forest territories), while the smallest was found in the *tugai* area (Kokralin). The forest in deserts is better seen as "other wooded land" (Table 6.2) according to FRA 2005 (FAO, 2005a).

6.3.2 Inventory of *tugai* forests in 2001-2003 and changes in 1990-2003

Delineated by the NS transect, four *tugai* forest compartments (3-6) were analyzed (Figure 6.2). A detailed mapping of these compartments shows the distribution of the forest and other wooded land classes as well other lands and inland water bodies.

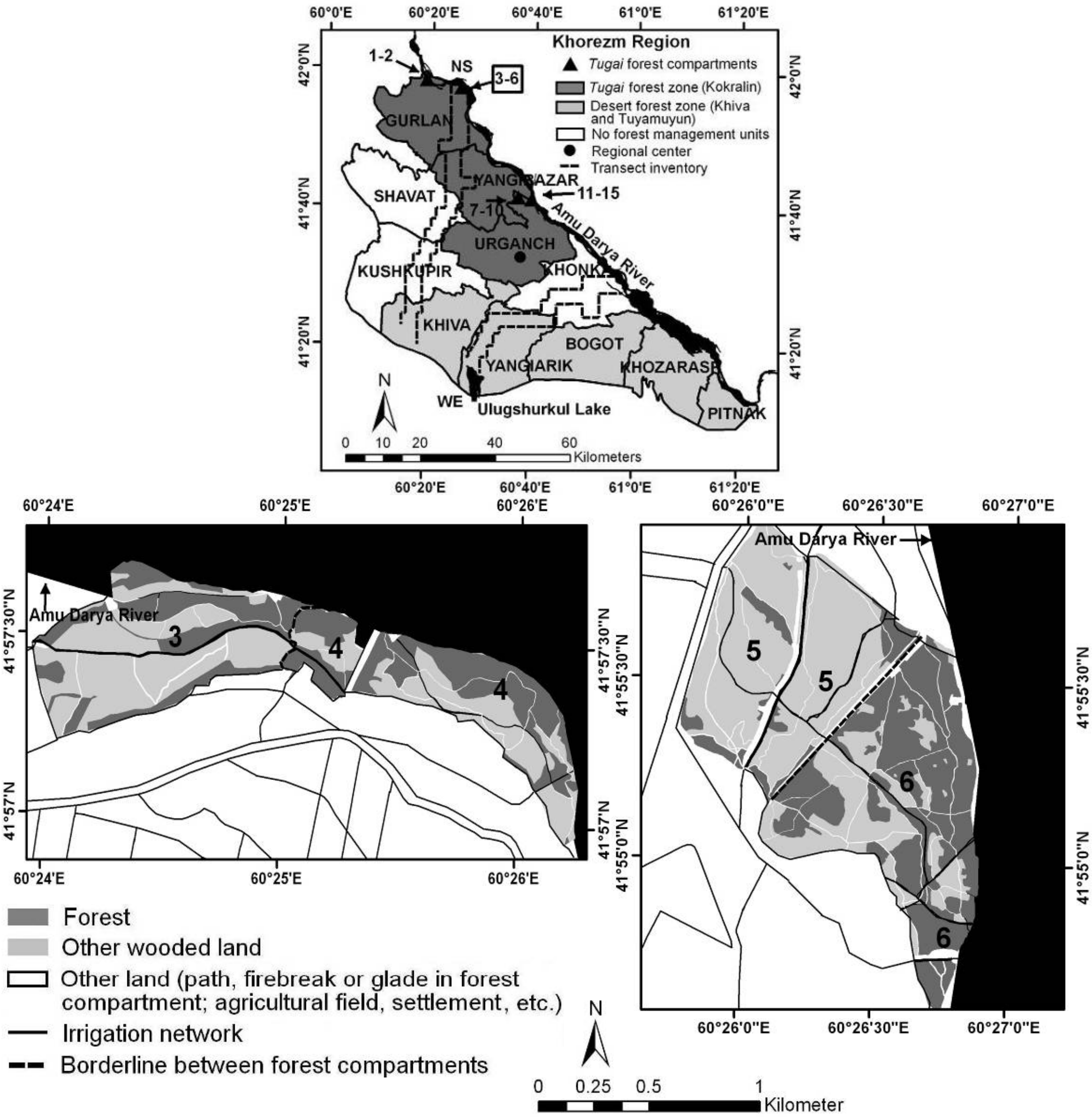

Figure 6.2: Extent of forest and other wooded land in *tugai* forest compartments, Khorezm

Tugai forest cover is less than 1% of the study area (Table 6.3). According to the inventory 2001-2003, the area of forests had drastically decreased to about 60% of the area measured in 1990 (Table 6.4 and Figure 6.3). Out of that 60%, ca. 40% had turned into "other wooded land" classified as having a canopy cover less than 10% with an annual forest degradation rate of ca. 3% (Table 6.5). This can still be regenerated naturally or with silvicultural efforts. The remainder (almost 20%) had been converted into agricultural land with an annual deforestation rate of almost 1.5%. In contrast, the area of other wooded land had increased by almost 4.4 times in 2003 as compared to 1990 (Table 6.4 and Figure 6.4).

Table 6.3: Spatial extent of *tugai* forests in the study transects

Transect	Transect area (ha)	Forest (ha)		
		Forest	Other wooded land	Total
NS	32,020	139.1	177.8	316.9
		(0.4)*	(0.6)	(1.0)
WE	23,020	–	–	–
Total	55,040	139.1	177.8	316.9
		(0.3)	(0.3)	(0.6)

* *Ratio to the transect area (%)*

Table 6.4: Distribution of area (ha) by FRA 2005 categories (FAO, 2005a) in *tugai* forest compartments, Khorezm in 1990 and 2003

Forest compartment	Forest		Other wooded land		Total area	
	1990*	2003**	1990	2003	1990	2003
3	67.1	29.0	15.7	50.2	82.8	79.2
4	87.2	34.7	1.6	27.5	88.8	62.2
5	77.3	9.6	19.4	68.9	96.7	78.5
6	110.5	65.8	3.9	31.2	111.4	97.0
Total	342.1	139.1	40.6	177.8	382.7	316.9
	(-59%)		(x4.4)		(-17%)	

*Reclassified data of the Khorezm forest inventory 1990 (KhFI, 1990); ** Inventory of *tugai* forests in 2001-2003

Table 6.5: Rates of forest degradation in *tugai* forest compartments, Khorezm

Area of forest	(%)	(% year^{-1})
Converted to other wooded land (forest degradation)	42	3.2
Converted to agricultural land (deforestation)	17	1.3
Total	59	2.3

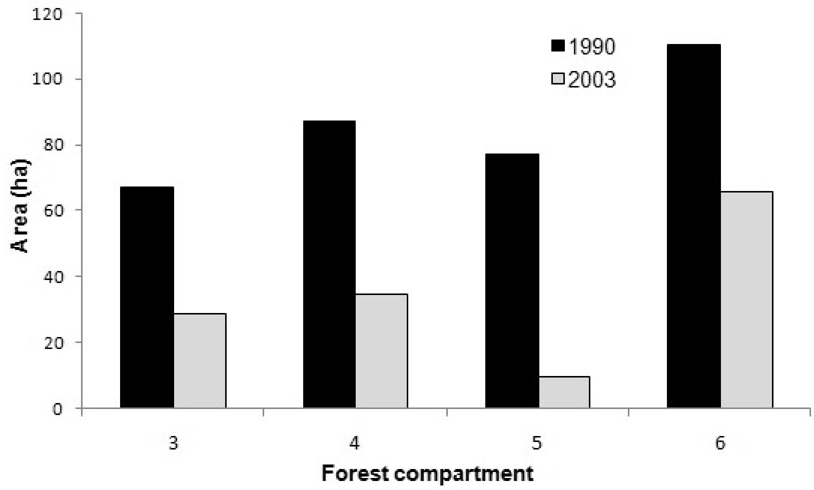

Figure 6.3: Changes in forest area in *tugai* forest compartments, Khorezm

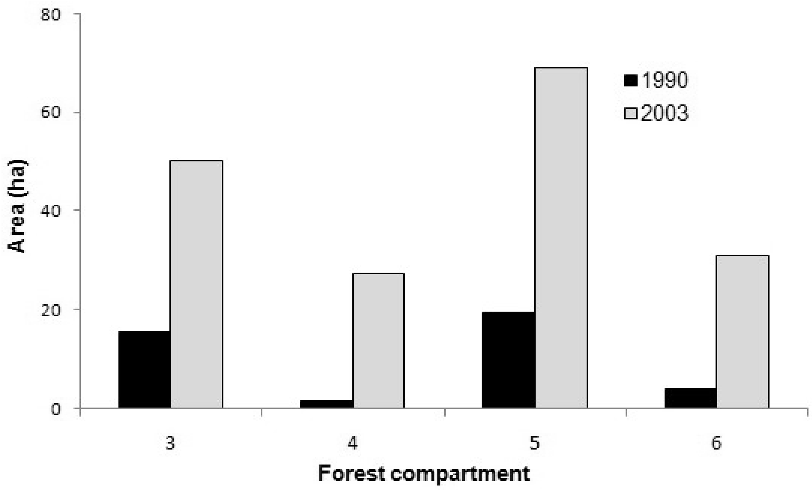

Figure 6.4: Changes in other wooded land in *tugai* forest compartments, Khorezm

The assessment revealed that the largest area in the *tugai* forest compartments was in "fair" or "good" vitality classes (Figure 6.5). Pests and diseases were the main disturbances affecting forest health and vitality. Areas of wildfire damage were not found in any *tugai* forest compartment.

The area of the *tugai* forest compartments 3, 4 and 6 was dominated by "premature" and "young" age classes (Figure 6.6), which indicates a certain level of natural regeneration in those compartments (section 3.1.3). The "mature" and "premature" classes appeared to a larger extent in the compartment 5, which indicates on-going degeneration of the *tugai* forest in this area.

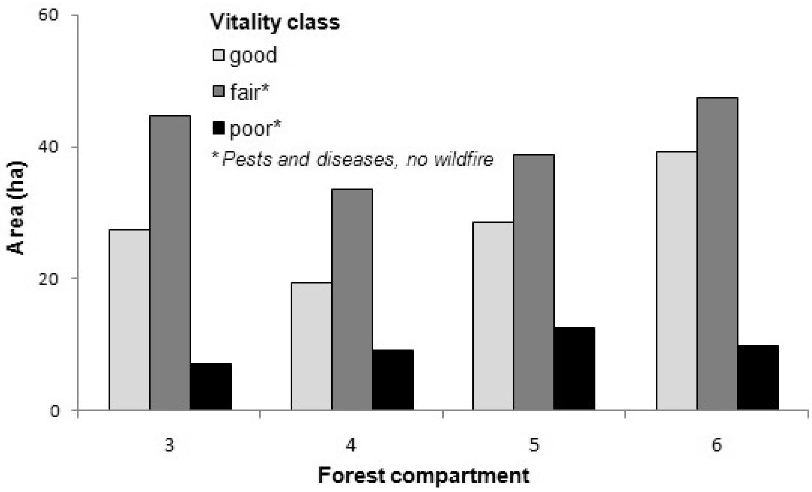

Figure 6.5: Distribution of area by vitality in *tugai* forest compartments, Khorezm

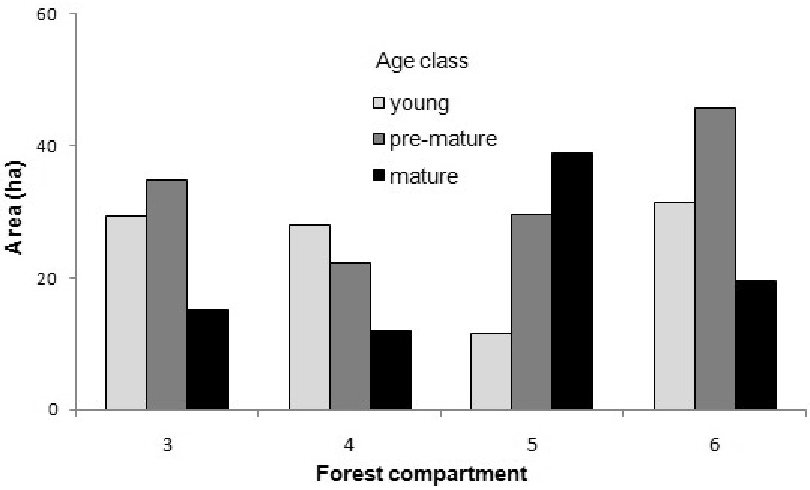

Figure 6.6: Distribution of area by age classes in *tugai* forest compartments, Khorezm

Single-species stands with *P. euphratica* and *pruinosa* dominated in all *tugai* forest compartments. Other tree species that have also been observed in *tugai* forests like *E. angustifolia* and *Salix* spp. (e.g., Treshkin, et al., 1998) were not found in the study compartments.

6.4 Discussion

Although the original datasets of the Khorezm forest inventory 1990 represent a significant share of the forest areas in this region, the forests in the desert zones have no clear forest structure in the botanical sense of the word forest. These areas are covered by single woody shrubs, e.g., *saxaul* or *qora saksovul* (*Haloxylon ammodendron* L.), *oq saksovul* (*H. persicum*), etc., and herbs such as wormwood (*Artemisia* L.) and milkvetch

(*Astragalus* L.), which do not exceed a height of 4 m and have a low stand volume of about 3 m^3 ha^{-1}, although their root systems may penetrate down to more than 6 m to reach the groundwater (Breckle, 2002; KhFI, 1990). Therefore, such forest should be classified as "other wooded land" performing ecological functions such as providing a natural protection against soil erosion and maintaining biodiversity. This classification would render the national forest statistics more realistic, and avoid potential confusion and misinterpretation, which are likely to occur when large forests are claimed in deserts. Obviously, this would then contradict the results previously reported by, e.g., Uzbekistan FRA 2005 (FAO, 2005a). Concerning the patches of *tugai* forests, these can be clearly classified as forest owing to their clear forest structure such as height of 7-10 m, higher stand density, etc. (Treshkin, 2001a; Novikova, 2001). This would also help delineating the class "other wooded land" where crown closure does not exceed 0.1.

Species distribution, vitality and age classes of *tugai* forests cannot be recognized from aerial photographs due to the subjectivity of such assessments, e.g., assessing vitality when only the upper layer of the crowns of dominant trees is visible while the lower layers and stems cannot be identified (Akça, 2000), or difficulties in delineating "young" and "mature" age classes in the unevenly aged *tugai* forests. Therefore these criteria should be assessed in the field surveys applying the appropriate method and sample size (section 3.7).

On other hand, the practical use of aerial photographs in forest mapping of boreal, tropical forests and savannas has been well developed since the early 1950s (e.g., Anuchin, 1982; Nyyssönen, 1964; Spurr, 1948). Today, GIS-based tools combined with analytical stereoscopic instruments for the transfer of forest extent from aerial photographs into GIS map formats is a standard procedure. At the same time, the presently small areas of *tugai* forests in Khorezm would require only ten stereoscopic pairs of aerial photographs, which are taken every five years for updating topographic maps. This makes this method a cheap and attractive procedure compared to the use of a single satellite image (Vakhidov, *personal communication*) or the time-consuming and labor-intensive traditional extensive field surveys as applied in the last forest inventory in 1990.

Since these aerial photographs are taken every five years (Ergeodezkadastr, 2001), they form a sound basis for studying the dynamics of the *tugai* forest areas over time. Moreover, since such photographs have also been taken in the past, this offers the opportunity to process these photographs according to the elaborated methodology and to use the information for completing the review of the *tugai* forests in entire Uzbekistan. This in turn would allow an accurate update while excluding the usual extrapolations and speculations as conducted in the past, since they were based on the inventory of very small parts of the *tugai* forests (KhFI, 1990). In addition, since such an inventory could be made for each administrative region, more targeted, site-specific recommendations could be prepared instead of the present general recommendations (KhFE, 2005).

The season of the year when the aerial photographs were taken may have affected structural forest parameters, especially as they were taken in November when deciduous trees begin to shed their leaves (Khamzina et al., 2006a). However, on the aerial photographs used, the crown shape was sufficiently visible to distinguish both "*tugai* forests" and "other wooded land" classes with their typical elements and photo-interpretation indicators (section 3.5). This confirms that the methodology elaborated could be applicable, and it should to be extended to other regions.

Basically, field verifications of the delineated polygons with "*tugai* forests" and "other wooded land" are required. Here, only simple visual observations are necessary. Verification of the area of *tugai* forests and other wooded land was, however, not needed, since the applied photogrammetry and GIS-based tools are obviously more accurate compared to field surveys as shown previously (Kleinn et al., 2005).

Tugai forest cover is less than 1% of the study area in Khorezm, which Lund (1999) defines as a low forest cover. Meantime, the estimated annual rate of forest degradation and deforestation in the studied *tugai* forest compartments during a period of 13 years (Table 6.5) is higher (3.2 and 1.3%, respectively) than, for example, the ca. 1% global annual forest loss in the tropics (FAO, 1997). The findings thus confirm the generalized results from Treshkin (2001a), Novikova (2001) and others in their surveys on *tugai* stocks in Karakalpakstan, Uzbekistan. A large area of *tugai* forests was converted to other wooded land in 1990-2002. However, this land can regenerate naturally or be restored through silvicultural measures. However, about 20% of the forests has been converted into agricultural land (Table 6.4), which cannot be reversed into *tugai* forests. Therefore, forest management plans should urgently be elaborated and implemented, while the elaborated survey and monitoring methods could be used to provide comprehensive supportive information.

The danger of infestation by diseases and insects can be higher in single-species stands such as *tugai* forests with *P. euphratica* and *pruinosa.* Although the largest part of the *tugai* forest compartments was in "fair" or "good" vitality classes, the necessity for increasing phyto-sanitarian services to avoid further spread of the infestations in "fair" and "poor" forest areas need to be applied.

Although the *tugai* forest compartments were dominated by "premature" and "young" age classes, which indicate a certain level of natural regeneration in those compartments, the recent sever water shortages 2000-2001 significantly affected the *tugai* forests (Treshkin, 2001b). Also, overgrazing, which frequently occurs in regenerated areas with young trees, may substantially reduce the regeneration process of the vulnerable *tugai* (Treshkin, et al., 1998). For example, this was observed in the forest compartment 5, where mostly "mature" and "premature" age classes occurred. In the future, due to low regeneration rates, these forest compartments can be transformed into agricultural land, e.g., flooded rice at the margins of the Amu Darya River. Therefore, control of overgrazing and illegal cutting is needed to conserve the unique *tugai* forests for future generations.

In the present case, photo interpretation of 10 photographs by one person would take about two weeks, while one additional week would be needed for field surveys. Rough calculations indicate low total costs, which include costs for a single stereoscopic pair of US$ 4, for photo interpretation and mapping of US$ 5-10 per stereoscopic pair, and US$ 30-50 for field surveys. If forest managers are in need of more information, the presently available aerial photographs with a scale of 1:20,000 would, however, be insufficient. With access to aerial photographs of a larger scale, further details could be extracted. Moreover, if these photographs are taken in summer when the trees are fully developed, extensive dendrometric data could be obtained, e.g., on species distribution, stand age and growing wood stock. In this regard, the methodology for extracting these parameters still needs to be elaborated. This demands additional photographs, but only a small number would be required to capture the relatively small areas of *tugai* forests in Khorezm or other regions in Uzbekistan.

6.5 Conclusions

As the extent of the *tugai* forests in the Khorezm region is small, these could be inventoried and mapped with the less than a dozen aerial photographs, and the photo interpretation by one person would take not more than two weeks. Field verification of the extent of the forest area was not required due to the advantages of the applied photogrammetry and GIS-based tools over field surveys. Limited field surveys were needed to collect species distribution, vitality and age classes of the *tugai* forests. The method elaborated is more attractive compared to more resource-demanding alternatives such as satellite imagery and extensive field surveys. Even though the date of the aerial photographs was not ideal, i.e., late November, the photographs portrayed sufficiently accurate information for the estimation of the forest area. Given that such photographs are taken every five years, the method offers a good basis for monitoring the dynamics of the *tugai* forest areas over time. The regional forest administration should request the aerial photographs of the past decades to update the status of the *tugai* forests on their territory and define site-specific recommendations for protecting and improving this unique ecosystem. However, with large-scale aerial photographs (<1:15,000) taken in the growing period when the trees are in full leaf, forest managers could extract more data, in particular on species composition, growing wood stock and age class. However, growing wood stock estimates would be suitable only for sanitary cutting in the *tugai*, since any industrial logging is forbidden in forests of Uzbekistan, which perform primarily ecological functions (FAO, 2006b).

The findings together with previous outputs from other regions (e.g., Treshkin, 2001a, Novikova, 2001) confirm the on-going reduction of the *tugai* forests, which are being degraded to other wooded land with sparse or single trees. Whereas these areas still can be recovered, about 20% of the *tugai* forests has been converted into agricultural land. The generated forest map indicates the areas that could be regenerated and provides sufficient information for forest managers to protect the unique *tugai* ecosystem. Finally, the presently used forest classification in Uzbekistan considers the desert forest zone as forests, whereas according to international standards it should be classified as other wooded land, since only single shrubs or woody shrubs and herbs occur here. These, however, have important ecological functions such as providing a natural protection against soil erosion as well as maintaining biodiversity.

7 GENERAL CONCLUSIONS, RECOMMENDATIONS AND OUTLOOK

This chapter presents the general conclusions and recommendations not only for forest and agricultural researchers interested in a suitable methodology for inventories of tree plantations and forests in Uzbekistan, but also for decision makers, farmers and foresters in Khorezm to support management strategies for tree plantations and floodplain (*tugai*) forests. The outlook regarding further studies completes the chapter.

7.1 Assessment methodology

7.1.1 Background and justification

A deficiency in knowledge and an inconsistency of inventory data on forests and tree plantations exist among both the forest administration and the farming population in Uzbekistan, Central Asia (CA) (e.g., FAO 2005a). The previously used inventory approaches were based on extensive field surveys of small and accessible forests such as floodplain *tugai* forests and other wooded land in *tugai* forests and deserts (KhFI, 1990). These resource-demanding inventory procedures that monitored, e.g., the size of the forest area, species composition, growing wood stock and other parameters, are however presently not possible for the forest administration. In addition, several critical parameters such as the extent and functionality of tree plantations and windbreaks in agricultural areas have never been assessed. The absence of updated and key information on multipurpose hedgerows and other tree plantations as well on *tugai* forests and other wooded land make sound decision making and proper forest management difficult. This is true for entire Uzbekistan including the study region of Khorezm, which is representative for the Amu Darya lowlands. Here, the last inventory was conducted in 1990.

Remote sensing techniques (photogrammetry and satellite imagery) combined with geographic information system (GIS)-based tools are, on the other hand, applied worldwide for inventories of forests and tree plantations. Despite a worldwide recognition, these procedures have not yet found an entry in the forest and agricultural research divisions of Uzbekistan, although aerial photographs with a scale of 1:20,000 are taken every five years by the Land and Geodesy Cadastre Center of Uzbekistan (*Ergeodezkadastr*), which undertakes aerial survey for updating topographic maps.

Hence, this study selected photogrammetry among an array of approaches used in forest and tree plantation inventories as a suitable, easy-to-use, cheap, and quick but comprehensive methodology. Following the validation of this methodology, existing tree plantations and forests in the study region Khorezm were mapped and assessed.

7.1.2 Scope and restriction of photogrammetry for forest and tree plantation inventories

The spatial extent of hedgerows/windbreaks and other tree plantations in the large agricultural fields typical for the Khorezm region could be accurately determined with a combination of existing aerial photographs and GIS-based tools. Although a large number of photographs would be required to assess the entire Khorezm region, a rough estimate suggested that photogrammetry is still cheaper than satellite imagery or conventional field surveys, in particular since aerial photographs are available. Also, owing to the small area of the *tugai* forests in the Khorezm region, these can be inventoried and mapped with less than a dozen aerial photographs, and photo interpretation would take one person about two weeks to complete. Photogrammetry is thus the most efficient and cheapest method to monitor the dynamics of these important forest areas.

Aerial photographs (scale 1:20,000) that were made available by *Ergeodezkadastr* (Ergeodezkadastr, 2001) were purposely taken in late November, since this is the most appropriate period for extracting data for updating topographic maps. During this period, the deciduous trees appeared with few or no leaves owing to the onset of leaf shedding, but an in-depth screening and verification of the results showed that trees could be identified with an acceptable accuracy, thus enabling the classification of tree plantation and forest thematic classes (Table 7.1). The mostly leafless horizontal crown projections portrayed by the aerial photographs were still effective for distinguishing, e.g., apple (*Malus* spp.) and apricot (*Prunus armeniaca* L.) orchards because of the appearance of branches and the species-specific planting schemes with large distances between trees and rows. In contrast, a further separation among these two species was not feasible with aerial photographs when both species have few or no leaves as is usual in late autumn. Similarly, tree species in the thematic classes of hedgerows/windbreaks and *tugai* forests could not be identified. Given the limitations of the aerial photographs, the photogrammetric procedures have to be complemented with field surveys to distinguish tree species accurately. Alternatively, large-scale aerial photographs (<1:15,000, Akça, 2000) taken during the summer (by default with a high resolution and quality) can bypass this constraint.

Table 7.1: Accuracy of photogrammetry and GIS-based tools for the assessment criteria in tree plantations and forests in Khorezm

Assessment criterion	Hedgerow/ windbreak	Other tree plantation	*Tugai* forests and other wooded land
Thematic class	2	2	2
Area and number	1	1	1
Species composition	3	3	3
Orientation to the prevailing winds	1	−	−
Reaching edges of related field	2	−	−
Crown closure	2	2*	2*
Mean stand height	2	−	−
Number of rows	3	−	−
Vitality (disturbance by pests, diseases)	4	4	4
Age class	4	4	4

1 = Acceptable accuracy, field verification is not needed; 2 = Acceptable accuracy, field verification is needed; 2 = Applied as additional criterion while delineating polygons of other tree plantations and tugai forests and other wooded land); 3 = Unacceptable accuracy, either large-scale aerial photographs (<1:15,000) or field surveys can be applied; 4 = Cannot be objectively assessed with photogrammetry, only field surveys can be applied; − = Not applied*

Field verification by visual assessments is needed to cross-check the data, e.g., the delineated polygons of hedgerows/windbreaks, other tree plantations and *tugai* forests (section 3.6). In contrast, field verification of the area of the delineated polygons is not required due to the proven precision of the applied photogrammetry and GIS-based tools (e.g., Zihlavnik et al., 2007). Also, hedgerow/windbreak orientation to the prevailing winds was more accurately measured (to the nearest 1°) with GIS-based tools than it could be done in the field (section 3.5.2).

Field-verified windbreak criteria such as mean stand height and crown closure were overestimated and underestimated, respectively, with 11% (Table 4.2). Although this may argue against the accuracy of photogrammetry when using 1:20,000-scale photographs, the absolute differences between the outcomes of the photogrammetry and field measurements were albeit small. For example, a 15% difference in the windbreak height class 5-10 m indicates a 1.2 m overestimation, but this hardly alters the overall assessment and classification. Windbreak crown closure was naturally underestimated with the aerial photographs due to the differences in the time of the growing season between photo-taking in November and field verification in July-August. Also, the overshadowing of the understory trees had an effect on the ocular estimation of crown closure similar to the frequent underestimations of crown closure as recorded previously (Akça, 2000). Finally, crown closure of other tree plantations and *tugai* forests was used only as an additional criterion when delineating their polygons and identifying thematic classes (sections 3.1.2-3.1.3).

Although the bird's-eye view of the aerial photographs allowed an acceptable accuracy in the assessment of whether the hedgerow/windbreak reached the edges of the related field (Table 4.1), the number of rows could not be accurately estimated with photogrammetry. This was due mainly overshadowing and clumping of the horizontal crown projections where individual rows of trees cannot be identified in the given scale of 1:20,000. Also, it was not possible to extract and count individual tree crowns or to measure their size. Those variables are needed if aerial estimations of growing wood stock are of interest (Akça, 2000; Pope, 1962). Consequently, the number of rows and growing wood stock can only be estimated by field surveys or with aerial photographs taken in summer at a scale of <1:15,000.

The criteria vitality (disturbance by pests and diseases) and age classes of tree plantations and forests could not be objectively assessed with photogrammetry. In horizontal crown projections, the lower parts (leaves, branches and stem) of dominant trees and the larger parts of intermediate and understory trees are not visible (Akça, 2000). Therefore, those parts are not available for assessments of vitality. The appearance of pollarded crowns of white mulberry (*Morus alba* L.) and willows (*Salix* spp.), and fast-growing hybrid poplars (*Populus* spp.) that does not differentiate much in shape, size and shadow in young and/or pre- and mature classes substantially limits the identification of age classes. Thus, the vitality and age classes can only be identified by field surveys. Also, if fruit and leaf yields are of interest, only field surveys can be recommended, since yield data cannot be assessed with photogrammetry.

The advantages of the elaborated methodologies substantiate the recommendations regarding establishment of a task force in the Main Forestry Department, in particular in *Uzgiprourmonloyiha* (Design and Survey Forestry Enterprise). Once the methodology is mastered and existing aerial photographs of the different regions of Uzbekistan are made available, this special unit should be mandated to conduct a nationwide inventory of forests.

7.2 Status of tree plantations and forests

Following the validation of various parameters and confirming the applicability of the available aerial photographs, the elaborated methodologies were employed to assess the functionality of hedgerows/windbreaks, other tree plantations and *tugai* forests in the study region Khorezm.

7.2.1 Hedgerows/windbreaks

The hedgerows in the landscape of Khorezm generally failed to meet the primary criteria determining windbreak functionality and thus cannot be considered as effectively functional (Table 7.2). Yet, when implementing proper design schemes and management, there is scope for improving these plantings. On the one hand, investing in a further extension of tree windbreaks is debatable, since during the winter period when winds leading to soil erosion may occur, the presently used deciduous trees are leafless and hence provide only very limited protection. Evergreen conifer species, e.g., eastern red cedar (*Juniperus virginiana* L.) and Chinese cedar (*Biota orientalis* (L.) Franco) showed low survival and growth rates under the harsh agro-environmental conditions characterized by saline soils and shallow saline groundwater tables (Khamzina et al., 2006a). On the other hand, extending windbreaks to other agricultural areas could improve microclimatic conditions during the growing season and hence could contribute not only to increasing crop yields, improving ecological services, and biodiversity conservation, but also to carbon sequestration and hence ease the effects of global warming. The extension of tree plantings is an option, in particular on degraded cropland, which could be set aside for afforestation (Khamzina et al., 2008). New plantings could become a source of useful by-products such as wood for domestic use and sale (Lamers and Khamzina, 2008), or leaves for feed when appropriate harvesting techniques are conveyed to land users. Reliable market channels need to be developed, and farmers and land users would need to be educated and trained regarding a proper maintenance of tree plantings.

Table 7.2: Functional assessment of existing hedgerows/windbreaks in Khorezm based on photogrammetry combined with GIS and field surveys

Criterion (rank/mark)	Criterion class	Result	Recommendation
Share of fields for hedge-rows/wind-breaks (P/3)	<0.5% (flooded) 1.5-2.0% (typical) >2.0% (pre-desert) 1.5-2.0% (overall)	0.4% (flooded) 1.4% (typical) 0.5% (pre-desert) 1.2% (overall)	Extension of share to reach recommended values, except flooded class
Species composition (P/3)	Single- and multi-species corresponding to reduced and extended functionality	Only single-species, dominated by *M. alba*, *Salix* and *Populus* spp. ca. 46, 22 and 20%, respectively	Diversification of species in hedgerows/ windbreaks (row of shrubs, medium-height row and tall row)
Orientation to prevailing wind direction (P/2)	>±45°, ±31-45° and ±1-30° of perpendicular (90°) to prevailing wind direction for low, fair and optimal shelter efficiency, respectively	Ca. 70 and 10% of hedgerows/windbreaks were oriented or nearly oriented to the prevailing NE and W winds in south Khorezm	Reorientation of ca. 20% of hedgerows/ windbreaks in SE+NW and N+S to intercept problem winds, especially in south Khorezm
Mean stand height (P/3)	<5 m, 5-10 m and >10 m for little, fair and optimal extent of shelter, respectively	Ca. 70% of hedgerows/windbreaks had critical height, including the heavily pollarded *M. alba* (sericulture) and *Salix* spp. (basketry)	Improvement of harvest techniques for hedgerows/windbreaks, e.g., every fourth tree (25% harvest) or every tree in interior row (50% harvest)
Reaching edges of related field (P/3)	Reaching or not reaching edges of related field for optimal or reduced extent of shelter, respectively	Almost 50% of hedgerows/windbreaks did not reach edges of related agricultural fields	Tree planting to reach edges of agricultural fields for ca. 50% of hedgerows/windbreaks
Crown closure (S/2)	Coefficient of <0.4, 0.4-0.6 and >0.6 for low, fair and optimal shelter efficiency, respectively	Ca. 60 and 30% of hedgerows/windbreaks had fair and optimal shelter efficiency, respectively	Tree planting to improve crown closure for ca. 10% of hedgerows/windbreaks
Number of rows (S/2)	Single-, double- and multiple-rows for reduced, fair and extended longevity of shelter, respectively	Ca. 65 and 5% of hedgerows/windbreaks had double- and multiple-row structure, respectively	Planting of additional row(s) for ca. 30% of hedgerows/windbreaks
Vitality (disturbance by pests and diseases) (S/2)	Dominance of healthy, lightly and severely affected trees for good, fair and poor vitality, respectively	Ca. 70 and 20% of hedgerows/windbreaks corresponded to good and fair vitality, respectively	Pest and disease control for ca. 30% of hedgerows/windbreaks

Table 7.2: (cont.)

Criterion (rank/mark)	Criterion class	Result	Recommendation
Age class (S/3)	Young and mature age classes for reduced efficiency of shelter; premature class is optimum	74 and 4% of hedgerows/windbreaks corresponded to young and mature age classes, respectively	Replanting of 4% of hedgerows/windbreaks of mature age

Criterion ranks: P = Primary windbreak criterion and S = Secondary windbreak criterion; Criterion marks: 1 = "good", 2 = "fair" and 3 = "poor"

7.2.2 Other tree plantations

In contrast to the windbreak plantings, the general occurrence of other tree plantations was mostly satisfactory (Table 7.3).

Table 7.3: Functional assessment of other tree plantations in Khorezm based on photogrammetry combined with GIS and field surveys

Criterion (mark)	Criterion class	Result	Recommendation
Share of other tree plantations within total area (2)	Other tree plantations including apple (*Malus* spp.), apricot (*Prunus armeniaca* L.), grape (*Vitis* L.), white mulberry (*M. alba*) and hybrid poplars (*Populus* spp.)	Total 1.2%, including 0.9% of fruit orchards (comprising 0.6, 0.3 and <0.1% of *Malus* spp., *P. armeniaca* and other fruit species, respectively), 0.1% of *Vitis* L., 0.2% of *M. alba* and <0.1 % of *Populus* spp.	Extension of other tree plantations, especially on marginal agricultural lands
Vitality (disturbance by pests and diseases) (2)	Dominance of healthy, lightly and severely affected trees for good, fair and poor vitality, respectively	Ca. 60 and 30% of area of other tree plantations appeared in good and fair vitality classes, respectively	Pest and disease control for ca. 40% of the area
Age class (2)	Young and mature age classes of *Malus* spp., *P. armeniaca*, *Vitis* L. and *M. alba* corresponding to reduced yields, optimum is premature class; young and pre-mature *Populus* spp. for reduced production, and optimum is mature class	Ca. 80 and 5% of area of other tree plantations in young and mature age classes, respectively	Replanting of ca. 5% of area of other tree plantations of mature age

Criterion marks: 1 = "good", 2 = "fair" and 3 = "poor"

Based on the growing interest of farmers and the declared policy of the national administration to re-vitalize fruit production and to encourage the production of wood and leaves for sericulture, photogrammetry offers opportunities to monitor the impact of such national policies. In this case, it seems worthwhile to invest in the elaboration of ideal aerial photographs with a scale of <1:15,000, instead of the available 1:20,000, preferably taken during the growing season, to determine in one go but accurately the different tree species, and to estimate growing stock for wood production. For monitoring fruit and leaf yields, field surveys, on the other hand, are necessary. In line with the encouragement of fruit, wood and leaf production, there is a growing need for knowledge of the farmers on protection of trees from pests and diseases and an increased access to phyto-sanitarian services, as well as to storage, processing and marketing facilities. This undeniably would stimulate the extension of such plantations in the Khorezm region.

7.2.3 *Tugai* forests and other wooded land

The assessment of the remaining *tugai* forests confirmed the recurrently described grim picture of a disappearing unique eco-system (Table 7.4).

The findings together with previous outputs from other regions in CA (e.g., Treshkin, 2001a) confirm both the on-going reduction in size of the *tugai* forests and the degradation of dense *tugai* forests to the status of other wooded land with sparse or single trees. Since many speculations exist about the rate of disappearance of the *tugai* forests (e.g., Novikova, 2001), the use of photogrammetry could clarify this with a high accuracy and hence could contribute to targeted and more site-specific interventions, and replace the present blanket recommendations. From the findings it can be concluded that some forest areas still could be recovered, but already about 20% of *tugai* forests has been lost or converted to agricultural land, in particular to flooded rice fields. The generated forest maps indicate those areas that could be regenerated, and provide sufficient information to protect these patches of the unique ecosystem. Nonetheless, for the implementation of any recommendations to safeguard the natural forests, an increased political will and enabling environment will be conducive. Since the reasons for the on-going degradation are mainly anthropogenic, safeguarding can only be reached in close collaboration with the farming community. Even with a closer involvement of the rural population it still will be difficult to reverse the degradation, and without its support it deems virtually impossible. Finally, the presently used forest classification in Uzbekistan considers the desert forest zone as "forests", whereas according to international standards it should be classified as "other wooded land", since only single shrubs or woody shrubs and herbs occur, which, however, have valuable ecological functions such as providing a natural protection against soil erosion and maintaining biodiversity.

Table 7.4: Functional assessment of *tugai* forests in Khorezm based on photogrammetry combined with GIS and field surveys

Criterion (mark)	Criterion class	Result	Recommendation
Tugai forest cover within total area (3)	Forest and other wooded land of <10 or >10% for low or high forest cover, respectively	Extremely low, ca. 0.6%, including ca. 0.3% of forest and 0.3% of other wooded land	Protection and conservation of *tugai* forests
Changes in forest area of *tugai* (3)	Reducing forest area (forest degradation and deforestation) and stable or increasing forest area (optimal forest condition)	*Tugai* forests reduced by ca. 60% in 1990-2003, of which ca. 40% could be reversed into forests such as other wooded land (annual forest degradation of 3%) and ca. 20% converted to agricultural land (annual deforestation of 1.5%)	Improvement of forest management by promoting natural regeneration and forest plantings, reducing overgrazing and illegal cutting, and increasing pest and disease control
Species distribution (3)	Single- or multi-species forest stands corresponding to reduced or extended vitality and longevity	*Tugai* forests dominated by single species *P. euphratica* and *pruinosa*	Promoting forest plantings, e.g., with *E. angustifolia* and *Salix* spp., naturally occurring in *tugai* forests
Vitality (disturbance by pests and diseases) (2)	Dominance of healthy, lightly and severely affected trees for good, fair and poor vitality, respectively	Ca. 50 and 35% of area of *tugai* forests appeared in fair and good vitality classes, respectively	Pest and disease control for ca. 65% of area of *tugai* forests
Age class (2)	Young, pre-mature and mature age classes corresponding to regeneration, optimal age and degeneration, respectively	Ca. 40 and 30% of area of *tugai* forests revealed in premature and young age classes, respectively	Promotion of natural regeneration and forest plantings for 30% of area occupied by mature trees, as well prevention of overgrazing for ca. 30% area with young trees

Criterion marks: 1 = "good", 2 = "fair" and 3 = "poor"

7.3 Outlook

Uzbekistan has declared its commitment to increase tree plantings for an improved exploitation of the potential ecological service function of this perennial type of vegetation. But despite this general declaration, little is known about the present tree stock in the country. With the methodology applied in this study, this gap could be closed, at least regarding the inventory of forests and tree plantations in the lowlands, while for some other species, e.g., Siberian elm (*Ulmus pumila* L.), swamp ash (*Fraxinus pennsylvanica* Marshall) etc., photographic indicators should be developed. In case the mountain areas are to be included, the methodology elaborated should be extended. In addition, promising species need to be selected, e.g., for windbreak design, but their suitability regarding tolerance to wood harvesting and coppicing for the production of annually recurring non-timber products (e.g., leaves) under different pruning intensity needs to be identified.

In several cases it was concluded that the scale of the presently available aerial photographs limits an accurate extraction of various dendrometric data such as identifying tree species, counting individual tree crowns or measuring their size, etc. In case larger-scale aerial photographs (<1:15,000) taken in the growing season would become available, some components of the developed methodologies should be extended and validated following limited but necessary field studies.

The year 2008 showed soaring food and energy prices owing primarily to the intensified bio-fuel programs, which have led to a general conversion of land from food crop to fuel crop cultivation. In particular, the marginal agricultural lands with permanently failing yields scattered over the study region Khorezm are potentially available for alternative uses such as the production of renewable energy. Yet, since not all areas are suitable for afforestation owing to bio-physical conditions impacting tree growth, and hence their benefits, it is necessary to study the spatial suitability of land for afforestation to benefit the livelihoods of the people and improve the environment.

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9 APPENDICES

Appendix 9.1: FRA 2005 Terms and Definitions (FAO, 2005a; FAO 2005b)

Forest extent

Category	Definition
Forest	Land spanning more than 0.5 ha with trees higher than 5 m and a canopy cover of more than 10%, or trees able to reach these thresholds in *situ*. **It does not include land that is predominantly under agricultural or urban land use.** Explanatory notes: 1. Forest is determined both by the presence of trees and the absence of other predominant land uses. The trees should be able to reach a minimum height of 5 m in *situ*. Areas under reforestation that have not yet reached but are expected to reach a canopy cover of 10% and a tree height of 5 m are included, as are temporarily unstocked areas, resulting from human intervention or natural causes, which are expected to regenerate. 2. Includes forest roads, firebreaks and other small open areas; forest in national parks, nature reserves and other protected areas such as those of specific scientific, historical, cultural or spiritual interest. 3. Includes windbreaks, shelterbelts and corridors of trees with an area of more than 0.5 ha and width of more than 20 m. 4. Includes plantations primarily used for forestry or protection purposes, such as rubber wood plantations and cork oak stands. 5. Excludes tree stands in agricultural production systems, for example in fruit plantations and agroforestry systems. The term also excludes trees in urban parks and gardens.
Other wooded land	Land not classified as “Forest”, spanning more than 0.5 ha; with trees higher than 5 m and a canopy cover of 5-10%, or trees able to reach these thresholds in *situ*; or with a combined cover of shrubs, bushes and trees above 10%. **It does not include land that is predominantly under agricultural or urban land use.**
Other land	All land that is not classified as “Forest” or “Other wooded land”.
Other land with tree cover (Subordinated to “Other land”)	Land classified as “Other land”, spanning more than 0.5 ha with a canopy cover of more than 10 % of trees able to reach a height of 5 m at maturity. Explanatory notes: 1. Includes groups of trees and scattered trees in agricultural landscapes, parks, gardens and around buildings, provided that the area, height and canopy cover criteria are met. 2. Includes tree plantations established mainly for other purposes than wood, such as fruit orchards.
Inland water bodies	Inland water bodies generally include major rivers, lakes and water reservoirs.

Appendix 9.1: (cont.)

Disturbances affecting forest health and vitality

Category	Definition
Disturbance by fire	Disturbance caused by wildfire, regardless of whether it broke out inside or outside the Forest/Other wooded land. Explanatory note: A wildfire is any unplanned and uncontrolled wildland fire which, regardless of ignition source, may require suppression response.
Disturbance by diseases	Disturbance caused by diseases attributable to pathogens, such as a bacteria, fungi, phytoplasma or virus.
Disturbance by insects	Disturbance caused by insect pests that are detrimental to tree health.
Other disturbance	Disturbance caused by factors other than fire, insects or diseases. Explanatory note: May includes areas affected by windfalls, acid rain, etc.

Appendix 9.2: Local wind speed and direction

Wind speeds in Yangibazar *Uchkhoz* (north)*

Month	Frequency	Calm**		Threshold wind***		Strong wind****	
		Frequency	%	Frequency	%	Frequency	%
Leafless season 2003							
January	1488	1457	97.9	31	2.1	–	–
February	875	795	90.9	80	9.1	–	–
March	1488	1191	80.0	253	17.0	44	3.0
November	1440	1317	91.5	116	8.1	7	0.5
December	1488	1436	96.5	52	3.5	–	–
Total	6779	6196	91.4	532	7.8	51	0.8
Vegetation season 2003							
April	1405	1065	75.8	314	22.3	26	1.9
May	1488	1361	91.5	117	7.9	10	0.7
June	1440	1337	92.8	94	6.5	9	0.6
July	1485	1428	96.2	55	3.7	2	0.1
August	1488	1481	99.5	7	0.5	–	–
September	1440	1427	99.1	13	0.9	–	–
October	1440	1414	98.2	26	1.8	–	–
Total	10,186	9513	93.4	626	6.1	47	0.5
Annual	16,965	15,709	92.6	1158	6.8	98	0.6
Leafless season 2004							
January	1488	1391	93.5	97	6.5	–	–
February	1392	1162	83.5	196	14.1	34	2.4
March	1459	1333	91.4	126	8.6	–	–
November	1440	1360	94.4	74	5.1	6	0.4
December	1488	1410	94.8	76	5.1	2	0.1
Total	7267	6656	91.6	569	7.8	42	0.6
Vegetation season 2004							
April	1440	1258	87.4	182	12.6	–	–
May	1488	1378	92.6	108	7.3	2	0.1
June	1421	1383	97.3	38	2.7	–	–
July	1488	1467	98.6	21	1.4	–	–
August	1488	1473	99.0	15	1.0	–	–
September	1441	1424	98.8	17	1.2	–	–
October	1488	1460	98.1	27	1.8	1	0.1
Total	10,254	9843	96.0	408	4.0	3	–
Annual	17,521	16,499	94.2	977	5.6	45	0.3

** Figure 3.10; ** Calms and winds of <3 m s^{-1}; *** Winds of 3-6 m s^{-1} which are capable of inducing soil erosion in the region (Molchanova et al., 1986); **** Winds of >6 m s^{-1}*

Although the share of threshold and strong winds did not exceed 10%, these may occur both in the vegetation and leafless seasons in the northern part of Khorezm. A high frequency of problem winds was registered in February-May 2003-2004.

Appendix 9.2: (cont.)

Wind speeds in Khiva *Uchkhoz* (south)*

Month	Frequency	Calm**		Threshold wind***		Strong wind****	
		Frequency	%	Frequency	%	Frequency	%
Leafless season 2003							
January	1488	1369	92.0	115	7.7	4	0.3
February	1294	1031	79.7	256	19.8	7	0.5
March	1488	1173	78.8	293	19.7	22	1.5
November	995	792	79.6	183	18.4	20	2.0
December	1488	1271	85.4	211	14.2	6	0.4
Total	6753	5636	83.5	1058	15.7	59	0.9
Vegetation season 2003							
April	1440	1007	69.9	369	25.6	64	4.4
May	1487	1268	85.3	213	14.3	6	0.4
June	1440	1207	83.8	229	15.9	4	0.3
July	1487	1129	75.9	349	23.5	9	0.6
August	1488	1411	94.8	77	5.2	–	–
September	1440	1315	91.3	125	8.7	–	–
October	1487	1378	92.7	107	7.2	2	0.1
Total	10,269	8715	84.9	1469	14.3	85	0.8
Annual	17,022	14,351	84.3	2527	14.8	144	0.8
Leafless season 2004							
January	1488	1231	82.7	244	16.4	13	0.9
February	1392	983	70.6	342	24.6	67	4.8
March	1530	1151	75.2	365	23.9	14	0.9
November	1437	1286	89.5	142	9.9	9	0.6
December	1488	1231	82.7	252	16.9	5	0.3
Total	7335	5882	80.2	1345	18.3	108	1.5
Vegetation season 2004							
April	1440	1028	71.4	410	28.5	2	0.1
May	1446	1011	69.9	424	29.3	11	0.8
June	1440	1135	78.8	300	20.8	5	0.3
July	1489	1153	77.4	327	22.0	9	0.6
August	1488	1229	82.6	259	17.4	–	–
September	1440	1301	90.3	139	9.7	–	–
October	1488	1349	90.7	139	9.3	–	–
Total	10,231	8206	80.2	1998	19.5	27	0.3
Annual	17,566	14,088	80.2	3343	19.0	135	0.8

** Figure 3.10; ** Calms and winds of <3 m s^{-1}; *** Winds of 3-6 m s^{-1} which are capable of inducing soil erosion in the region (Molchanova et al., 1986); **** Winds of >6 m s^{-1}*

The share of threshold and strong winds in the south of Khorezm was higher (ca. 20%) than in the north. They may occur both in the vegetation and leafless seasons. A high frequency of problem winds was registered in February-July 2003-2004.

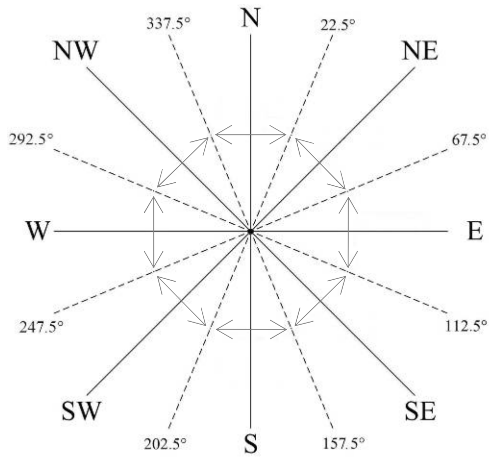
Appendix 9.2: (cont.)

Mean and maximum wind speeds (m s^{-1})

Month	Yangibazar *Uckhoz* (north)*		Khiva *Uchkhoz* (south)*	
	2003	2004	2003	2004
January	0.6 (4.1)**	1.1 (4.1)	1.0 (7.2)	1.5 (8.2)
February	1.1 (5.1)	1.5 (8.7)	1.6 (7.2)	2.0 (12.9)
March	1.9 (9.3)	1.1 (5.7)	1.5 (8.2)	1.6 (8.2)
April	1.8 (9.3)	1.2 (5.7)	2.0 (8.7)	1.7 (6.2)
May	1.1 (8.2)	1.1 (6.2)	1.2 (7.2)	1.8 (7.2)
June	0.9 (8.2)	0.7 (4.6)	1.2 (6.2)	1.5 (6.2)
July	0.6 (7.7)	0.6 (4.1)	1.6 (7.2)	1.5 (8.2)
August	0.4 (3.1)	0.6 (4.1)	1.6 (8.0)	1.5 (5.1)
September	0.6 (3.6)	0.4 (4.6)	0.9 (4.1)	0.9 (4.1)
October	0.6 (5.1)	0.5 (6.2)	0.8 (6.2)	0.7 (5.1)
November	0.9 (9.8)	0.7 (7.7)	1.4 (9.8)	0.9 (8.7)
December	0.8 (4.1)	0.9 (8.7)	1.3 (7.2)	1.5 (6.2)
Annual	0.9 (6.2)	0.9 (5.9)	1.3 (7.3)	1.4 (7.2)

** Figure 3.10; ** Between brackets maximum wind speed*

The mean and maximum annual wind speeds in the south of Khorezm were higher than in the north. The mean wind speed was <2 m s^{-1} in both Khiva and Yangibazar in 2003-2004. Yet, threshold winds of 3-6 m s^{-1} (Molchanova et al. 1986) and even >6 m s^{-1} were registered in different months. Available long-term wind speed data from 1990-2000 (Glavgidromet, 2003) indicate the same range and seasonal variations of wind speed as measured in 2003-2004.



Wind directions in degrees, e.g., NE direction corresponds to 22.6-67.5°

Appendix 9.2: (cont.)

Wind directions in Yangibazar *Uchkhoz* (north)*

Month	Frequency of threshold and strong wind direction								
	N	NE	E	SE	S	SW	W	NW	Total
Leafless season 2003									
January	–	10	–	3	7	3	7	–	31
February	–	5	–	12	36	16	11	–	80
March	–	9	45	79	64	45	56	–	297
November	14	9	32	20	9	4	14	20	123
December	–	1	–	1	43	6	–	–	52
Total	14	34	77	115	159	74	88	20	581
Vegetation season 2003									
April	1	13	84	115	84	34	7	1	340
May	16	34	6	9	16	13	21	10	127
June	29	36	6	1	6	7	9	10	103
July	21	26	5	2	5	–	–	–	57
August	–	7	–	–	–	–	–	–	7
September	–	9	3	1	–	–	–	–	13
October	1	6	3	7	1	4	1	1	26
Total	68	131	107	135	112	58	38	22	671
Annual	82	165	184	250	271	132	126	42	1252
Leafless season 2004									
January	–	–	36	61	–	–	–	–	97
February	–	14	14	56	28	49	70	–	230
March	–	25	18	3	4	42	34	–	126
November	11	9	6	4	11	7	17	14	80
December	8	2	5	15	20	2	9	20	78
Total	19	50	79	139	63	100	130	34	614
Vegetation season 2004									
April	–	84	33	17	42	–	6	–	182
May	–	54	13	1	31	7	3	–	110
June	1	37	–	–	–	–	–	–	38
July	–	15	2	–	–	3	2	–	21
August	–	15	–	–	–	–	–	–	15
September	3	7	4	3	–	–	–	–	17
October	3	6	6	–	7	3	1	1	28
Total	7	218	58	21	80	13	12	1	410
Annual	26	268	137	160	143	113	142	35	1024

* *Figure 3.10*

Wind directions were different by month, season and year, e.g., April and May 2003, February and July 2003, April 2003 and April 2004.

Appendix 9.2: (cont.)

Due to the seasonal difference of wind directions, the frequency of each direction for 2-year observations was calculated.

Frequency of wind direction in Yangibazar *Uchkhoz* (north)* in 2003-2004

Wind direction	Frequency
NE	433
S	414
SE	410
E	321
W	268
SW	245
N	108
NW	77
Total	2276

** Figure 3.10*

Opposite wind directions can be joined in one group, e.g., N and S, since windbreaks of EW orientation would be suitable for both winds coming from north and south, etc.

Prevailing wind direction and class mark* of windbreak orientation in Yangibazar (north)** in 2003-2004

Wind			Windbreak perpendicular (90°) to wind			
Direction	Degree	Frequency	Orientation	Degree	Class*	Class mark*
NE+SW	22.6-67.5° and 202.6-247.5°	678	SE+NW	112.6-157.5° and 292.6-337.5°	>±45° ±31-45° ±1-30°	Poor Fair Good
E+W	67.6-112.5° and 247.6-292.5°	589	N+S	1-22.5°, 337.6-360° and 157.6-202.5°	>±45° ±31-45° ±1-30°	Poor Fair Good
N+S	1-22.5°, 337.6-360° and 157.6-202.5°	522	E+W	67.6-112.5° and 247.6-292.5°	>±45° ±31-45° ±1-30°	Poor Fair Good
SE+NW	112.6-157.5° and 292.6-337.5°	487	NE+SW	22.6-67.5° and 202.6-247.5°	>±45° ±31-45° ±1-30°	Poor Fair Good
Total		2276				

** Table 3.2; ** Figure 3.10*

Since frequency of prevailing wind directions was more or less equally distributed, any windbreak orientation in the northern part of Khorezm would be suitable.

Appendix 9.2: (cont.)

Wind directions in Khiva *Uchkhoz* (south)*

Month	Frequency of threshold and strong wind direction								
	N	NE	E	SE	S	SW	W	NW	Total
Leafless season 2003									
January	12	18	27	19	7	–	16	19	119
February	35	35	44	47	4	4	41	53	263
March	–	101	56	13	30	86	28	–	315
November	65	3	13	23	35	30	30	5	203
December	12	71	46	4	28	36	19	–	217
Total	124	228	186	106	104	156	134	77	1115
Vegetation season 2003									
April	–	237	79	43	14	50	9	–	433
May	–	48	4	34	34	49	49	–	219
June	–	55	9	–	29	43	98	–	233
July	52	89	7	15	22	37	119	16	358
August	–	4	–	–	6	7	59	–	77
September	6	50	3	3	3	7	53	–	125
October	1	40	10	15	9	22	10	–	109
Total	59	523	112	110	117	215	397	16	1549
Annual	183	751	298	216	221	371	531	93	2664
Leafless season 2004									
January	111	89	7	–	7	7	10	24	257
February	88	81	19	49	110	49	6	8	409
March	31	92	52	61	31	38	67	8	379
November	–	12	35	23	20	32	29	1	151
December	18	67	52	18	33	31	30	9	257
Total	248	341	165	151	201	157	142	50	1455
Vegetation season 2004									
April	–	151	72	14	13	63	98	–	412
May	36	195	26	–	25	55	98	–	435
June	9	82	29	14	29	35	108	–	305
July	27	9	–	7	7	22	211	52	336
August	13	57	39	48	39	7	57	–	259
September	4	36	11	9	3	6	70	–	139
October	3	21	34	16	7	12	45	–	139
Total	92	551	211	108	123	200	687	52	2024
Annual	340	892	376	259	324	357	829	102	3479

* *Figure 3.10*

Dominant NE and W wind directions by month, season and year were identified. Other wind directions were also observed.

Appendix 9.2: (cont.)

Since other than the dominant NE and W wind directions were observed, the frequency of each direction for 2-year observations was calculated.

Frequency of wind direction in Khiva *Uchkhoz* (south)* in 2003-2004

Wind direction	Frequency
NE	1643
W	1360
SW	728
E	674
S	545
N	523
SE	475
NW	195
Total	6143

** Figure 3.10*

Opposite wind directions can be joined in one group, e.g., N and S, since windbreaks of EW orientation would be suitable for both winds coming from north and south, etc.

Prevailing wind direction and class mark* of windbreak orientation in Khiva (south)** in 2003-2004

Wind			Windbreak perpendicular (90°) to wind			
Direction	Degree	Frequency	Orientation	Degree	Class*	Class mark*
NE+SW	22.6-67.5° and 202.6-247.5°	2371	SE+NW	112.6-157.5° and 292.6-337.5°	>±45° ±31-45° ±1-30°	Poor Fair Good
E+W	67.6-112.5° and 247.6-292.5°	2034	N+S	1-22.5°, 337.6-360° and 157.6-202.5°	>±45° ±31-45° ±1-30°	Poor Fair Good
N+S	1-22.5°, 337.6-360° and 157.6-202.5°	1068	E+W	67.6-112.5° and 247.6-292.5°	>±45° ±31-45° ±1-30°	Poor Fair Good
SE+NW	112.6-157.5° and 292.6-337.5°	670	NE+SW	22.6-67.5° and 202.6-247.5°	>±45° ±31-45° ±1-30°	Poor Fair Good
Total		6143				

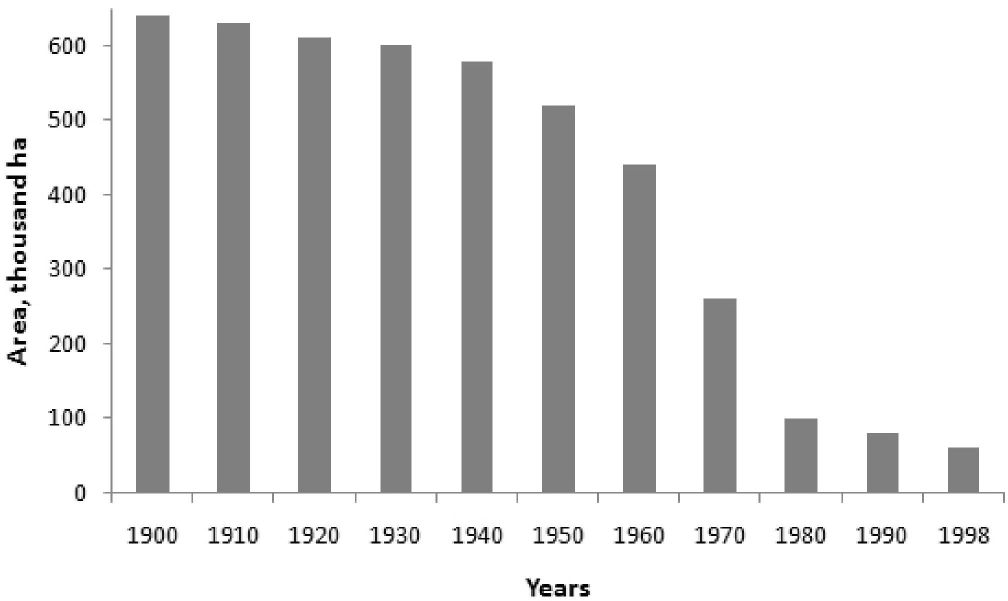
** Table 3.2; ** Figure 3.10*

SE+NW and N+S would be the most suitable windbreak orientations in the southern part of Khorezm.

Appendix 9.3: Extent of *tugai* forests

Extent of *tugai* forests in Central Asia and neighboring regions (Treshkin et al., 1998)

Habitat region	Total forest area (1000 ha)
Lower reach and delta of the Amu Darya River (Uzbekistan)	33.0
Middle reach of the Amu Darya River (Uzbekistan and Turkmenistan)	30.0
Valley of the Vaksh River (Tadjikistan)	35.0
Delta of the rivers Murgab and Tedjen (Turkmenistan)	5.3
Delta of the Syr Darya River (Uzbekistan and Kazakhstan)	4.5
Basin of the Atrek River with tributaries Sumbar and Chandir (Turkmenistan and Iran)	3.1
Valley of the Zeravshan River (Uzbekistan)	3.0
Valley of the rivers Chu and Ili (Kyrgyzstan)	2.6
Delta of the Tarim River (China)	2.5
Gobi Desert (Mongolia)	0.5
Total	119.5



Reduction of *tugai* forests along the Amu Darya River in 1900-1998 (Treshkin, 2001a)

Appendix 9.4: Reclassification of national classes of forest extent used in the Khorezm forest inventory 1990 (KhFI, 1990) into FRA 2005 categories (FAO, 2005a)

The total area of forest lands (also called "the forest reserve lands" or "the state forest fund") is the total area of all types of land and water in charge of the forest service or under its control. It consists of (a) the forest land, which is the main part of the forest reserve area, and (b) the non-forest land (Table 1). The total area of the forest reserve land, as far is known, reflects the land classification, which is based on state land ownership in the former USSR.

The "non-forest land" consists of lands which, though under the control of the state forest service, are not intended for or are unsuitable for the growing of forests. These include areas of different non-forest and non-exploited lands (water bodies, agriculture lands, sands, swamps, ravines, etc.), which are shown in the table as two general subclasses, "water bodies" and "other lands".

The "forest land" is the area of lands actually covered by forests and intended for forest growing. This likewise consists of two main parts: the "closed forest area including forest plantations" and "treeless area" (Table 1). The latter include lands suitable for the growing of forest but not presently covered by forest, e.g., areas under dead stands, waste lands, clearings and sparse forest with single trees or areas with a canopy cover of less than 30% (Zagreev et al., 1992). "Open forest plantations" and "forest nurseries" are presented as separate classes of the "forest land" (Table 1).

National data have been incorporated into the latest international classification by the Forest Resources Assessment developed in 2005 (FRA 2005), in order to provide information that is relevant for many other forest-related international processes like biodiversity conservation, productive and protective functions of forest resources, etc. Table 1 and Appendix 9.1 present both national and international classifications and their definitions for the extent of forests. Table 2 shows a comparison of the national and FRA 2005 classifications for the extent of forest and their reclassified data.

Appendix 9.4: (cont.)

Table 1: Extent of forests by national classification

Class	Definition
Forest land	
Closed forest, including forest plantation	Forest including plantations planted for forest restoration with closed crowns, sufficient annual growth and regular arrangement of the main species.
Open forest plantation	Young trees planted for forest restoration with still open crowns.
Forest nursery	Land assigned for growing of plantings in selected areas not in the forests. Seedlings are grown on these lands before they will be replanted in forest, usually 1-3 years depending on species.
Sparse forest stand	Single trees and trees combined with bushes, not corresponding to standards, crowns without required density and closing of crowns, insufficient annual growth and irregular arrangement of the main species.
Not covered by forest	Sites of forest fires and dead trees, clearings, waste lands not covered by trees and bushes.
Non-forest land	
Water body	Canals, drainages, lakes and water reservoirs.
Garden	Land assigned for gardens and vineyards.
Other land	Land assigned for arable crops, grasslands and pastures, and non-exploited lands like sands, swamps, etc.

Table 2: Comparisons of the national and FRA 2005 classifications for the extent of forests

National class	FRA class				
	Forest	Other wooded land	Other land	Other land with tree cover	Inland water body
Closed forest, including forest plantation	X				
Open forest plantation		X			
Forest nursery	X				
Sparse forest stand		X			
Not covered by forest			X		
Water body					X
Garden				X	
Other land			X		

ACKNOWLEDGEMENTS

The research was conducted in the framework of German/Uzbek project "Economic and ecological restructuring of land- and water use in the Region Khorezm (Uzbekistan): A pilot project in development research". The German Ministry for Education and Research (BMBF; project number 0339970A), and the Ministry for Schools, Science and Research of the State of Northrhine-Westfalia financially supported this study.

I am very grateful to Prof. Paul L.G. Vlek, for giving me an opportunity to perform this study with ZEF and the German-Uzbek Project. My sincere thanks are to Dr. Christopher Martius and Dr. John P.A. Lamers for their dedicated work, guidance and support during all stages of this work. I'm very thankful to Dr. Martin Worbes for his valuable advice on forestry as well as for his help in organizing of the photogrammetric process for this study in *Altmann & Möllenkamp GbR*, Holzerode, Goettingen. I would like to express my gratitude to Dr. Evgeniy Botman who shared ideas and advise on local tree windbreaks and for his assistance during the field stage of the study.

I would like to thank my field team, in particular Gairat and Shuhrat Yakubov for data collection in long drives throughout Khorezm. I enjoyed the collaboration with my colleague and friend Dr. Asia Khamzina. I'm grateful to Mr. Spartak Vakhidov from *Ergeodezkadastr* for providing this study with a set of aerial photographs and Mr. Erkinbay Bobojanov from the Khorezm Forestry Enterprise for the access to the data on the Khorezm forest inventory 1990. I'm also grateful to Prof. Ruzimbay Eschanov from the Urgench State University and the project office managers Mrs. Liliana Sin in Urgench and Natalia Shermetova in Tashkent as well as the Khorezm project team for their logistic and networking support.

Many thanks for the kind assistance of ZEF team in Bonn, Dr. Günther Manske, Dr. Ahmad Manschadi, Mrs. Rosemarie Zabel, Sandra Staudenrausch and many others. And I would like to express my thanks and appreciation to my friends and colleagues Dr. Nodir Djanibekov, Dr. Akmal Akramkhanov, Dr. Hayot Ibrakhimov, Dr. Irina Forkutsa, Dr. Inna Rudenko, Dr. Kirsten Kienzler, Dr. Marc Müller, Dr. Susanne Herbst, Dr. Darya Zavgorodnyaya, Dr. Mehriddin Tursunov, Dilfuza Djumaeva, Oksana Forkutsa, Elena Kan, Dr. Gerd Rücker, Dr. Christopher Conrad and many others for the wonderful time in Urgench and Bonn.