Summary

Nature in the Netherlands is threatened by increasing fragmentation, desiccation, acidification and disturbance. Proactive nature management is therefore desired to safeguard the natural richness. A relevant question in nature management is where and how abundant plant species occur in a certain area. It is also desirable to species response to potential changes in their environment. For example, a higher air temperature as a result of global warming, a dryer soil resulting from groundwater extraction or attenuation of nutrient richness as a result of grazing.

To answer such questions, KWR Watercycle Research Institute (Nieuwegein, the Netherlands) developed the PROBE model. PROBE calculates the probability that a plant species (or a combination thereof) will be present given a certain combination of soil and vegetation characteristics. For example, given a dry, acidic, sandy soil, PROBE will indicate that heather vegetation with Calluna vulgaris (common heather) is very likely to occur, while Salicornia (glasswort) vegetation very much is not. Likewise, PROBE states that vegetation with nitrogen and chlorophyll rich leaves is more likely to consist of Urtica doica (common nettle) than of Drosera intermedia (sundew).

PROBE’s results are based on the soil and vegetation characteristics that are observed in an area. PROBE input is then an estimate of the spatial variation in the value of these soil and vegetation characteristics. This information is however not readily available and has to be deduced from sources that relate merely indirectly to the desired information. To illustrate, a standard soil map is indicative for the soil acidity (pH) at best, is not an accurate estimator. It is of course possible to measure the desired characteristics in the field, using for example an observation well for groundwater table estimates, or laboratory analysis of a leaf sample to determine leaf nitrogen. Such measurements are however valid only for a small spatial extent at a certain moment in time and therefore hardly representative for the true spatial variation of the characteristics. In all, obtaining suitable input data for the PROBE model is among the challenges for using this model.

This thesis presents remote sensing (RS) as an alternative method to obtain information on the spatial variation in soil and vegetation characteristics. RS refers to observing the earth surface from an elevated position. More specifically, a sensor in a satellite or airplane registers the intensity of the solar radiation reflected by the earth surface. The sun emits various types of radiation and the human eye is sensitive to only one of these: visible light. We refer to this as the visible spectrum (VIS) of sunlight. The human eye is insensitive to other solar radiation spectra, such as near infrared (NIR) and shortwave infrared (SWIR). In contrast, many RS sensors are sensitive to this kind of radiation. A RS image therefore visualises the intensity of VIS, NIR and SWIR radiation reflected from the earth surface. A RS image should be considered as an advanced aerial photograph containing additional information that would otherwise be invisible.
The aim of RS sciences is to create a meaningful interpretation of RS images. In this case meaning translating RS images to soil and vegetation characteristics. This is fundamentally possible because the reflection intensity of VIS, NIR and SWIR spectra carries information on the chemical and structural composition of plant leaves. The reason for this is the absorption of specific parts of the full sunlight spectrum by different leaf constituents. Chlorophyll for example absorbs mainly blue and red radiation. Green radiation is not absorbed, but is instead reflected by it, explaining why we perceive leaves as green. After all, the reflected fraction of solar radiation can be intercepted by our eyes, or, alternatively, an RS sensor. Furthermore, it holds that a higher concentration of a leaf constituent enhances absorption intensity of the associated spectra. Because reflection and absorption are complementary, the absorption intensity can be deduced from the perceived reflection intensity. From this data, the concentration of the absorbing constituent in the leaf can be estimated. Using this method, RS scenes of primarily tropical and broadleaf forests have been successfully translated to estimates of vegetation characteristics such as leaf nitrogen and chlorophyll.

From this theoretical basis the research described in this thesis focusses on two questions. Firstly, are RS based estimates of soil and vegetation characteristics a viable alternative for PROBE input compared to current information sources? We furthermore note that the method to translate RS data to soil and vegetation characteristics hardly has been applied to the type of vegetation for which PROBE was designed: namely short grass and herbaceous vegetation in a temperate oceanic climate (in this case: the Netherlands). The second question therefore reads: how will this type of vegetation influence the estimation of soil and vegetation characteristics from RS data.

Estimates of soil and vegetation characteristics from RS are not necessarily 100% accurate. If their estimation accuracy exceeds that of alternative methods the added value of RS is already demonstrated. Such a comparison is made in Chapter 2 for the nature area 'Kampina' in the southern Netherlands. Two soil characteristics (mean groundwater table and soil pH) were estimated from conventional methods: a hydrological model and a soil map. Both characteristics were also derived from a RS image. Field measurements of both characteristics at a fixed number of locations provided independent validation data to gauge the accuracy of both methods. From this it emerged that RS is considerably (groundwater table) or at least as (pH) accurate as the conventional methods. This fuelled our confidence to investigate RS further.

Next we investigated the relation between vegetation characteristics (more specifically, the concentration of leaf constituents) and the pattern of absorption and reflection of solar radiation over the various spectra. From here we will refer to this pattern as the spectral properties. In Chapter 3 the spectral properties as well as the concentration of various leaf constituents is measured for 35 plant species from various Dutch natural ecosystems. The spectral properties were measured directly from the leaf surface instead of from an aerial of space borne platform, ensuring that the pure and undisturbed leaf spectral properties were acquired. The relation between spectral properties and leaf constituents appeared weaker than expected based on comparable earlier research. This was partly accounted for by
observing that the collected species employed different growing strategies. This could lead to unequal proportionality between the measured constituents on one hand and the constituents that modulate the spectral signal on the other hand. This explanation was further corroborated when the relations improved when the species were slotted into groups of distinct growing strategies. The results of this chapter recommend to estimate firstly those leaf constituents that directly modulate the leaf spectral signal.

Chapter 4 again looked at the relation between leaves and spectral properties. This however, a ‘larger’ vantage point was used, namely a 4 m² vegetation canopy. This allowed us to test the spectra - leaf characteristics relation in a situation where the spectral signal no longer originated from a single leaf but rather from a multitude of leaves. In addition the optimal method to measure and express leaf characteristics for maximal correlation to canopy spectra was investigated. An experiment was designed that measured canopy spectral reflection at breast height and a range of vegetation characteristics (among others leaf nitrogen content, leaf chlorophyll content and leaf tannin content) from a mixed sample of leaf material from throughout the canopy for 40 2 * 2 m vegetation plots in the Kampina nature area. These latter measurements were subsequently expressed in three variations: mass per mass dry leaf material (milligram (mg) · mg⁻¹ dry mass), mass per leaf area unit (mg · m⁻² leaf) and mass per ground area unit (mg · m⁻² ground area). All three expressions of all vegetation characteristics were statistically related to the canopy spectra. The accuracy of this relation varied between the different vegetation characteristics, but was predominantly influenced by the expression. We relate from this that the expression is a highly relevant consideration in relation characteristics to canopy spectra and suggest that the most appropriate expression can be determined beforehand for different characteristics. Furthermore, this experiment found that the canopy spectrum is not governed only solely by leaf constituent concentrations. The canopy height, density and plant growth form (together the canopy architecture) appear to form the canopy spectral properties as well. This influence was found to either enhance or distort the estimation of vegetation characteristics. The former was the case when variation in the plant characteristic was in line with architectural variation. For example, the lignin (a leaf constituent related to plant woodiness) concentration was always high for dwarf shrub vegetation and low in grasslands. Absence of this linear relation distorted the relation between vegetation characteristics and spectra, for example when similar chlorophyll concentrations were observed at distinctly different canopy architectures. This was also apparent from results of the first chapter, in which slightly different vegetation characteristics were estimated. Therefore we recommend that that the form and function of the vegetation should be mirrored in the plant characteristic that we seek to estimate from RS.

Chapters 3 and 4 characterized the relation between spectral properties and vegetation characteristics in great detail. The final chapter utilizes those findings to translate a RS scene of the east Ameland dune and slick nature area to estimates of three vegetation characteristics. The value of RS for PROBE was subsequently tested by using these estimates as PROBE input. This allowed PROBE to calculate the spatial distribution of several plant species. A vegetation map of east Ameland was thus created relatively fast and cheap. Upon
comparison with a pre-existing vegetation map of the same area however, it became clear that PROBE had frequently wrongly predicted species occurrence. This was attributed firstly to inaccuracies in the translation of the RS scene to vegetation characteristics. This did not disqualify RS for use with PROBE however. We demonstrated that alternative methods to estimate the same vegetation characteristics would have a comparable margin of error. RS remained a relatively accurate predictor that was cheap and quick as well. Secondly it appeared that the plant species that PROBE attempted to predict were difficult to distinguish based solely on vegetation characteristics. Some species were nearly identical from a characteristics point of view and were thus indistinguishable for PROBE. As long as PROBE is confronted with such species, it will remain to generate poor predictions for oost Ameland. It is therefore recommended to engage PROBE only for species with distinctly different soil or vegetation characteristics. It holds however that not all soil and vegetation characteristics are equally suitable to differentiate between plant species. This research also found that not all soil and vegetation characteristics can be equally well estimated from RS. The overlapping window between these two qualifications is therefore small. Using RS in conjuncture with PROBE is then fore mostly valuable when the plant species of interest display strong variation in those soil and vegetation characteristics that can be well derived from RS. We encourage further research to determine for which species and characteristics this is the case.