PROSAIL MODEL FOR REFLECTANCE SIMULATIONS OF MOUNTAINOUS NON-FOREST COMMUNITIES

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ABSTRACT

Monitoring vegetation cover, especially in mountain and protected areas is an important issue. The analyses were conducted in Krkonoše Mountains in the Krkonoše National Park, Czech Republic. Heterogeneous non-forest mountain communities were analysed. The aim of the study was to check the possibility of using the Radiative Transfer Model to simulate the reflectance of very diverse mountain non-forest communities. In field measurements, biophysical parameters were collected and calculated to input parameters to the PROSAIL model. At the same time a reference spectrum was acquired. Then, the PROSAIL model was used to simulate the spectrum for each polygon. The accuracy was tested using Root Mean Square Error (*RMSE*) and normalised Root Mean Square Error (*nRMSE*) values for comparison with the reference spectrum. The average RMSE value for the whole analysed range was equal 0.129. The biggest errors were noticed in the near infrared (0.242) and the smallest in the 400-600 nm range (0.017). Generally, all noticed *RMSE* and *nRMSE* values are very diverse and quite big. The acquired results show that PROSAIL can be used to simulate the reflectance, but the model has to be adjusted, especially in the near infrared range.

INTRODUCTION

Monitoring vegetation cover is an important issue on global, regional and local scales. Also vegetation in mountain areas is very sensitive to changes in the environment. It is very important to easily monitor the state of vegetation cover, without interfering with the environment in protected areas. For this task, remote sensing data are very useful, which are often used in plant monitoring (1). It is possible to recognize objects and to analyse their state by analysing the spectrum using hyperspectral data. These kinds of techniques are very useful for analysing natural mountain vegetation communities (2,3,4).

Two approaches are used to retrieve biophysical parameters based on remote sensing data: a statistical method and modelling (5,6). In the statistical approach, imageries and biophysical parameters are simultaneously acquired during field measurements. The parameter values are correlated with values calculated from images (for example vegetation indices). Based on a regression model, the biophysical parameters are calculated for the whole image. The whole process is quite time-consuming and expensive due to many field measurements.

In the modelling approach, a physics-based model is used to represent the photon transport occurring inside leaves and canopy. Radiative Transfer Models (RTM) can be used to simulate the hyperspectral reflectance and, after a successful inversion procedure, to retrieve biophysical variables from remote sensing data (7). Also, RTM are quite rarely used to analyse reflectance of grassland (8,9,10,11,12,13).

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The aim of this study was to check the possibility of using a Radiative Transfer Model to simulate the reflectance of very diverse mountain non-forest communities. The PROSAIL model was tested (7). During field measurements, a reference spectrum and biophysical parameters as input parameters to the model were collected. Then, the PROSAIL model was used to simulate the spectrum on each polygon. The accuracy was tested using the reference spectrum. For successful modelling, the PROSAIL could be used to acquire biophysical parameters (especially pigment content or Leaf Area Index (*LAI*)). The model was inverted and parameters could be acquired from the spectrum.

The PROSAIL model was previously used to model the biophysical variables values quite successfully to grasslands vegetation (8,10,11), but the analysed ecosystems were more homogeneous. In this study, the model was tested based on a very diverse mountain vegetation.

The study area is located in Krkonoše Mountains, in the part of Krkonoše National Park in the Czech Republic near the places: Malá Úpa, Velká Úpa, and Pec pod Sněžkou. This area was also explored using hyperspectral images acquired in the Airborne Prism Experiment (APEX) (4).

The vegetation in this area is very heterogeneous – the most common plants are grasses, but also plants from *Fabaceae* and/or *Bryophyta* were on the same polygon. The most common plants noticed on the research areas were: grasses (like *Deschampsia caespitose*, *Nardus stricta*), *Fabaceae* (like *Lupinus polyphyllus*, *Trifolium pratense*) and others: *Rumex alpinus*, *Vaccinium myrtillus*. All of these plants have completely different structures, different heights, leaf angles etc. and that is why simulating the reflectance using RTM is not easy. Polygons with grass dominance with different heights (25 polygons), quite small plants (maximum 20 cm height) with *Fabaceae* like *Trifolium pratense* and grasses (5 polygons) and a dense, high and very diverse canopy with *Rumex alpinus* or *Lupinus polyphyllus* (7 polygons) were found in the analysed areas.

METHODS

Using the Radiative Transfer Model, the canopy is described as a layer consisting of leaves and the spaces between them in the model (14,6). In this study, the PROSAIL[1] model was used (7). The PROSPECT-5 model (14) was used for the leaf level and 4-SAIL (15,16) for the canopy level. The input parameters to both models are presented in Table 1.

Table 1: Input parameters to the PROSAIL model.

Abbreviation	Input variable	Units
Cab	Chlorophyll content	μg/cm^2
Car	Carotenoid content	μg/cm^2
Cbrown	Brown pigment content	-
Cw	Equivalent Water Thickness (amount of water)	Cm
Cm	Dry matter content	g/cm^2
N	Leaf structure parameter	-
LAI	Leaf Area Index	m^2/m^2
angl	Average leaf angle	degrees
posil	Soil brightness parameter	-
skyl	Ratio of diffuse to total incident radiation	%
hspot	Hot spot size parameters (responsible for reducing the hot spot)	m/m
ihot		-
tts	Solar zenith angle	degrees
tto	Observer (instrument) zenith angle	degrees
psi	Relative azimuth angle	degrees

1 PROSPECT+SAIL=PROSAIL, http://teledetection.ipgp.jussieu.fr/prosail/ (last date accessed: 20 Jan 2014)

The PROSPECT and SAIL models are quite rarely used for heterogeneous communities; these models were used to simulate spectral reflectance in the different kinds of meadows, mainly on flat areas (8,9,10,11,12,13).

The field measurements performed to model PROSAIL were conducted in Krkonoše Mountains on 37 test polygons on 28th, 29th and 30th August 2013. The size of each polygon was at least 100 m^2. The following information was collected during the field measurements: chlorophyll content using a chlorophyll content meter CCM-200, fresh biomass, dry matter amount, information about the canopy structure such as *LAI* using a LAI-2000 Plant Canopy Analyzer, Average Leaf Angle, canopy height, and date and time of measurement. The spectrum for each polygon was also collected using a ASD FieldSpec 3 FR.

Field measurements were used to calculate input parameters for each polygon separately. Chlorophyll and carotenoid content in µg/cm^2 were calculated using *CCI* and *LAI*. Brown pigment content was recalculated from the dry matter amount. Dry matter and water content were calculated using the *LAI* and the amount of water.

The structural parameters for each polygon were estimated empirically and from the literature (8,10,11,13). One of the hot spot size parameters was calculated using leaf average, leaf length, and canopy height. The Solar zenith angle was estimated from the coordinates, time and date of the measurements. Other parameters (soil brightness parameter, ratio of diffuse to total incident radiation, second hot spot size parameter, observer zenith, and azimuth observer angle) were fixed based on previous studies (10,11,13).

For each polygon using the PROSAIL model, the reflectance was calculated from 400 to 2500 nm with 1 nm spectral resolution. Then, the acquired results were compared with the spectrum collected during field measurements. The Root Mean Square Error (*RMSE*) for the whole range 400-2500 nm and for specific ranges 400-600, 400-800, 800-1500 and 1500-2500 nm was calculated to estimate the accuracy. The normalized Root Mean Square Error (*nRMSE*) was calculated for the same ranges from the *RMSE* value divided by the range of value of field reflectance.

RESULTS AND DISCUSSION

As a result, the values of Root Mean Square Error (*RMSE*) and normalised Root Mean Square Error (*nRMSE*) were acquired for each polygon.

The average *RMSE* value for the whole analysed range from 400 to 2500 nm was equal to 0.129 (Table 2, Figures 1 and 2). The biggest errors in specific ranges were noticed in the near infrared (0.242) and the smallest in the 400-600 nm range (0.017). The biggest differences in *RMSE* values acquired for different polygons were also noticed at 800-1500 nm, whereas the smallest differences were noticed at 400-600 nm. In the 400-600 nm range, smaller *RMSE* values were noticed for more diverse and dense communities.

Quite similar results were noticed for *nRMSE* – the average value in the whole range was equal 22%. The maximum average was noticed in the near infrared (53%), the minimum at 400-800 nm (19%). The biggest differences in *nRMSE* were noticed at 400-600 nm, the smallest differences at 400-800 nm.

Generally, the best results were acquired in visible light, where pigment content has the biggest influence, but based on the *nRMSE* it is noticeable, that the errors are quite diverse, even in this range. In the near infrared range, dry matter and *LAI* values have the strongest influence on the modelling. In this range, the biggest errors were noticed. All noticed *RMSE* and *nRMSE* values are very diverse and quite big as compared to other studies (8,9,10,11,13). This is probably related to the fact that the analysed vegetation communities are very diverse – different plant communities with diverse structure and density cover. Based on this data PROSAIL cannot be used in the inversion process. However, the results in visible light were quite good, so that, after calibration, it will be possible to retrieve the pigment (chlorophyll or carotenoids) content from this data. It is necessary to calibrate the model prior to continuing with the next steps of modelling.

Table 2: RMSE and nRMSE values acquired in the spectrum simulation using the PROSAIL model.

Error		Wavelength range in nm				
		400-2500	400-600	400-800	800-1500	1500-2500
RMSE	Max	0.204	0.077	0.181	0.402	0.187
	Min	0.069	0.002	0.022	0.104	0.030
	Average	0.129	0.017	0.095	0.242	0.085
nRMSE	Max	34%	121%	31%	83%	66%
	Min	13%	3%	6%	31%	15%
	Average	22%	21%	19%	53%	32%

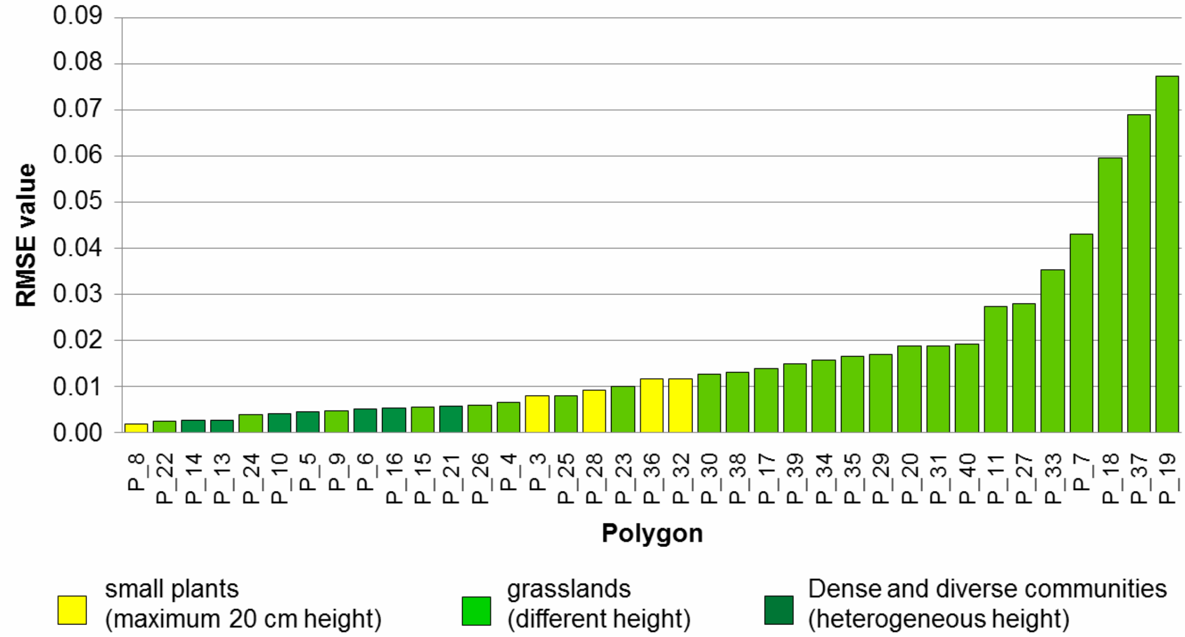

Figure 1: Values of the Root Mean Square Error calculated for the range 400-600 nm.

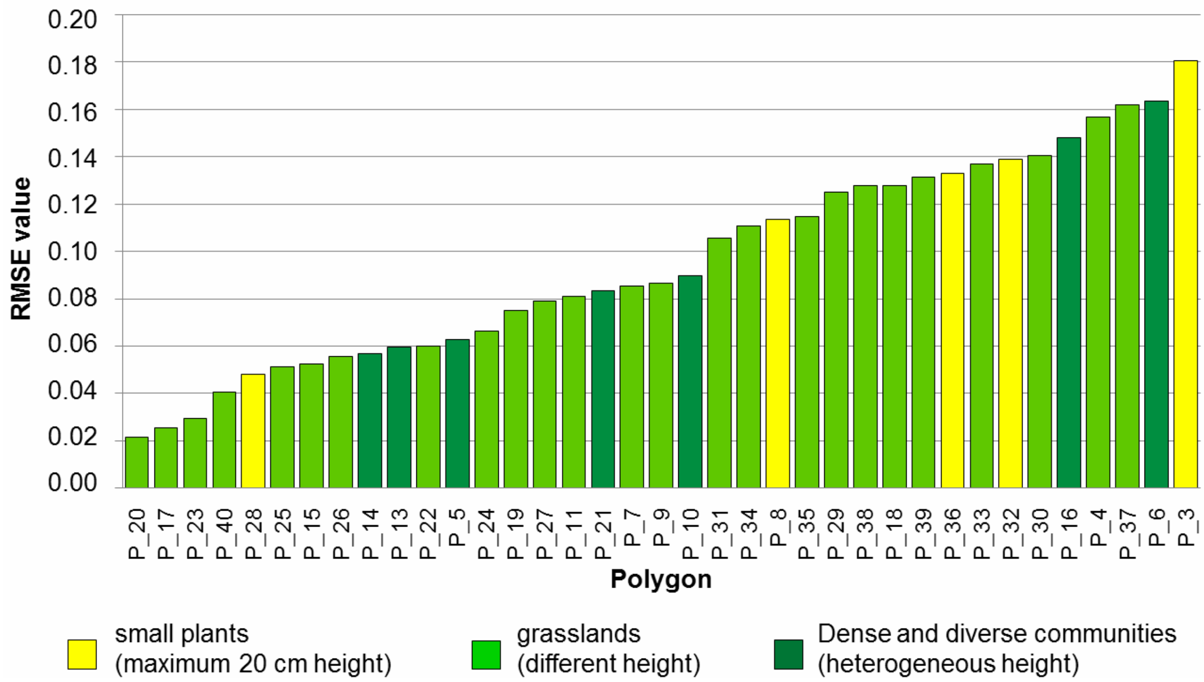

Figure 2: Values of the Root Mean Square Error calculated for the range 400-800 nm.

CONCLUSIONS

The acquired results showed that PROSAIL can be used to simulate the reflectance, but it has to be adjusted, especially in the near infrared range, to start the inversion process. The acquired RMSE and nRMSE values were quite big, especially in the near infrared (9, 11). Quite small errors were noticed in visible light. The model is quite efficient in modelling the spectrum, where pigment content has the biggest influence. In the near infrared, the amount of biomass has the biggest influence and the model is not successful in this range.

Analysed plant communities are very diverse, with different structures and density covers. Probably, that is why the model is not successful enough in modelling the reflectance. Also, the errors can be related to the method of collecting input data.

Finally, the PROSAIL model can be used for simulating the reflectance of mountain non-forest communities, but it is necessary to make adjustments in the model, especially to correct the near infrared spectrum range.

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