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封面图说:内地多呈灌木状的沙棘,在青藏高原就表现为高大的乔木,在拉萨河以及雅鲁藏布江沿岸常常可以看到高大的沙棘林和沼泽塔头湿地相映成趣的美丽景观。

彩图提供:陈建伟教授 国家林业局 E-mail: cites.chenjw@163.com

范秀华, 刘伟国, 卢文敏, 方晓雨. 长白山红松臭冷杉光谱反射随海拔的变化. 生态学报, 2011, 31(14): 3910-3917.

Fan X H, Liu W G, Lu W M, Fang X Y. Changes of spectral reflectance of *Pinus koraiensis* and *Abies nephrolepis* along altitudinal gradients in Changbai Mountain. Acta Ecologica Sinica, 2011, 31(14): 3910-3917.

长白山红松臭冷杉光谱反射随海拔的变化

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摘要: 使用光谱仪测量长白山主要针叶树种红松、臭冷杉不同海拔针叶的光谱反射率, 对比了两树种不同海拔间光谱反射率、光谱指数的差异。结果表明: 两种针叶树在不同海拔的光谱反射率变化明显, 可见光区和近红外区各波段的光谱反射率与海拔有很强的相关性, 光谱指数也有显著差异, 说明相关生理状况发生明显变化, 随海拔的升高, 叶绿素的含量降低, 单位叶绿素的类胡萝卜素含量增大; 对比各海拔光谱反射率发现, 1279 m 处红松、臭冷杉针叶的色素含量较高, 叶绿素指数说明 748 m 处红松、臭冷杉针叶叶绿素含量显著高于 1040 m 和 1279 m 处, Car: Chl 指数表明红松、臭冷杉均在 748 m 处受到较弱的胁迫, 臭冷杉在 1040 m 受到较强的胁迫。

关键词: 色素; 海拔梯度; 光谱反射率

Changes of spectral reflectance of *Pinus koraiensis* and *Abies nephrolepis* along altitudinal gradients in Changbai Mountain

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Abstract: In order to assess the influence of altitudinal gradients on the spectral reflectance of *Pinus koraiensis* and *Abies nephrolepis* which are two dominant conifers in Changbai Mountain, we measured the spectral reflectance of their needles at different altitudinal study sites, using a spectral analysis system in 2008 (Unispec-SC spectral analysis system). Samples were chosen in three altitudinal sites (748 m, 1040 m and 1279 m, respectively) to represent the variability of spectral reflectance in our study. Six trees were selected for each studied species in each study site. Measurements were performed at noon during sunny day. Before we assessed the variation of the spectral reflectance, ordinary methods measuring the pigment contents were adopted to examine the correlations between pigment contents and spectral indices. And spectrophotometer was used to analyze the pigment concentrations. Most of the spectral indices were significantly correlated with pigment concentration at the 0.05 level. We compared the characters of spectral reflectance and spectral indices among study sites. The ratios of spectral reflectance for each wavelength were calculated. Spectral indices for each species, including three indices for chlorophyll and two for carotenoid and two for Car:Chl, were analyzed subsequently.

To quantify relationships between spectral reflectance and altitudes, Pearson correlation coefficients were analyzed for altitudinal gradients and specific wavelength. The results showed that there were significant differences in the spectral reflectance among different altitudinal sites. Strong correlations were found between elevation and wavelength in visible and near infrared regions. Spectral indices also showed significant variations with altitude increase. Maybe this means the changes of physiological conditions. The chlorophyll content decreased and the carotenoid content per unit chlorophyll concentration (Car:Chl) increased with the increasing of the altitude. Lower total pigment concentration of *P. koraiensis*

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and *A. nephrolepis* occurred at medium altitudinal site (i. e., 1040 m). Both studied species, *P. koraiensis* and *A. nephrolepis*, showed the highest total pigment content at higher altitudinal site (i. e., 1279 m). Significant differences among altitudinal sites were found for every studied species. Strong correlations occurred in most of waveband, although there were obviously differences between two studied species. Chlorophyll indices indicated that the highest chlorophyll content of *P. koraiensis* and *A. nephrolepis* occurred in lower altitudinal site (i. e., 748 m). The highest Car :Chl in needles of *A. nephrolepis* occurred was in medium elevation (1040 m) in broad-leaved Korean pine mixed forest and spruce-fir mixed forest. These indicated *P. koraiensis* and *A. nephrolepis* in 748 m confronted lower stress, and *A. nephrolepis* confronted the highest stress in 1040 m among three gradients. Spectral reflectance curve and spectral indices varied with the elevation. It suggested that the physiological status of *P. koraiensis* and *A. nephrolepis* changed. But there was no significant difference in spectral characters between medium elevation (1040 m) and higher elevation (1279 m) in *P. koraiensis*. This may be attributed to the variations of special character of ecotone. Trees always showed higher chlorophyll concentration in their dominant distribution regions, thus the dominant distribution region of *P. koraiensis* was probably lower than 1040 m.

Key Words: pigment; altitudinal gradient; spectral reflectance

植物色素通常包括叶绿素(Chl)、类胡萝卜素(Car)、花青素等,其中叶绿素又包括叶绿素 a 和叶绿素 b 等,类胡萝卜素又包括 α -胡萝卜素、 β -胡萝卜素、叶黄素等。各类色素都具有各自的特征吸收峰,水分也同样具有相应的特征吸收峰。当光照射到叶片时,一部分被叶片吸收,一部分被反射,还有一部分透过叶片,所以光谱反射特征与植物叶片的色素含量、叶片的含水量都密切相关^[1],测量植物的光谱反射特征可以作为监测植物生长状况、光合作用、水分、受胁迫情况等的有效手段^[2]。国内外学者使用光谱反射已进行了大量的研究和开创性的应用,如植物色素与光谱反射的相关性、植物随海拔变化的生理适应^[3]、植物对干旱条件及其它恶劣环境的适应对策^[4-6]、绿色植物生产力的估计^[7]、监测植物群落季节变动^[8]、生物多样性研究^[9]、检测植物病虫害^[10]及生物入侵格局、火灾监测、应用于碳循环和水循环的监测^[11]、环境污染监测^[12]等等,但由于光谱反射特征与叶片结构特征、植被特征等也同样有关系,种间或不同植被类型的对比仍有难度。

国内外对植物光谱反射率随海拔的变化已经进行了一些研究^[13-14]。长白山森林群落随海拔梯度的变化明显,植物光谱反射率随海拔的变化是有待揭示的问题。红松、臭冷杉作为长白山重要的针叶树种,具有重要的经济价值和生态系统服务价值,并且在生态演替过程中具有重要的作用,所以研究红松、臭冷杉幼树随海拔的变化尤为重要。本次研究的目的,一是研究海拔变化对红松、臭冷杉幼树光谱反射率的影响,分析其随海拔变化的生理反应;二是以期将本次研究结果与其他树种的研究结果结合,用于各海拔森林群落的演替方向的预测模型。

1 研究区概况与研究方法

1.1 研究区概况

本研究在长白山北坡进行,不同海拔的海拔高度及地理坐标如表 1,长白山自然保护区北坡属温带大陆性山地气候,其气候特点是春季干燥多风、夏季温暖多雨、冬季漫长寒冷。年平均气温为 3.3 °C,8 月份平均温度 20.5 °C,1 月份平均温度 -16.5 °C,极端最高温度 32.3 °C,极端最低气温 -37.6 °C,年平均降水量在 600—900 mm 之间。土壤为山地暗棕色森林土,土层厚度 20—100 cm,缓坡排水良好^[15]。不同海拔群落类型如表 1 所示^[16]。

1.2 研究方法

1.2.1 不同海拔针叶光谱数据测量

本研究使用 Unispec-SC 光谱仪(美国 PPS 公司)测量叶片光谱反射率,测量时卤光灯的光强设定为 100%,整合时间为 4 ms,重复扫描次数为 3 次,叶夹上的光纤探头与针叶表面成 60°夹角,每 10 min 参比 1

次。每个海拔带选取健康生长的红松、臭冷杉幼树各 6 株,每株选取 20 片成熟、健康的针叶进行测量,每片叶子测 1 次。各海拔带的数据测量均在晴天的中午进行,日期分别是 2008 年 7 月 25 日(748 m)、7 月 28 日(1040 m)、7 月 19 日(1279 m)。

表 1 研究地的海拔、地理坐标及群落类型

Table 1 Altitude, latitude, longitude and the community of research site

海拔 Altitude /m	纬度 Latitude	经度 Longitude	群落类型 Community type
748	42° 21'N	128° 08'E	阔叶红松林
1040	42° 15'N	128° 04'E	阔叶红松林与云冷杉林过渡带
1279	42° 08'N	128° 08'E	云冷杉林

1.2.2 针叶色素浓度测量

分别在野外采集红松、臭冷杉针叶,置于冰盒中,带回实验室,立即使用光谱仪分组测量针叶的光谱反射率,其中红松每 3 针 1 组,臭冷杉 8 针 1 组,红松每组针叶选自同一束,臭冷杉每组选自生长位置接近、颜色相近的针叶,然后使用 Arnon 法测量色素的含量:将每组针叶剪碎,放入 80% 的丙酮溶液中浸泡,24h 后使用 722N 分光光度计测量浸泡液 663、646、470 nm 的光密度值,然后根据 Lichtenthaler 等对 Arnon 法修正后的公式分别计算叶绿素、类胡萝卜素的含量。

1.3 数据处理

依据室内测定的每组针叶光谱反射率与每组的叶绿素、类胡萝卜素浓度,计算各种光谱指数与针叶叶绿素含量、类胡萝卜素含量、以及单位叶绿素的类胡萝卜素含量的相关关系,相应的光谱指数用于各海拔之间的对比。

常用的光谱指数之一有植被归一化指数(*NDVI*, Normalized difference vegetation index),这个指数与叶绿素的含量有很好的线性关系^[1]。叶绿素归一化指数(*ChlNDI*, Chl normalized difference index)也是反映叶绿素含量的较好指数^[17]。 $mSR_{index} = (R_{ref} - R_{445}) / (R_{index} - R_{445})$,通常参比波长(R_{ref})在 750—900 nm 范围内,指数波长(R_{index})在 660—720 nm 范围内,本研究中,使用 800 nm 和 680 nm 分别作为参比波长和指数波长^[18]。同时红边位置(λ_{RE} , red edge)也是叶绿素含量较好的评价器^[19]。

类胡萝卜素指数(Carotenoid reflectance index, *CRI*)反映波长 550 nm 和 700 nm 处反射值倒数与 510 nm 处反射值倒数的差异,该指数对 Car 的变化更为敏感^[20]。由于类胡萝卜素在 445 nm 处有一个吸收峰^[21],与结构无关色素指数(*SIPI*, structure-independent pigment index)反映出单位叶绿素的类胡萝卜素含量(CarChl)。由于光化学反射指数(*PRI*, photochemical reflectance index)^[22]和叶黄素循环中的色素有负相关,随着色素含量的波动,过多的辐射被叶黄素循环中的色素吸收,未能进行光合作用,所以当其低时,光合速率就低,研究发现 *PRI* 也与单位叶绿素的类胡萝卜素含量有很高的相关性^[23]。

光谱仪测得的数据利用 Multispec5.1 软件处理,计算出光谱反射率 R_λ 和光谱指数,其中 R_λ 是叶片反射与参比反射的比值。各光谱指数与色素浓度的 Pearson 相关系数、不同海拔光谱指数的多重比较(Tamhane's *T2*)通过 SPSS13.0 统计软件实现。

2 结果与分析

2.1 红松、臭冷杉各光谱指数与叶绿素、类胡萝卜素含量的相关性

统计发现,常用的光谱指数 *SIPI* 和 *PRI* 与红松、臭冷杉的单位叶绿素的类胡萝卜素含量的相关性不显著,*CRI500* 和 *CRI700* 与类胡萝卜素的相关性也不显著。 λ_{RE} 、*ChlNDI* 与红松、臭冷杉的叶绿素含量均表现出极显著的相关性。此外,红松、臭冷杉针叶的色素含量与各波段反射率的相关性并不相同,所以分别为红松、臭冷杉建立了与各自色素含量相关性较高的光谱指数(表 2)。

2.2 不同海拔带光谱反射率的对比

对比红松 3 个海拔带的光谱反射率,在可见光范围内, R_{1040} 高于 R_{748} 和 R_{1279} , $R_{1040} : R_{748}$ 最高达 1.30,

$R_{1279}:R_{1040}$ 最低达 0.66。对比 748 m 和 1279 m 的光谱反射率,在 400—505 nm 范围内, $R_{1279}:R_{748}$ 小于 1,最低达 0.8,而 505—700 nm 范围内, $R_{1279}:R_{748}$ 均大于 1(如图 1),说明 1040 m 处红松的色素含量较低。对比臭冷杉 3 个海拔带的光谱反射率,在可见光范围内, R_{1040} 高于 R_{1279} 和 R_{748} , $R_{1040}:R_{748}$ 最高达 2.77, $R_{1279}:R_{1040}$ 最低达 0.26。对比 748 m 和 1279 m 处的光谱反射率,在可见光范围内, $R_{1279}:R_{748}$ 恒小于 1(如图 1),说明 748 m 和 1279 m 的臭冷杉的色素含量高于 1040 处的。

表 2 红松、臭冷杉各光谱指数与叶绿素、类胡萝卜素含量的相关系数

Table 2 The correlations between the spectral indices and the concentration of Chl and Car of *P. koraiensis* and *A. nephrolepis*

项目 Item	单位叶绿素的 类胡萝卜素含量 The Car: Chl ratio	相关系数 Correlation coefficients	叶绿素含量 Chlorophyll concentration	相关系数 Correlation coefficients	类胡萝卜素含量 Carotenoid concentration	相关系数 Correlation coefficients	
光谱指数 Spectral indices	红松 <i>P. koraiensis</i>	R_{702}/R_{400}	0.465 ***	$(R_{800}-R_{710})/(R_{800}+R_{710})$	0.798 ***	R_{613}/R_{684}	-0.746 ***
		$(R_{702}-R_{400})/(R_{702}+R_{400})$	0.433 ***	R_{800}/R_{550}	0.822 ***	$(R_{613}-R_{684})/(R_{613}+R_{684})$	-0.754 ***
		$R_{613}^*R_{550}/(R_{800}^*R_{684})$	0.543 ***	<i>ChlNDI</i>	0.764 ***	R_{560}	-0.458 ***
		<i>SIP1</i>	-0.008	<i>mSR</i>	0.555 **	<i>CRI</i> ₅₅₀	0.222
		<i>PRI</i>	-0.172	<i>NDVI</i>	0.454 ***	<i>CRI</i> ₇₀₀	0.316
		λ_{PE}	0.685 * *	$(R_{545}-R_{567})/(R_{545}+R_{567})$	0.671 ***		
	臭冷杉 <i>A. nephrolepis</i>	R_{606}/R_{596}	0.599 ***	$(R_{740}-R_{695})/(R_{740}+R_{695})$	0.720 ***	R_{696}	-0.698 ***
		$(R_{606}-R_{596})/(R_{606}+R_{596})$	0.6 ***	R_{740}/R_{695}	0.681 ***	<i>CRI</i> ₅₅₀	0.145
		$(1/R_{692}-1/R_{565})/R_{800}$	-0.605 ***	<i>Chl NDI</i>	0.712 ***	<i>CRI</i> ₇₀₀	0.17
		<i>SIP1</i>	0	<i>mSR</i>	0.504 ***		
		<i>PRI</i>	-0.387	<i>NDVI</i>	0.663 ***		
				λ_{PE}	0.651 ***		

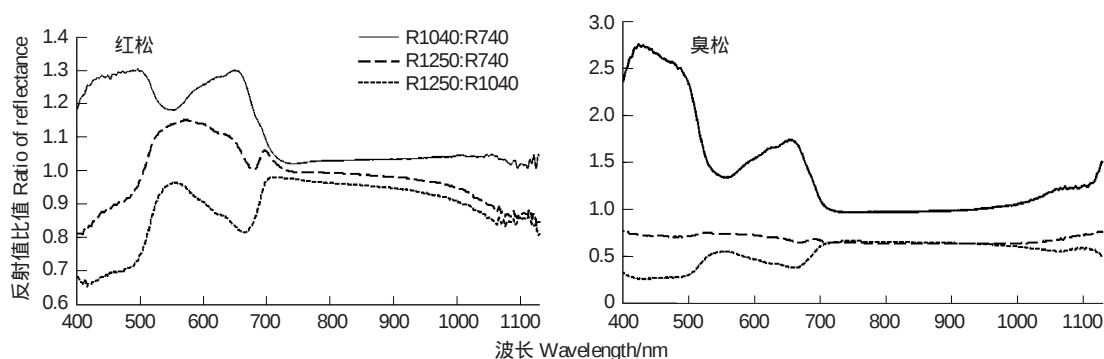
* $P<0.05$; ** $P<0.01$; *** $P<0.001$ 

图 1 红松、臭冷杉不同海拔光谱反射率的比值曲线

Fig.1 The ratio of spectral reflectance of *P. koraiensis* and *A. nephrolepis* among different altitudes

2.3 叶绿素光谱指数对比

分别对比红松和臭冷杉 3 个与叶绿素含量相关性显著的光谱指数(表 3),红松在 748 m 处的光谱指数值均显著高于 1040 m 处和 1279 m 处的指数值,1279 m 处的光谱指数值与 1040 m 的值无显著差异。臭冷杉在 748 m 的光谱指数均显著高于 1040 m 和 1279 m 处,1279 m 的指数,除 $Chl NDI$,其余均显著高于海拔 1040 m

处,这说明 1040 处针叶的叶绿素含量低于另外两个海拔。

表 3 红松、臭冷杉不同海拔叶绿素指数比较
Table 3 Comparing chlorophyll indices of *P. koraiensis* and *A. nephrolepis* among different altitudes

红松 <i>P. koraiensis</i>		臭冷杉 <i>A. nephrolepis</i>	
光谱指数 Spectral indices	均值的大小关系 Comparing of mean values	光谱指数 Spectral indices	均值的大小关系 Comparing of mean values
<i>ChlNDI</i>	$M_{748} > M_{1040}^{***}$	<i>ChlNDI</i>	$M_{748} > M_{1279}^{***}$
R_{800}/R_{550}	$M_{1040} > M_{1279}$	R_{740}/R_{695}	$M_{748} > M_{1040}^{***}$
	$M_{748} > M_{1279}^{**}$		$M_{1040} < M_{1279}$
	$M_{748} > M_{1040}^{***}$		$M_{748} > M_{1279}^{***}$
	$M_{1040} < M_{1279}$		$M_{748} > M_{1040}^{***}$
	$M_{748} > M_{1279}^{**}$		$M_{1040} < M_{1279}^{***}$
$(R_{800}-R_{710})/(R_{800}+R_{710})$	$M_{748} > M_{1040}^{*}$	$(R_{740}-R_{695})/(R_{740}+R_{695})$	$M_{748} > M_{1279}^{***}$
	$M_{1040} > M_{1279}$		$M_{748} > M_{1040}^{***}$
	$M_{748} > M_{1279}^{***}$		$M_{1040} < M_{1279}^{***}$

所有光谱指数的值用 M 表示,the value of each spectral indices is presented by M

2.4 类胡萝卜素指数

分别对比红松、臭冷杉类胡萝卜素指数,红松 1279 m 的光谱指数和 1040 m 的光谱指数差异不显著,748、1279、1040 m 的光谱指数差异显著,臭冷杉类胡萝卜素指数,1279 m 的 $(R_{545}-R_{567})/(R_{545}+R_{567})$ 指数值大于 1040 m 和 748 m 的指数值,748 m 的值大于 1040 m,因为 R_{696} 与类胡萝卜素的含量负相关,所以大小关系与 $(R_{545}-R_{567})/(R_{545}+R_{567})$ 的相反(表 4)。

表 4 红松、臭冷杉不同海拔类胡萝卜素指数比较
Table 4 Comparing carotenoid indices of *P. koraiensis* and *A. nephrolepis* among different altitudes

红松 <i>P. koraiensis</i>		臭冷杉 <i>A. nephrolepis</i>	
光谱指数 Spectral indices	均值的大小关系 Comparing of mean values	光谱指数 Spectral indices	均值的大小关系 Comparing of mean values
R_{613}/R_{684}	$M_{748} < M_{1040}^{***}$	$(R_{545}-R_{567})/(R_{545}+R_{567})$	$M_{748} < M_{1279}^{***}$
$(R_{613}-R_{684})/(R_{613}+R_{684})$	$M_{1040} < M_{1279}$		$M_{748} > M_{1040}$
	$M_{748} < M_{1279}$		$M_{1040} < M_{1279}^{**}$
	$M_{748} < M_{1040}^{***}$	R_{696}	$M_{748} < M_{1279}^{***}$
	$M_{1040} < M_{1279}$		$M_{748} < M_{1040}^{***}$
	$M_{748} > M_{1279}^{***}$		$M_{1040} > M_{1279}^{***}$

2.5 Car :Chl 指数

对比各海拔红松、臭冷杉与单位叶绿素的类胡萝卜素含量相关性较高的指数,红松、臭冷杉在 1040 m 的指数值均显著小于 748 m 和 1279 m 的值,红松在 748 m 的指数值显著小于 1279 m 的,臭冷杉 748 m 的 R_{606}/R_{596} 值大于 1279 m 的值,显著小于 1040 m 的值,1279 m 处的 $(1/R_{692}-1/R_{565})/R_{800}$ 的值显著大于 1040 m 和 748 m 的值(表 5)。

2.6 光谱反射率随海拔的变化

如图 2 所示,在可见光范围内,红松的光谱反射率与海拔呈正相关,相关系数在 500—600 nm 和 700 nm 两个波段出现峰值,臭冷杉与海拔呈负相关,但相关系数并不高。红松、臭冷杉近红外波段(NIR)的光谱反射率均与海拔变化呈负相关,臭冷杉表现强的负相关。近红外波段的反射率反映水分含量和叶片结构的信息^[21],说明臭冷杉针叶的水分含量和结构随海拔的变化较为明显。

表5 红松、臭冷杉不同海拔 Car:Chl 指数的比较

Table 5 Comparing the indices concerning the Car:Chl ratio of *P. koraiensis* and *A. nephrolepis* among different altitudes

红松 <i>P. koraiensis</i>		臭冷杉 <i>A. nephrolepis</i>	
光谱指数 Spectral indices	均值的大小关系 Comparing of mean values	光谱指数 Spectral indices	均值的大小关系 Comparing of mean values
R_{702}/R_{400}	$M_{748} > M_{1040}$ $M_{1040} < M_{1279}^{***}$ $M_{748} > M_{1279}$	R_{606}/R_{596}	$M_{748} < M_{1279}^{***}$ $M_{748} < M_{1040}^{***}$ $M_{1040} > M_{1279}^{***}$
$R_{613} \times R_{550} / (R_{800} \times R_{684})$	$M_{748} < M_{1040}^{***}$ $M_{1040} < M_{1279}$ $M_{748} < M_{1279}^{***}$	$(1/R_{692} - 1/R_{565})/R_{800}$	$M_{748} < M_{1279}^{***}$ $M_{748} < M_{1040}$ $M_{1040} < M_{1279}^{***}$

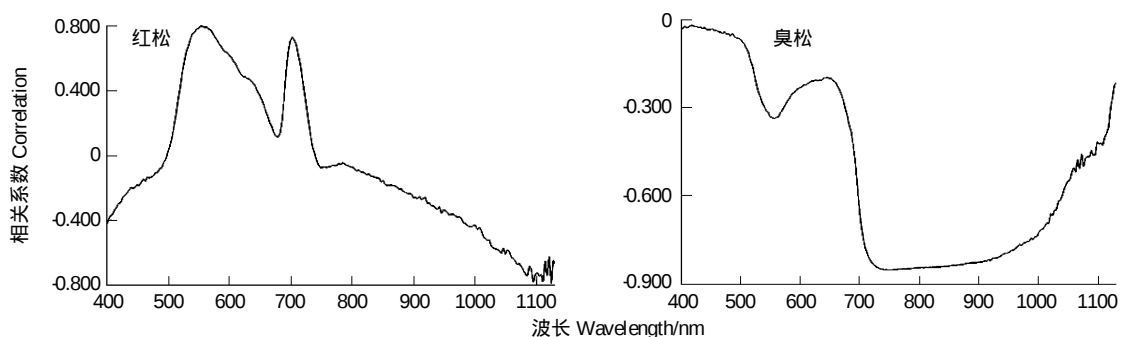


图2 红松、臭松光谱反射率各波段与海拔的相关性曲线

Fig. 2 The relativity between reflectance of every wave band and altitudinal gradients

3 结论与讨论

对比红松和臭冷杉的光谱反射率,发现红松和臭冷杉在 1040 m 处的色素含量较低,由于类胡萝卜素、叶绿素在 400—500 nm 的范围内具有吸收峰,叶绿素还在 600—700 nm 范围内有吸收峰,所以红松在 1279 m 处的针叶色素含量高于 748 m,但 748 m 处叶绿素的含量可能较高。

本研究所使用的光谱指数随海拔梯度均有明显差异,这说明不同海拔红松、臭冷杉针叶的色素含量和组成变化明显。*NDVI*、*ChlNDI* 是常用的光谱指数,*NDVI* 对叶绿素浓度表现出一定的饱和性,*ChlNDI* 弥补了这一不足^[1],实验表明 *ChlNDI* 与叶绿素浓度有较高的相关性,所有的指数均选取相关系数较高的指数进行比较。通过比较发现,748 m 处红松、臭冷杉针叶的叶绿素含量高于 1040 m 处,红松 1040 m 和 1279 m 处叶片的叶绿素含量没有显著差别,臭冷杉 748 m 处叶片的叶绿素含量明显高于 1279 m 处。

实验表明,*CRI* 与红松、臭冷杉的类胡萝卜素含量的相关性并不显著,所以分析了另外与类胡萝卜素浓度相关性较高的两个指数。不同海拔间进行对比,发现 748 m 处的红松、臭冷杉叶片的类胡萝卜素含量相对于另外两个海拔带低,红松 1040 m 和 1279 m 的类胡萝卜素含量没有显著差别,臭冷杉 1040 m 处的类胡萝卜素含量显著低于 1279 m 处。

单位叶绿素的类胡萝卜素含量很好的反映了植物所受胁迫的情况,当单位叶绿素的类胡萝卜素含量高时,说明植物所受胁迫也较强^[13-14,22]。实验发现 *SIPI* 与红松、臭冷杉单位叶绿素的类胡萝卜素含量的相关性并不高。本研究分析了另外两个相关性较高的指数,对比发现,发现 748 m 处的红松叶片单位叶绿素的类胡萝卜素含量相对于另外两个海拔带较低,红松 1040 m 和 1279 m 的没有显著差别,臭冷杉 1040 m 处单位叶绿素的类胡萝卜素含量显著高于 748 m 处和 1279 m 处的。

由此可见,随海拔变化,林下红松、臭冷杉幼树的光谱反射特征和光谱指数都有明显变化,证明相关生理状况发生变化,但是在 1040 m 和 1279 m 红松针叶的叶绿素和类胡萝卜素浓度并没有明显差别,这可能与过

渡带特殊的植物群落类型有关,因为红松的核心分布区在 1200 m 以下^[24-25],本文的研究表明,红松核心分布区很可能低于 1040 m。在 1200 m 以上,红松更新幼苗所受胁迫较强,很难进入主林层^[24]。臭冷杉在 1040 m 针叶单位叶绿素的类胡萝卜素含量最高,这可能因为臭冷杉在长白山北坡的最适海拔高度是 1290—1500 m^[24],而 900—1100 m 正是阔叶红松林和云冷杉林的过渡带^[16],过度带的植物种类多,竞争压力大。对于更低海拔带红松和更高海拔的臭冷杉光谱反射率的变化,有待进一步研究。

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Dynamics of microbial biomass during litter decomposition in the alpine forest	 ZHOU Xiaoping, WU Fuzhong, YANG Wanqin, et al (4144)
The aerodynamic roughness length of biological soil crusts: a case study of Gurbantunggut Desert	 WANG Xueqin, ZHANG Yuanming, ZHANG Weimin, et al (4153)
Differences among population quantities and community structures of pests and their natural enemies in tea gardens of different altitudes	KE Shengbing, DANG Fenghua, BI Shoudong, et al (4161)

2009 年度生物学科总被引频次和影响因子前 10 名期刊★

(源于 2010 年版 CSTPCD 数据库)

排序 Order	期刊 Journal	总被引频次 Total citation	排序 Order	期刊 Journal	影响因子 Impact factor
1	生态学报	11764	1	生态学报	1.812
2	应用生态学报	9430	2	植物生态学报	1.771
3	植物生态学报	4384	3	应用生态学报	1.733
4	西北植物学报	4177	4	生物多样性	1.553
5	生态学杂志	4048	5	生态学杂志	1.396
6	植物生理学通讯	3362	6	西北植物学报	0.986
7	JOURNAL OF INTEGRATIVE PLANT BIOLOGY	3327	7	兽类学报	0.894
8	MOLECULAR PLANT	1788	8	CELL RESEARCH	0.873
9	水生生物学报	1773	9	植物学报	0.841
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