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Composite indicator for monitoring of Norway spruce stand decline using remote sensing methods

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Forest decline

is a complex disorder involving abiotic and biotic stresses on a forest stand that results in a slow, progressive decrease in growth with loss of health and vigor

Kaennel et al. 1995, NAL Glossary by United States Department of Agriculture, National Agricultural Library (2014) https://www.nal.usda.gov/

Study area

Study area

Acid-rain
1980..

Weather fluctuations
2010..

Impact of drought on spruce

Appropriate indicator of spruce decline

State of the art

Forest decline indicators detected by *in situ* assessment* related to

- Tree damage
- Tree mortality
- Crown condition (discoloration, defoliation)
- Stand structure

Selected individual forest decline indicators based on airborne and satellite data**

- Biochemical parameter (chlorophyll concentration)
- Dead trees
- Crown condition (discoloration, defoliation)
- Metal concentration in leaves

* National Forest Inventory NFI, forest health monitoring programs (ICP Forests, FHM, Forest Europe)

** Mišurec et.al. 2012, Heurich et al. 2010, Crosby et al. 2012, Tuominen et al. 2009, Campbell et al. 2004, Solberg 2010, Lausch et al. 2016

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Composite indicator - ?

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Objectives

- to determine the indicators of spruce decline from field which will form a composite indicator;

- to explore spectral reflectance properties of spruce stands for categories of the composite spruce decline indicator;

- to investigate the potential of vegetation indices extracted from time-series hyperspectral airborne and multispectral satellite data to predict the development of the composite spruce decline indicator.

Field data

Indicator	Description	Range within study area, %					
		2010 (n =62)		2013 (n=78)		2015 (n=27)	
		Range	Mean	Range	Mean	Range	Mean
Dead trees	Fraction of dead trees	0..41	6	0..50	7	0..35	11
Broken trees	Trees with mechanical or wind break	0..43	8	0.44	9	0..35	8
Resin exudation	Trees with honey fungus resin exudation	0..18	5	0..44	8	0..21	6
Discoloration	Decreasing chlorophyll concentration causing color changes in foliage	0..33	10	0..33	7	0..23	5
Dry tree top	Fraction of trees with dry tree tops	0..40	10	0..33	10	0..18	9
Reduced increment	Reduced increment of top shoots	-	-	0..66	20	0..45	13
IUFRO vitality	Categorization based on visual classification of 10 trees per plot, distinguishing vital individuals, normal/average grown trees, and weak/suppressed trees	0..50	20	0..33	10	0..67	9

Remote Sensing data

Satellite multispectral

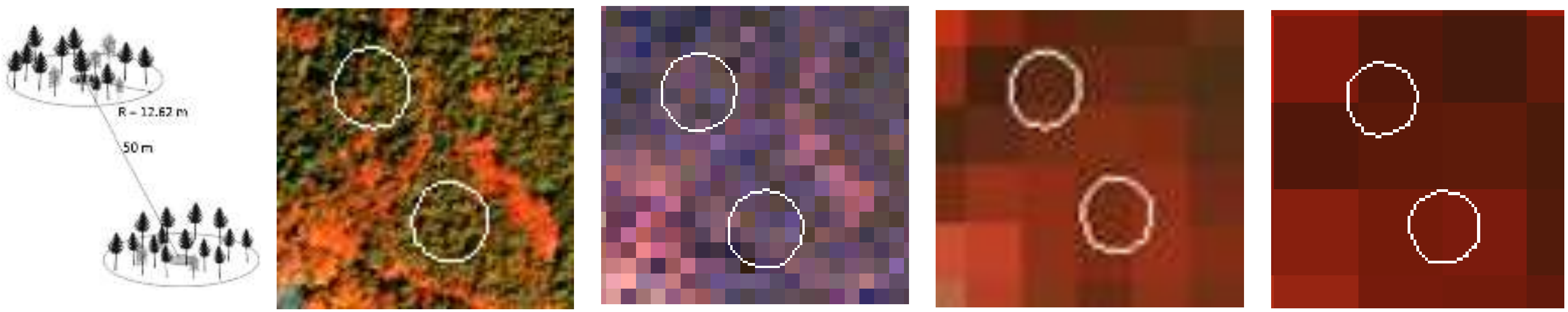
MODIS
Landsat ETM
Sentinel -2

Airborne hyperspectral

Study area

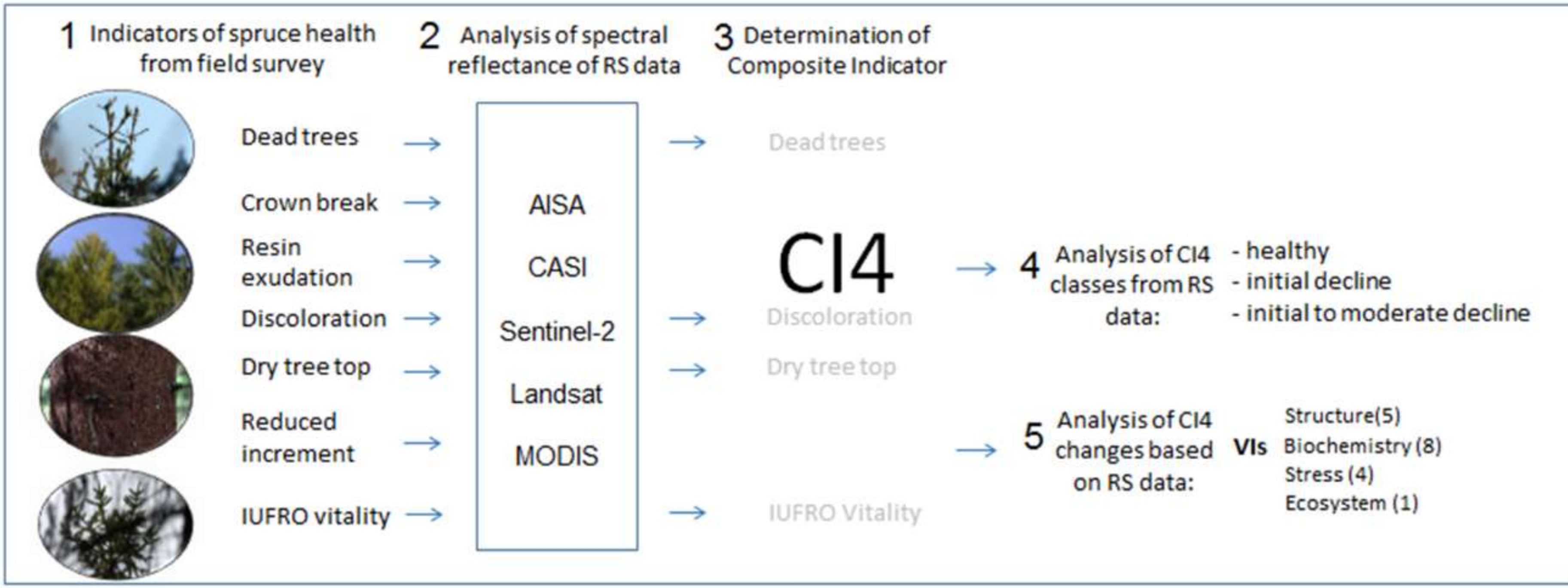
Date	Sensor	Spectral range [μm]	Number of spectral bands	Spatial resolut. [m]
		Airborne data		
10.8.2010	HyMap	0.45..2.49	125	5
8.9.2013	AISA	0.40..1.99	65	5
5.6.2015	CASI	0.37..1	72	1
		Satellite data		
2010	Landsat 5	0.45..2.35	6	30
2013	Landsat 8	0.45..2.29	6	30
2015	Landsat 8	0.45..2.29	6	30
7.8.2015	Sentinel-2	0.49..2.19	9	20
2015	MODIS	0.45..2.16	7	250

Remote Sensing data

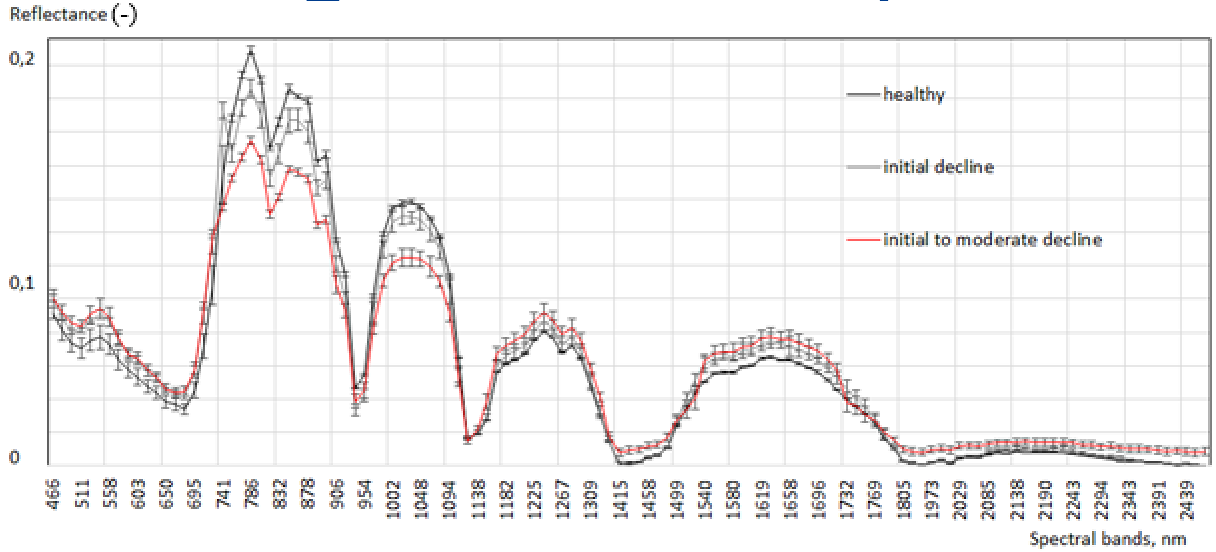


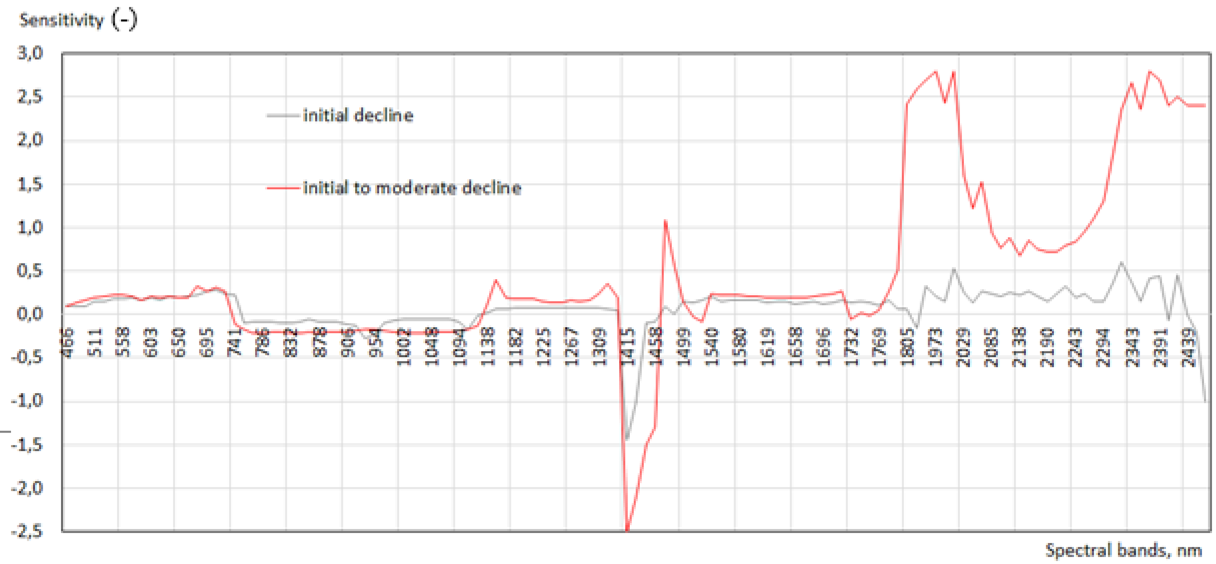
field | 1 m | 5 m | 20 m | 30 m

Workflow


1 Indicators of spruce health from field survey
2 Analysis of spectral reflectance of RS data
3 Determination of Composite Indicator
Dead trees
Crown break
Resin exudation
Discoloration
Dry tree top
Reduced increment
IUFRO vitality
AISA
CASI
Sentinel-2
Landsat
MODIS
Dead trees
CI4
Discoloration
Dry tree top
IUFRO Vitality
4 Analysis of CI4 classes from RS data:
- healthy
- initial decline
- initial to moderate decline
5 Analysis of CI4 changes based on RS data:
VIs
Structure(5)
Biochemistry (8)
Stress (4)
Ecosystem (1)

Decline categories of composite indicator





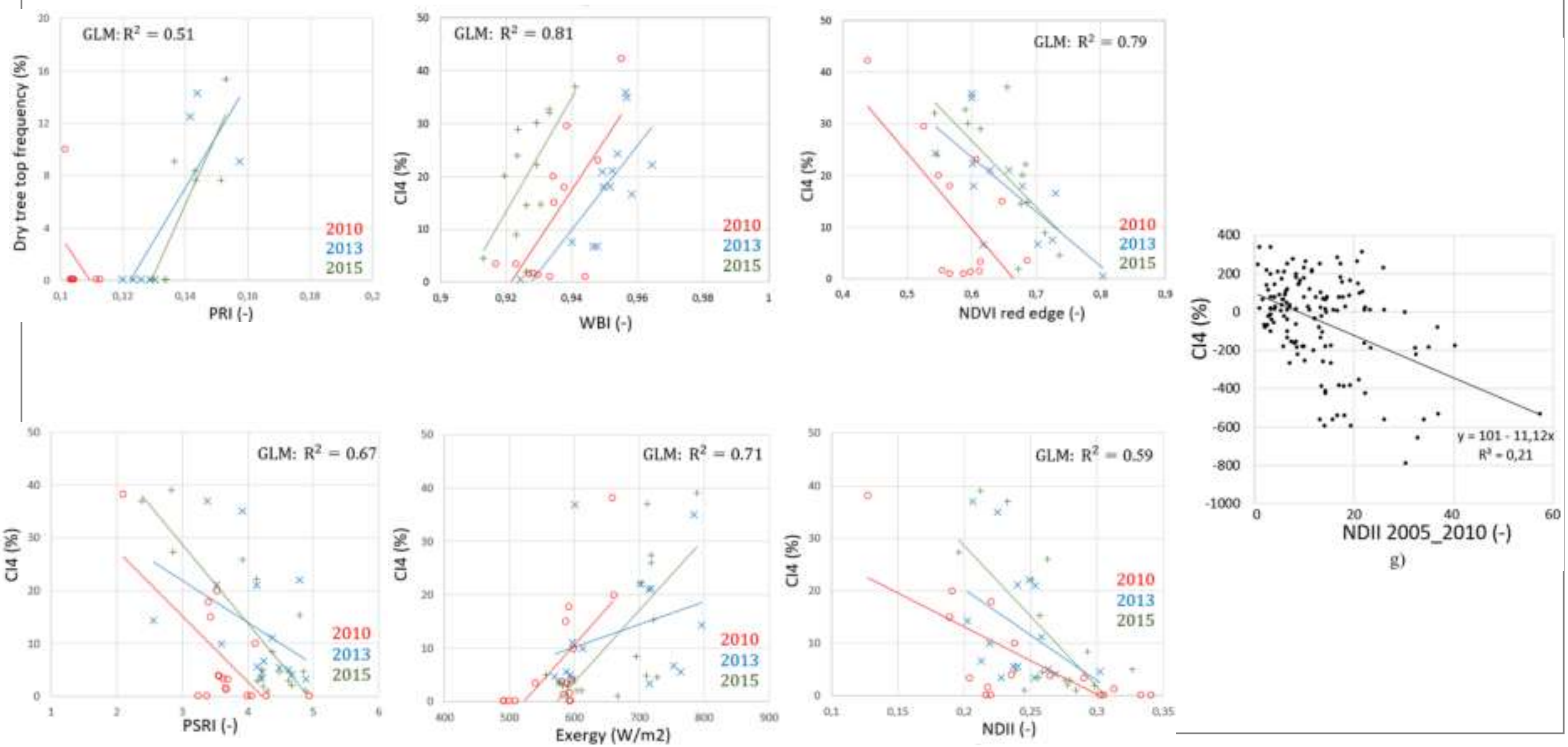
Healthy

Initial

Initial to moderate decline

VI	Equation	Data used	Referense	R^2
Vegetation structure				
$NDVI_{red\_edg}$	$(\rho_{750}-\rho_{705})/(\rho_{750}+\rho_{705})$	HS	Gitelson and Merzlyak 1994	**0.57**
NDVI	$(\rho_{820}-\rho_{650})/(\rho_{820}+\rho_{650})$	MS	Rous et al. 1974	0.39
SR	ρ_{820}/ρ_{650}	MS	Birth et al. 1968	0.21
GNDVI	$(\rho_{820}-\rho_{550})/(\rho_{820}+\rho_{550})$	MS	Gitelson et al. 1998	0.09
GRVI	ρ_{820}/ρ_{550}	MS	Sripada et al. 2006	0.05
Biochemistry				
PSRI	$(\rho_{680}-\rho_{500})/\rho_{750}$	MS	Merzlyak et al. 1999	**0.71**
WBI	ρ_{970}/ρ_{900}	HS	Penuelas et al. 1995	**0.63**
SIPI	$(\rho_{800}-\rho_{445})/(\rho_{800}-\rho_{680})$	HS	Penuelas et al. 1995	0.02
MSI	ρ_{1620}/ρ_{820}	MS	Hunt et al. 1989	0.36
CARI	$(\rho_{700}-\rho_{670})-0.2*(\rho_{700}-\rho_{550})$	HS	Kim 1994	0.14
ARI_NIR	$\rho_{800} \times (1/\rho_{550} - 1/\rho_{700})$	MS	Gitelson et al. 2001	0.06
NDMI	$(\rho_{860} - (\rho_{1640}-\rho_{2130}))/\rho_{860} + (\rho_{1640}-\rho_{2130})$	MS	Wang et al. 2007	0.34
NDWI	$(\rho_{857}-\rho_{1241}) / (\rho_{857}+\rho_{1241})$	HS	Gao 1996	0.41
Phisiology/stress				
PRI	$(\rho_{531}-\rho_{570}) / (\rho_{531}+\rho_{570})$	HS	Gamon et al. 1997	0.42
NDII	$(\rho_{819}-\rho_{1649})/(\rho_{819}+\rho_{1649})$	MS	Hardisky et al. 1983	**0.57**
CRI_550	$(1/\rho_{515})-(1/\rho_{550})$	HS	Gitelson et al. 2003, 2006	0.18
CRI_700	$(1/\rho_{515})-(1/\rho_{700})$	HS		0.17
Ecosystem state				
Exergy	$E_x = E^{out}\left(K + \ln\frac{E^{out}}{E^{in}}\right) + B$	MS	Jorgensen and Svirezhev, 2004	**0.57**

Relationships between CI4 and selected VIs across the entire time period



Conclusion

- dead tree, discoloration, dry tree top and IUFRO vitality were composed to CI4;
- sensitivity peaks for decline categories of CI4 were explored;
- PRI, WBI, NDVI, PSRI, NDII and exergy demonstrated a good potential to estimate CI4;
- use of airborne hyperspectral vegetation indices (VIs) was shown to be more efficient in matching composite spruce decline indicator CI4 than the satellite VIs.

Thank You for Your attention!