Site index curves for pedunculate oak (*Quercus robur* L.) in Srem region of Serbia: mapping the current site productivity as reference point for risk analysis

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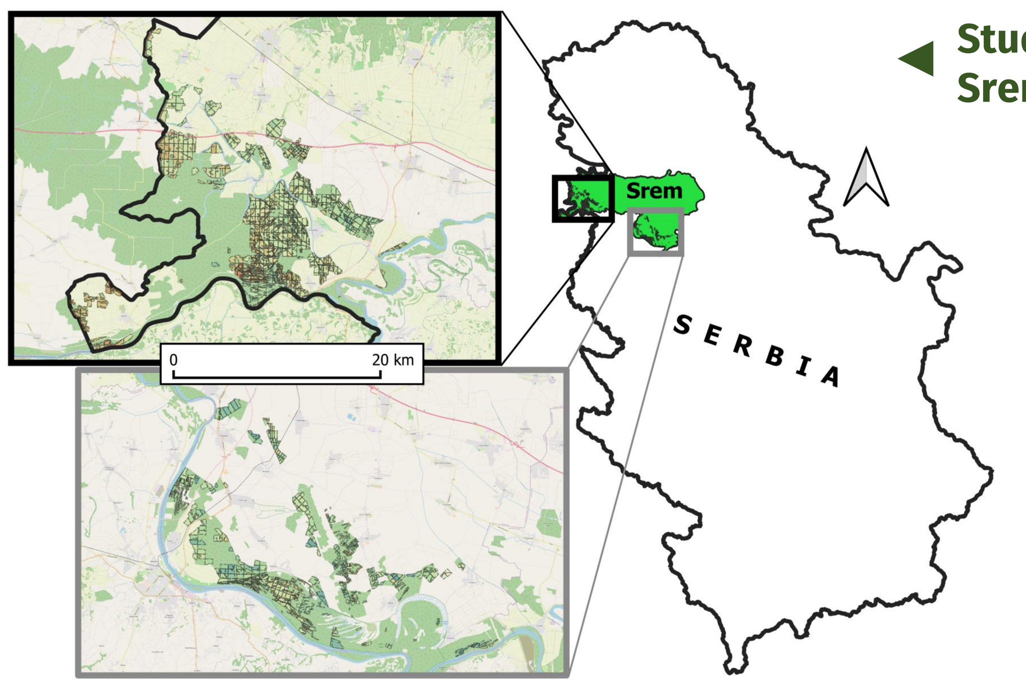
1. INTRODUCTION

Predicting the possible environmental and socio-economic consequences of climate change depends on a reliable comparison of the current and future productivity. Although sustainable forest management should rely on forest site productivity figures, tools for the productivity stratification of highly valuable pedunculate oak stands in the Srem region of Serbia are currently lacking. The most commonly used scale for site quality classification is obtained by sectioning the height-age oscillation range with the desired number of the expected site index curves. The ideal data source for height growth modelling is forest inventory surveys since they contain the complete variation heights along a spatial and ecological gradient. Yet, the usage of those datasets in natural stands is usually restricted due to the unknown age structure. However, fact that light-demanding species are naturally preconditioned to even-aged structure, together with huge commercial interest for pedunculate oak wood, have affected the management plans to contain useful records of stand's age.

- **Development of the first dynamic site index curves (SI) for the pedunculate oak in the Srem region of Serbia.**
- **Creating the spatially continuous productivity map covering a total of 22 management units**

2. MATERIAL & METHODS

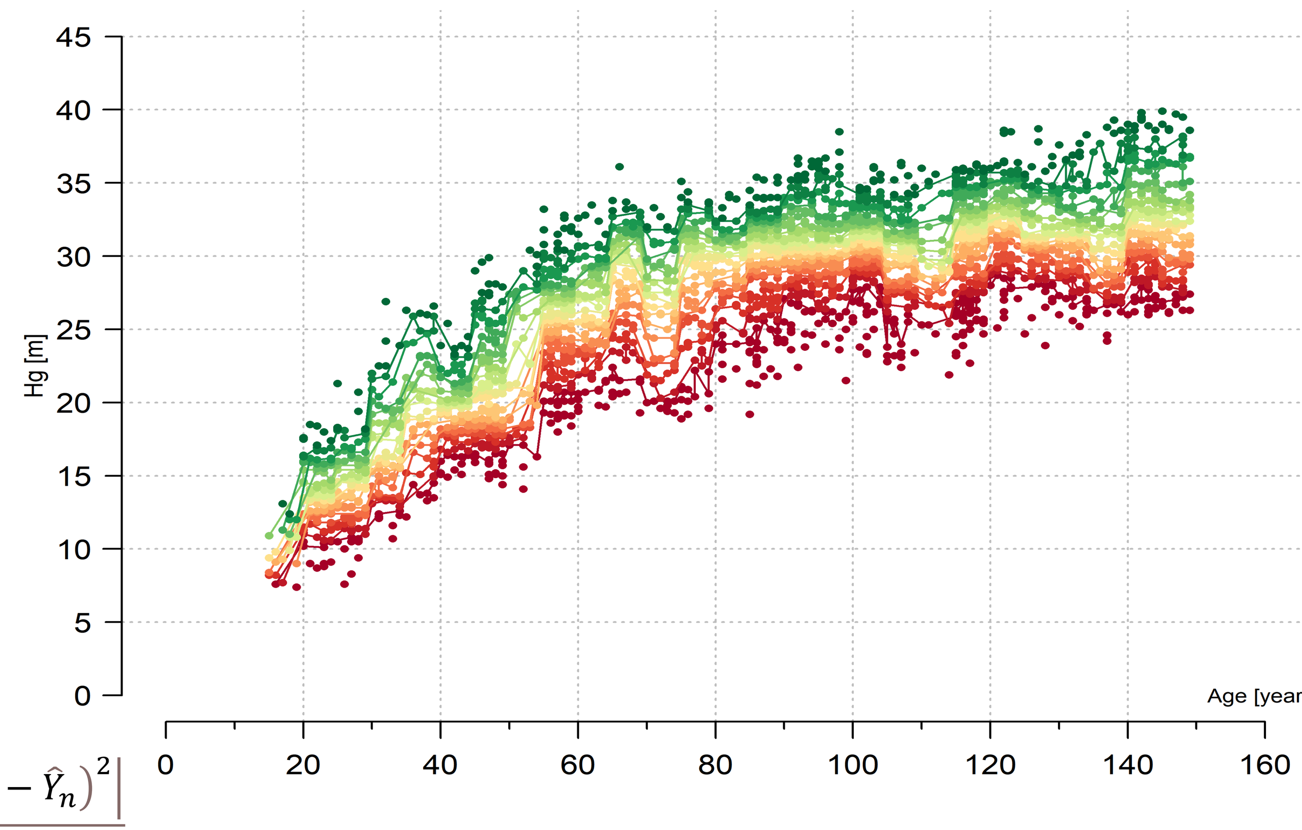


Study of height growth of pedunculate oak are collected in Srem region located in north-western part of Serbia.

Models were calibrated & verified by using the network of 3636 detailed temporary sample plots (TSP).

	Parametrisation					Verification				
Age	N	$\bar{X}(SD)$		min	max	N	$\bar{X}(SD)$		min	max
20	153	24	3.91	15	30	93	24.81	3.25	19	30
40	251	41.2	5.68	31	50	155	43.77	4.68	31	50
60	252	61.03	5.43	51	70	226	59.81	4.59	51	70
80	257	81.18	5.77	71	90	244	83.35	5.2	71	90
100	301	100.05	5.62	91	110	366	99.81	5.27	91	109
120	258	121.11	5.28	111	130	262	120.81	4.78	112	130
140	261	140.11	5.44	131	149	206	140.95	4.98	131	149

The candidate models were fitted to artificially established growth trajectories.



Five flexible polymorphic equations with variable asymptotes, derived by the generalized algebraic difference approach (GADA).

Base equation	Site-related parameters	Solution for X with initial conditions (H_0, T_0)	Dynamic form	
Hossfeld IV $H = \frac{b \cdot T^c}{T^c + a}$	$a = \beta_1 R_0^{-1}$; $b = \beta_2 + R_0$	$X_0 = H_0 - \beta_1 + \sqrt{(H_0 - \beta_1)^2 + \frac{2H_0 e^{\beta_2}}{T_0^c}}$	$H = H_0 \cdot \frac{T^c(T_0^c X_0 + e^{\beta 2})}{T_0^c(T^c X_0 + e^{\beta 2})}$	M1
Chapman-Richards: $H = a \cdot (1 - e^{-c \cdot T})^b$	$a = e^{X_0}$; $b = \beta_1 + \frac{\beta_2}{X_0}$	$X_o = \frac{(\ln H_0 - \beta_1 L_0) + \sqrt{(\ln H_0 - \beta_1 L_0)^2 - 4\beta_2 L_0}}{2}$; $L_0 = \ln(1 - e^{-cT_0})$	$H = H_0 \cdot \left(\frac{1 - e^{-cT}}{1 - e^{-cT_0}}\right)^{\beta_1 + \frac{\beta_2}{X_0}}$	M2
	$a = e^{X_0}$; $b = \beta_1 + \frac{\beta_2}{X_0}$	$X_o = \frac{(\ln H_0 - \beta_1 \ln(1 - e^{-cT_0}))}{1 + \beta_2 \ln(1 - e^{-cT_0})}$	$H = H_0 \cdot \left(\frac{1 - e^{-cT}}{1 - e^{-cT_0}}\right)^{\beta_1 + \beta_2 \cdot X_0}$	M3
Lundqvist: $H = a \cdot e^{-b \cdot T^{-c}}$	$a = e^{X_0}$; $b = \beta_1 + \frac{\beta_2}{X_0}$	$X_o = \frac{\beta_1 \cdot T^{-c} + \ln H_0 + L_0}{2}$; $L_0 = \sqrt{(\beta_1 \cdot T_0^{-c} + \ln H_0)^2 + 4\beta_2 \cdot T_0^{-c}}$	$H = e^{X_0} \cdot e^{-(\beta_1 + \frac{\beta_2}{X_0}) \cdot T^{-c}}$	M4
Weibull: $H = a \cdot (1 - e^{-b \cdot T^c})$	$a = X_0$; $b = \beta_1 + \beta_2 X_0$	$X_0 = \frac{\ln H_0 - \beta_1 \cdot \ln(1 - e^{-T^c})}{1 + \beta_2 \cdot \ln(1 - e^{-T^c})}$	$H = e^{X_0 + (\beta_1 + \beta_2 X_0) \cdot \ln(1 - e^{-T^c})}$	M5

The best model is selected using:

- **quantitative measures of goodness of fit**

$$\bar{e} = \frac{\sum_{n=1}^{N}(Y_n - \widehat{Y_n})}{N} \qquad RMSE = \sqrt{\frac{\sum_{n=1}^{N}(Y_n - \hat{Y}_n)^2}{N - p}}$$

$$MEF = 1 - \frac{\sum_{n=1}^{N}(Y_n - \hat{Y}_n)^2}{\sum_{n=1}^{N}(Y_n - \bar{Y})^2} \qquad MAD = \frac{\sum_{n=1}^{N}\left|(Y_n - \hat{Y}_n)^2\right|}{N}$$

- **the analysis of residual scattering and**
- **the biological plausibility**

Expected SI_{100} for oak was first determined and then subsequently mapped for pure and mixed stands.

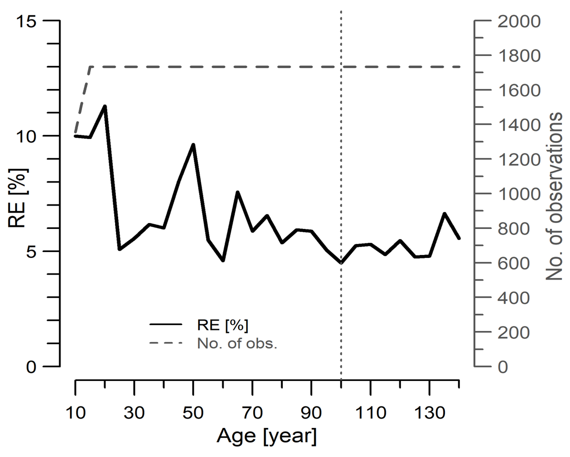
3. RESULTS & DISCUSSION

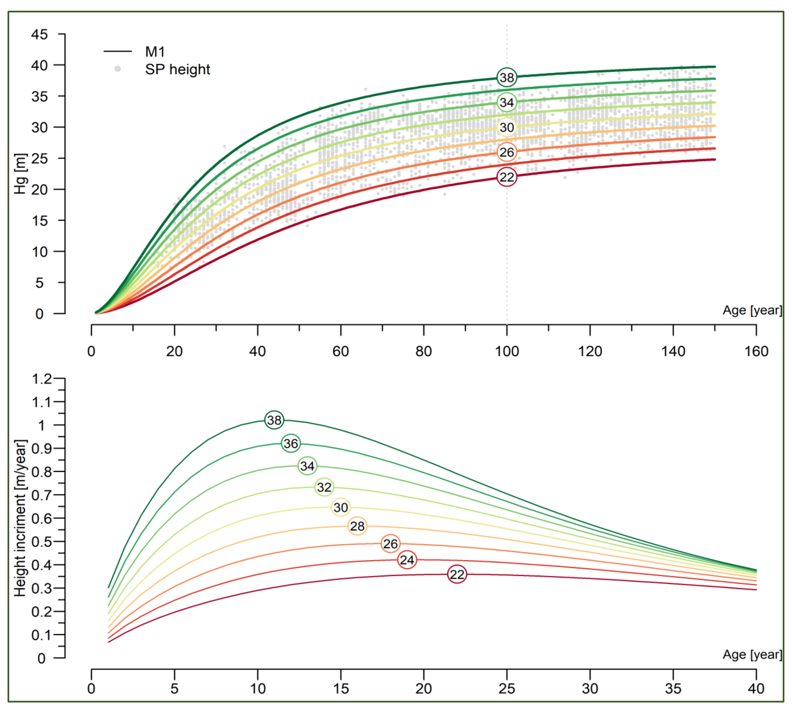
Model	Par.	Estimate	Standard error	t-value	p
M1	β_1	22.21846	2.640614	8.414127	***
	β_2	9.105472	0.2967	30.689166	***
	c	1.690559	0.061311	27.573571	***
	ρ_1	0.804632			
M2	β_1	-4.819214	0.959261	-5.023882	***
	β_2	21.198305	3.387182	6.25839	***
	c	0.028152	0.001047	26.876751	***
	ρ_1	0.788599			
M3	β_1	7.347052	0.988377	7.43345	***
	β_2	-1.7448	0.279239	-6.248406	***
	c	0.028154	0.001047	26.884978	***
	ρ_1	0.788547			
M4	β_1	-99.295894	34.830912	-2.850798	**
	β_2	434.709643	130.822338	3.322901	***
	c	0.886917	0.045135	19.65043	***
	ρ_1	0.83759			
M5	β_1	104.147915	18.576513	5.60643	***
	β_2	-24.54002	5.157348	-4.758264	***
	c	0.333087	0.005972	55.771999	***
	ρ_1	0.81869	2.305662	2.305662	

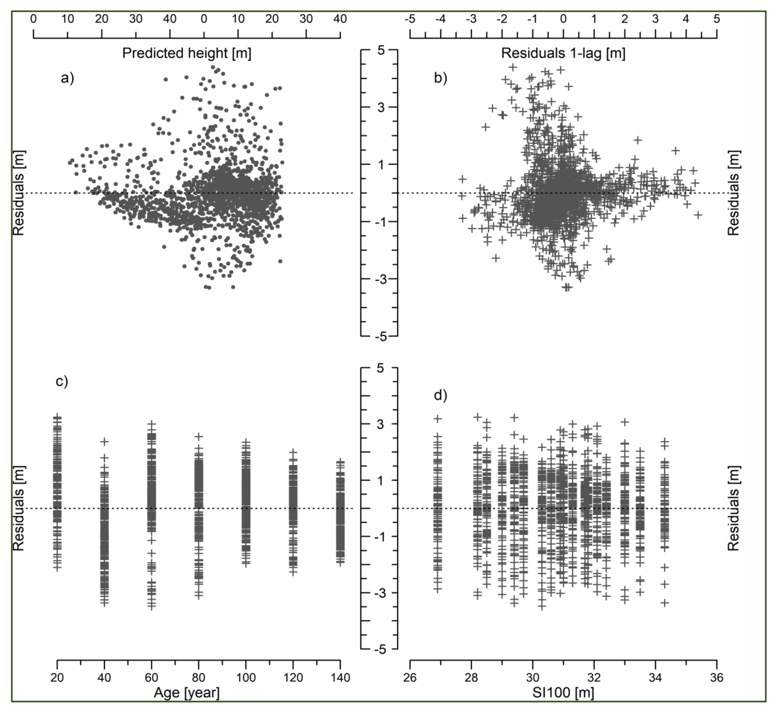
Model	Fitting statistics					Validation statistics			Growth		
	$\bar{e}$	$RMSE$	R^2	d-w	AIC	Bias	MAD	MEF	Asy.	Culm.	Age
M1	0.0631	1.1195	0.9676	1.98	3793.96	-0.0099	0.2439	0.9975	43.4	1.13	11
M2	0.0388	1.0973	0.9707	1.98	3898.04	0.0076	0.2457	0.9975	42.1	1.69	1
M3	0.0387	1.0972	0.9707	1.98	3897.97	0.0064	0.2460	0.9975	42.0	1.79	1
M4	0.0592	1.2588	0.9614	2.01	3970.89	0.0100	0.2440	0.9975	47.8	1.53	7
M5	0.0481	1.1879	0.9656	1.99	3942.91	0.0008	0.2474	0.9975	44.5	1.37	5

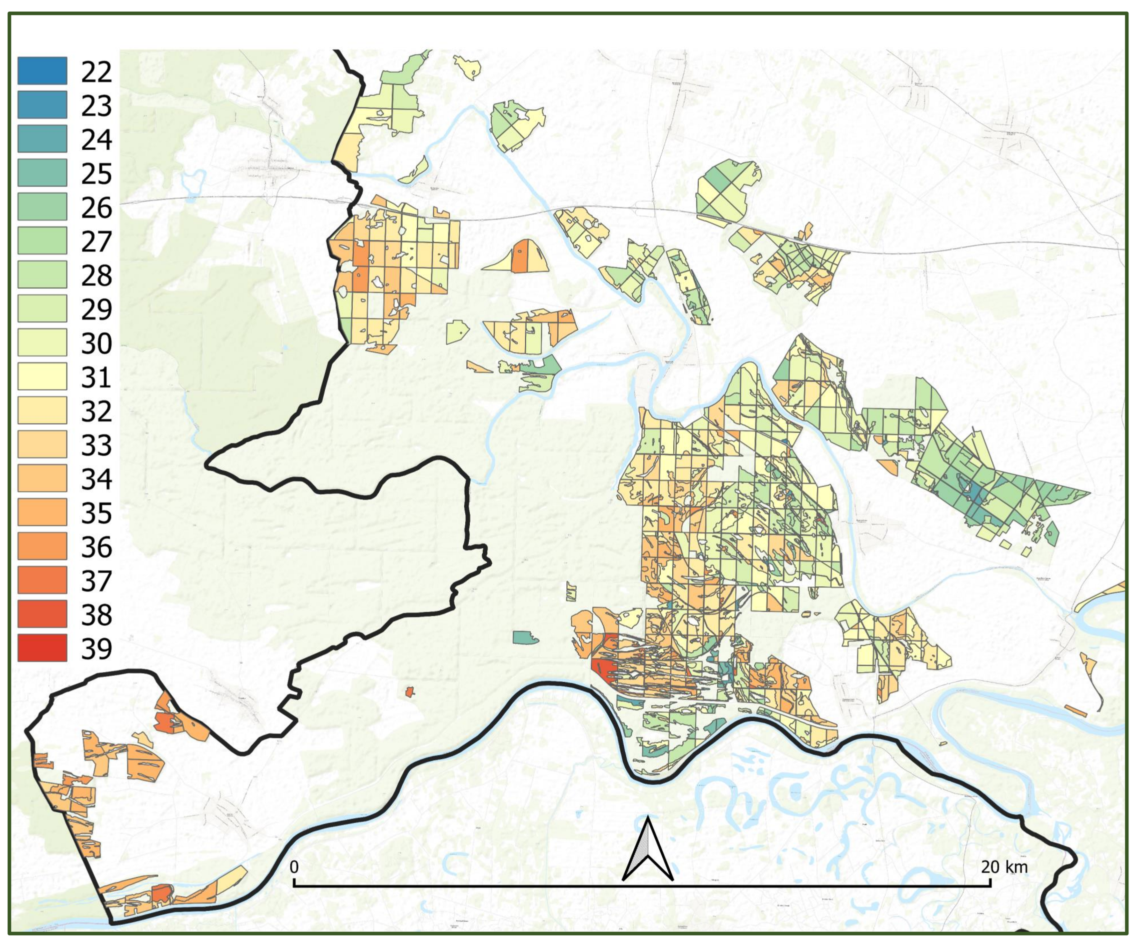
$$H = H_0 \cdot \frac{T^{1.690559}\left(T_0^{1.690559} X_0 + e^{9.105472}\right)}{T_0^{1.690559}\left(T^{1.690559} X_0 + e^{9.105472}\right)}$$

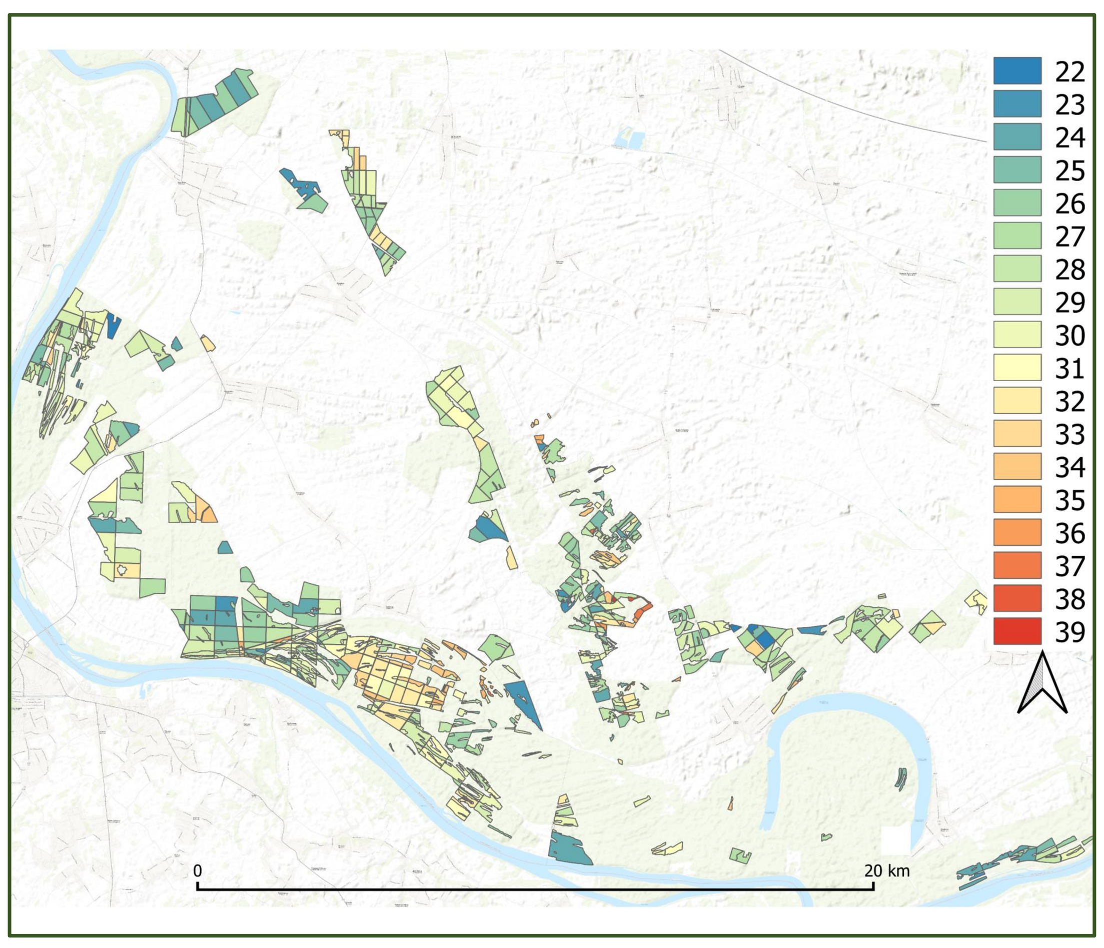
$$X_0 = H_0 - 22.21846 + \sqrt{(H_0 - 22.21846)^2 + \frac{2H_0 \cdot e^{9.105472}}{T_0^{1.690559}}}$$











4. REFERENCES

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