Supplementary Materials: Hyperspectral Sensors as a Management Tool to Prevent the Invasion of the Exotic Cordgrass *Spartina densiflora* in the Doñana Wetlands

Javier Bustamante, David Aragonés, Isabel Afán, Carlos J. Luque, Andrés Pérez-Vázquez, Eloy M. Castellanos and Ricardo Díaz-Delgado

Table S1. Cut-points used in image classification for each combination of spectral detection algorithm and Hyperspectral image for images without atmospheric correction.

Sensor [1]	Algorithm [2]	User Cut-Point [3]	ENVI Cut-Point [4]
CASI	SAM	0.132	0.05
	MF	0.399	0.4
	CEM	0.481	0.8
	ACE	0.010	0.65
	OSP	0.775	0.7
	TCIMF	0.438	0.4
CASI-4M	SAM	0.122	0.05
	MF	0.427	0.4
	CEM	0.480	0.8
	ACE	0.012	0.65
	OSP	0.807	0.7
	TCIMF	0.459	0.4
CASI-4M-SR	SAM	0.127	0.05
	MF	0.395	0.4
	CEM	0.484	0.8
	ACE	0.133	0.65
	OSP	0.784	0.7
	TCIMF	0.428	0.4
AHS	SAM	0.117	0.05
	MF	0.489	0.4
	CEM	0.575	0.8
	ACE	0.178	0.65
	OSP	0.798	0.7
	TCIMF	0.517	0.4
AHS-4M-SR	SAM	0.118	0.05
	MF	0.435	0.4
	CEM	0.519	0.8
	ACE	0.176	0.65
	OSP	0.789	0.7
	TCIMF	0.465	0.4

[1] CASI image at the original resolution of 1 m. CASI-4m: CASI image resampled at the resolution of the AHS image (4 m). AHS image at the original resolution of 4 m. SR = spectrally resampled to bands 1–20 of AHS; [2] SAM = Spectral Angle Mapper, MF = Matched Filter, CEM = Constrained Energy Minimization, ACE = Adaptive Coherence Estimator, OSP = Orthogonal Subspace Projection, TCIMF = Target-Constrained Interference-Minimized Filter; [3] Cut-point selected by the user using training polygons as the mean between the 95% upper confidence limit of the background and the 95% lower confidence limit of the target. Provided for analysis repeatability; [4] Cut-point selected by default by ENVI Target Detection Wizard.

Table S2. Cut-points used in image classification for each combination of spectral detection algorithm and Hyperspectral image after atmospheric correction and MNF transformation.

Sensor [1]	Algorithm [2]	User Cut-Point [3]	ENVI Cut-Point [4]
CASI-QM	SAM	1.108	0.6
	MF	0.368	0.4
	CEM	0.368	0.8
	ACE	0.007	0.3
	OSP	0.701	0.7
	TCIMF	0.465	0.4
CASI-4M-QM	SAM	1.322	0.6
	MF	0.413	0.4
	CEM	0.413	0.8
	ACE	0.010	0.3
	OSP	0.751	0.7
	TCIMF	0.456	0.4
CASI-4M-SR-QM	SAM	1.010	0.6
	MF	0.389	0.4
	CEM	0.389	0.8
	ACE	0.163	0.3
	OSP	0.697	0.7
	TCIMF	0.669	0.4
AHS-QM	SAM	0.756	0.6
	MF	0.473	0.4
	CEM	0.473	0.8
	ACE	0.139	0.3
	OSP	0.631	0.7
	TCIMF	0.482	0.4
AHS-4M-SR-QM	SAM	1.010	0.6
	MF	0.389	0.4
	CEM	0.389	0.8
	ACE	0.163	0.3
	OSP	0.697	0.7
	TCIMF	0.669	0.4

(1) CASI image at the original resolution of 1 m. CASI-4m: CASI image resampled at the resolution of the AHS image (4 m). AHS image at the original resolution of 4 m. SR = spectrally resampled to bands 1–20 of AHS. QM = Quick Atmospheric Correction and MNF transformation; (2) SAM = Spectral Angle Mapper, MF = Matched Filter, CEM = Constrained Energy Minimization, ACE = Adaptive Coherence Estimator, OSP = Orthogonal Subspace Projection, TCIMF = Target-Constrained Interference-Minimized Filter; (3) Cut-point selected by the user using training polygons as the mean between the 95% upper confidence limit of the background and the 95% lower confidence limit of the target. Provided for analysis repeatability; (4) Cut-point selected by default by ENVI Target Detection Wizard.

Table S3. Validation of the prediction of the spectral detection algorithms using the test polygons in each hyperspectral image with atmospheric correction.

Sensor [1]	Algorithm [2]	OE (%) [3]	CE (%)	CCR (%)	K	AUC
CASI-QM	SAM	0.41	0	99.85	0.9967	1
	MF	0.34	0.43	99.61	0.9916	0.9998
	CEM	0.34	0.43	99.61	0.9916	0.9998
	ACE	0.38	11.37	92.72	0.8499	0.9981
	OSP	0.42	1.50	98.90	0.9766	0.9997
	TCIMF	0.87	3.01	97.79	0.9530	0.9988
CASI-4m-QM	SAM	0	1.47	99.06	0.9799	1
	MF	2.06	1.18	98.50	0.9676	0.9990
	CEM	2.06	1.18	98.50	0.9676	0.9990
	ACE	1.72	11.09	92.32	0.8402	0.9933
	OSP	0.69	1.28	98.94	0.9772	0.9991
	TCIMF	5.15	2.75	96.38	0.9217	0.9946
CASI-4m-SR-QM	SAM	0.51	0	99.81	0.9960	1
	MF	0	0.29	99.81	0.9960	1
	CEM	0	0.29	99.81	0.9960	1
	ACE	0.34	0	99.88	0.9973	1
	OSP	0.86	1.37	98.81	0.9745	0.9989
	TCIMF	0.17	0.49	99.63	0.9919	0.9999
AHS-QM	SAM	1.06	0	99.62	0.9917	0.9998
	MF	0	0	100	1	1
	CEM	0	0	100	1	1
	ACE	0.53	0	99.81	0.9958	1
	OSP	0.18	1.50	98.98	0.9780	0.9994
	TCIMF	0	0	100.00	1	1
AHS-4m-SR-QM	SAM	0.17	0	99.94	0.9987	1
	MF	0	0	100	1	1
	CEM	0	0	100	1	1
	ACE	0.86	0	99.69	0.9932	0.9998
	OSP	0	2.65	98.31	0.9640	0.9999
	TCIMF	0.69	6.58	95.57	0.9064	0.9691

[1] Statistical validation at the pixel level with 77 test polygons (Table 3). CASI image at the original resolution of 1 m, sample size: target n = 9244 pixels, background n = 15599 pixels. CASI-4m: CASI image resampled at the resolution of the AHS image (4 m), sample size: target n = 582 pixels, background n = 1019 pixels. AHS image at the original resolution of 4 m, sample size: target n = 568 pixels, background n = 997 pixels. CASI & AHS-4m-SR images at 4m resolution in the area of spatial and spectral overlap sample size: target. n = 583 pixels, background n = 1019 pixels. The subfix QM indicates the images where atmospherically corrected and a MNF transformation applied; [2] AM = Spectral Angle Mapper, MF = Matched Filter, CEM = Constrained Energy Minimization, ACE = Adaptive Coherence Estimator, OSP = Orthogonal Subspace Projection, TCIMF = Target-Constrained Interference-Minimized Filter; [3] OE = omission error, CE = commission error, CCR = correct classification rate, K=Cohen's Kappa, AUC = area under the curve of the ROC plot. Producer's accuracy = (1 − OE), User's accuracy = (1 − CE). Omission and commission errors are in relation to the target. Cut-points selected for each algorithm and hyperspectral image are provided in Table S2.

Table S4. Evaluation of the prediction of the spectral detection algorithms for each hyperspectral image at a new site using presence/absence data of *S. densiflora*.

Sensor [1]	Algorithm [2]	OE (%) [3]	CE (%)	CCR (%)	K	AUC
CASI	SAM	13.95	20.59	81.98	0.63	0.89
	MF	2.33	14.71	90.09	0.80	0.94
	CEM	2.33	17.65	88.29	0.76	0.94
	ACE	2.33	22.06	85.59	0.71	0.95
	OSP	18.60	26.47	76.58	0.53	0.83
	TCIMF	0.00	19.12	88.29	0.77	0.94
CASI-4M	SAM	13.95	14.71	85.59	0.70	0.92
	MF	34.88	11.76	79.28	0.55	0.88
	CEM	34.88	11.76	79.28	0.55	0.88
	ACE	25.58	19.12	78.38	0.55	0.88
	OSP	20.93	27.94	74.77	0.49	0.84
	TCIMF	32.56	8.82	81.98	0.61	0.89
CASI-4M-SR	SAM	13.95	14.71	85.59	0.70	0.91
	MF	2.33	20.59	86.49	0.73	0.92
	CEM	2.33	20.59	86.49	0.73	0.92
	ACE	2.33	8.82	93.69	0.87	0.96
	OSP	18.6	27.94	75.68	0.51	0.84
	TCIMF	2.33	22.06	85.59	0.71	0.92
AHS	SAM	13.95	16.18	84.68	0.68	0.90
	MF	16.28	16.18	83.78	0.66	0.93
	CEM	16.28	16.18	83.78	0.66	0.93
	ACE	51.16	2.94	78.38	0.50	0.96
	OSP	20.93	23.53	77.48	0.54	0.85
	TCIMF	16.28	13.24	85.59	0.70	0.94
AHS-4M-SR	SAM	13.95	16.18	84.68	0.68	0.91
	MF	6.98	16.18	87.39	0.74	0.94
	CEM	6.98	16.18	87.39	0.74	0.94
	ACE	6.98	2.94	95.50	0.90	0.97
	OSP	18.60	25.00	77.48	0.54	0.86
	TCIMF	2.33	16.18	89.19	0.78	0.94

[1] Statistical validation at 111 points sampled at the "Codo de la Esparraguera" using 2-m diameter circles and reclassified as presence (*Spartina densiflora* coverage > 50%) or absence. Sample size = 43 presences vs. 68 absences. Points with intermediate coverage of *S. densiflora* 1%–50% were discarded. Results provided for comparative purpose with other studies. CASI image at the original resolution of 1 m. CASI-4m: CASI image resampled at the resolution of the AHS image (4 m). AHS image at the original resolution of 4 m. SR = spectrally resampled to bands 1–20 of AHS. QM = Quick Atmospheric Correction and MNF transformation; [2] AM = Spectral Angle Mapper, MF = Matched Filter, CEM = Constrained Energy Minimization, ACE = Adaptive Coherence Estimator, OSP = Orthogonal Subspace Projection, TCIMF = Target-Constrained Interference-Minimized Filter; [3] OE = omission error, CE = commission error, CCR=correct classification rate, K = Cohen's Kappa, AUC = area under the curve of the ROC plot. Producer's accuracy = (1 − OE), User's accuracy = (1 − CE). Omission and commission errors are in relation to the target. Cut-points selected for each algorithm and hyperspectral image are provided Table S1.

Table S5. Evaluation of the prediction of the spectral detection algorithms for each hyperspectral image at a new site using presence/absence data of *S. densiflora*. Images with atmospheric correction and MNF transformation.

Sensor [1]	Algorithm [2]	OE (%)[3]	CE (%)	CCR (%)	K	AUC
CASI-QM	SAM	4.65	22.06	84.68	0.69	0.93
	MF	2.33	14.71	90.09	0.80	0.95
	CEM	2.33	14.71	90.09	0.80	0.95
	ACE	4.65	14.71	89.19	0.78	0.95
	OSP	37.21	11.76	78.38	0.53	0.88
	TCIMF	18.60	11.76	85.59	0.70	0.92
CASI-4M-QM	SAM	2.33	26.47	82.88	0.66	0.94
	MF	30.23	11.76	81.08	0.59	0.90
	CEM	30.23	11.76	81.08	0.59	0.90
	ACE	27.91	19.12	77.48	0.53	0.85
	OSP	46.51	11.76	74.77	0.44	0.88
	TCIMF	39.53	11.76	77.48	0.51	0.87
CASI-4M-SR-QM	SAM	6.98	17.65	86.49	0.73	0.95
	MF	2.33	20.59	86.49	0.73	0.92
	CEM	2.33	20.59	86.49	0.73	0.92
	ACE	9.30	5.88	92.79	0.85	0.96
	OSP	51.16	13.24	72.07	0.38	0.86
	TCIMF	13.95	16.18	84.68	0.68	0.89
AHS-QM	SAM	13.95	5.88	90.99	0.81	0.94
	MF	18.60	13.24	84.68	0.68	0.94
	CEM	18.60	13.24	84.68	0.68	0.94
	ACE	20.93	2.94	90.09	0.78	0.97
	OSP	18.60	17.65	81.98	0.63	0.89
	TCIMF	20.93	13.24	83.78	0.66	0.94
AHS-4M-SR-QM	SAM	6.98	4.41	94.59	0.89	0.97
	MF	9.30	14.71	87.39	0.74	0.94
	CEM	9.30	14.71	87.39	0.74	0.94
	ACE	30.23	1.47	87.39	0.72	0.96
	OSP	37.21	8.82	80.18	0.56	0.90
	TCIMF	44.19	5.88	79.28	0.53	0.91

[1] Statistical validation at 111 points sampled at the "Codo de la Esparraguera" using 2-m diameter circles and reclassified as presence (*Spartina densiflora* coverage > 50%) or absence. Sample size = 43 presences vs. 68 absences. Points with intermediate coverage of *S. densiflora* 1%–50% were discarded. Results provided for comparative purpose with other studies. CASI image at the original resolution of 1 m. CASI-4m: CASI image resampled at the resolution of the AHS image (4 m). AHS image at the original resolution of 4 m. SR = spectrally resampled to bands 1–20 of AHS. QM = Quick Atmospheric Correction and MNF transformation; [2] AM= Spectral Angle Mapper, MF=Matched Filter, CEM = Constrained Energy Minimization, ACE = Adaptive Coherence Estimator, OSP = Orthogonal Subspace Projection, TCIMF = Target-Constrained Interference-Minimized Filter; [3] OE = omission error, CE = commission error, CCR=correct classification rate, K = Cohen's Kappa, AUC = area under the curve of the ROC plot. Producer's accuracy = (1 − OE), User's accuracy = (1 − CE). Omission and commission errors are in relation to the target. Cut-points selected for each algorithm and hyperspectral image are provided Table S2.

Table S6. Coefficients of GLM model fitted to AUC between model predictions and *S. densiflora* presence/absence at the evaluation site of "Codo de la Esparraguera".

	Estimate [2]	**Std. Error**	***t*-Value**	***P*** [3]
Intercept [1]	0.967	0.012		
sensor (CASI)	**−0.025**	**0.006**	**−4.468**	**0.0001**
spatial resolution (4M)	**−0.028**	**0.007**	**−3.721**	**0.0005**
spectral resolution (SR)	**0.021**	**0.006**	**3.683**	**0.0006**
atm. correction (RAW)	0.007	0.012	0.595	ns
Algorithm (CEM)	−0.004	0.012	−0.355	ns
Algorithm (MF)	−0.004	0.012	−0.355	ns
Algorithm (OSP)	**−0.050**	**0.012**	**−4.02**	**0.0002**
Algorithm (SAM)	0.015	0.012	1.248	ns
Algorithm (TCIMF)	**−0.027**	**0.012**	**−2.212**	**0.0321**
atm. correction (RAW):Algorithm (CEM)	−0.020	0.018	−1.114	ns
atm. correction (RAW):Algorithm (MF)	−0.018	0.018	−1.001	ns
atm. correction (RAW):Algorithm (OSP)	**−0.051**	**0.018**	**−2.903**	**0.0057**
atm. correction (RAW):Algorithm (SAM)	**−0.054**	**0.018**	**−3.084**	**0.0035**
atm. correction (RAW):Algorithm (TCIMF)	0.009	0.018	0.522	ns
Null deviance: 0.077896 on 59 degrees of freedom				
Residual deviance: 0.017334 on 45 degrees of freedom				
AIC: −286.69				

[1] Model formula AUC ~ sensor + spatial_resolution + spectral_resolution + atmospheric_correction × Algorithm. The intercept is the mean AUC for sensor (AHS) + spacial resolution (1M) + spectral resolution (ORI) + atmospheric correction (QM) + algorithm (ACE); [2] A negative estimate indicates a decrease in performance in relation to reference model in intercept; [3] Significant effects in bold, ns = not significant. The t-value tests for an estimate significantly different from 0; [4] SAM = Spectral Angle Mapper, MF = Matched Filter, CEM = Constrained Energy Minimization, ACE = Adaptive Coherence Estimator, OSP=Orthogonal Subspace Projection, TCIMF = Target-Constrained Interference-Minimized Filter, RAW = no atmospheric correction, QM = Quick Atmospheric correction and MNF transformation. 4M = 4 m spatial resolution, ORI = original bands, SR = spectrally resampled.