

Supplementary material

Colonisation patterns of supralittoral arthropods in naturally stranded wrack debris on Atlantic sandy beaches of Brazil and Spain

M. Carmen Ruiz-Delgado^{A,E}, Jenyffer Vierheller Vieira^B, M. José Reyes-Martínez^A, Carlos Alberto Borzone^B, Raimundo Outerelo^C, Juan Emilio Sánchez-Moyano^D and Francisco José García-García^A

^ADepartamento de Sistemas Físicos, Químicos y Naturales, Universidad Pablo de Olavide, Carretera Utrera Kilómetro 1, E-41013 Sevilla, Spain.

^BCentro de Estudos do Mar, Departamento de Ciências da Terra, Universidade Federal do Paraná, Avenida Beira Mar, s/n CEP 83255-000, Pontal do Sul, Pontal do Paraná, Paraná Brazil.

^CDepartamento de Zoología y Antropología Física, Facultad de Biología, Universidad Complutense de Madrid, Calle José Antonio Novais, 12, E-28040 Madrid, Spain.

^DDepartamento de Zoología, Universidad de Sevilla, Avenida Reina Mercedes 6, E-41012 Sevilla, Spain.

^ECorresponding author. Email mcruidel@upo.es

Table S1. Results of the mixed-model ANOVA for wrack biomass, the community structure indices (total density, species richness, Shannon–Wiener index) and the densities of the main taxa (*Platorchestia monodi*, *Phaleria testacea*, Nitidulidae and Cleridae) in southern Brazil between treatments (two levels; fixed factor), beaches (two levels; fixed factor), sampling times (six levels; fixed factor) and blocks (three levels; random factor and nested in beach)

d.f., degrees of freedom; m.s., mean square; ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$. Bold values indicate significant interactions of interest analysed by pairwise comparisons

Source	d.f.	Wrack biomass		Total density		Species richness		Diversity		<i>P. monodi</i>		<i>P. testacea</i>		Nitidulidae		Cleridae	
		m.s.	<i>F</i>	m.s.	<i>F</i>	m.s.	<i>F</i>	m.s.	<i>F</i>	m.s.	<i>F</i>	m.s.	<i>F</i>	m.s.	<i>F</i>	m.s.	<i>F</i>
Treatment (Tr)	1	1782.02	8.30*	34.65	41.75**	70.08	26.24**	4.41	16.53*	39.24	37.34**	44307.00	3.55	90.80	31.94**	47.65	49.97**
Beach (Be)	1	5255.20	107.61***	25.91	3.94	21.33	4.94	1.91	9.96*	13.55	4.47	161482.55	18.49*	366.33	39.29**	381.21	29.28**
Time (Ti)	5	3329.07	130.45***	28.46	5.35**	28.03	10.77***	1.81	11.49***	5.56	3.33*	12723.41	4.74**	36.76	8.15***	13.31	3.02*
Block (Bl)(Be)	4	48.84	3.56**	6.58	2.19	4.32	1.74	0.19	0.87	3.03	4.22**	8735.86	1.89	9.32	2.92*	13.02	4.39**
Tr × Be	1	419.25	1.95	19.32	23.28**	1.12	0.42	0.00	0.00	0.00	0.00	39823.24	3.19	0.10	0.04	16.76	17.58*
Tr × Ti	5	360.90	9.12***	19.54	10.21***	17.66	7.21***	1.28	5.73**	9.31	9.71***	15915.85	5.45**	31.30	8.18***	2.74	0.55
Be × Ti	5	957.41	37.52***	24.28	4.57**	21.84	8.39***	1.04	6.58***	12.57	7.54***	12460.36	4.64**	39.01	8.65***	27.33	6.20**
Tr × Bl(Be)	4	214.60	15.63***	0.83	0.28	2.67	1.07	0.27	1.20	1.05	1.46	12472.32	2.69*	2.84	0.89	0.95	0.32
Ti × Bl(Be)	20	25.52	1.86*	5.32	1.77*	2.60	1.05	0.16	0.71	1.67	2.32**	2682.78	0.58	4.51	1.41	4.41	1.48
Tr × Ti × Be	5	85.72	2.17	8.19	4.28**	2.37	0.97	0.15	0.69	1.13	1.18	15270.19	5.24**	3.00	0.79	4.97	1.01
Tr × Ti × Bl(Be)	20	39.59	2.88***	1.91	0.64	2.45	0.99	0.22	1.01	0.96	1.33	2921.92	0.63	3.83	1.20	4.94	1.66*
Residual	360	13.73		3.00		2.49		0.22		0.72		4625.74		3.19		2.97	
Cochran's test Transformation		C = 0.0547; n.s. Square root		C = 0.055; n.s. log(x+1)		C = 0.049; n.s. –		C = 0.0395; n.s. –		C = 0.039; n.s. log(x+1)		C = 0.301; n.s. –		C = 0.040 log(x+1)		C = 0.053; n.s. log(x+1)	

Table S2. Results of the mixed-model ANOVA for wrack biomass, community structure indices (total density, species richness, Shannon–Wiener index) and the densities of the main taxa (*Talitrus saltator*, and Tenebrionidae larvae) in south-western Spain between treatments (two levels; fixed factor), beaches (two levels; fixed factor), sampling times (six levels; fixed factor) and blocks (three levels; random factor and nested in beach)

d.f., degrees of freedom; m.s., mean square; ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$. Bold values indicated significant interactions analysed by pairwise comparisons

Source	d.f.	Wrack biomass		Total density		Species richness		Diversity index		<i>T. saltator</i>		Tenebrionid larvae	
		m.s.	<i>F</i>	m.s. × 10 ⁷	<i>F</i>	m.s.	<i>F</i>	m.s.	<i>F</i>	m.s.	<i>F</i>	m.s.	<i>F</i>
Treatment (Tr)	1	11.27	63.13**	2.20	24.36**	20.02	19.09*	0.54	5.20	19.29	27.25**	15.58	4.12
Beach (Be)	1	14.82	9.00*	10.94	217.46***	35.02	14.09*	15.14	85.27***	641.03	329.41***	3.57	4.49
Time (Ti)	5	2.22	3.17*	1.86	9.98***	14.44	6.55***	1.28	5.48**	66.60	21.60***	18.46	4.31**
Block (Bl)(Be)	4	1.65	8.26***	0.50	0.35	2.48	1.05	0.18	0.96	1.95	0.50	0.80	0.28
Tr × Be	1	4.06	22.72**	0.85	9.42*	2.52	2.40	0.06	0.59	0.29	0.41	0.01	0.00
Tr × Ti	5	5.34	24.37***	0.16	3.06*	0.95	0.47	0.18	0.86	13.99	3.10*	9.57	2.74*
Be × Ti	5	10.56	15.07***	1.36	7.31***	24.52	11.11***	2.68	11.51***	30.54	9.91***	43.33	10.12***
Tr × Bl(Be)	4	0.18	0.90	0.09	0.64	1.05	0.44	0.10	0.57	0.71	0.18	3.78	1.34
Ti × Bl(Be)	20	0.70	3.52***	0.19	1.32	2.21	0.93	0.23	1.26	3.08	0.79	4.28	1.52
Tr × Ti × Be	5	2.76	12.61***	0.16	3.01*	10.14	4.98**	0.65	3.06*	2.37	0.53	1.89	0.54
Tr × Ti × Bl(Be)	20	0.22	1.10	0.05	0.38	2.04	0.86	0.21	1.16	4.51	1.15	3.49	1.24
Residual	360	0.20		0.14		2.37		0.18		3.91		2.82	
Cochran's test		C = 0.0549; n.s.		C = 0.270; n.s		C = 0.046; n.s.		C = 0.052; n.s.		C = 0.053; n.s.		C = 0.049; n.s.	
Transformation		Fourth root		–		–		–		log(<i>x</i> +1)		log(<i>x</i> +1)	

Table S3. Total abundance (number of individuals) and percentage composition (percentage of community) of arthropods found in the wrack deposits on beaches of southern Brazil (Cem and Assenodi)

Taxa	Cem		Assenodi	
	Total abundance	Percentage of community	Total abundance	Percentage of community
Amphipoda				
Talitridae				
<i>Platorchestia monodi</i>	1283	53.10	771	37.00
Isopoda				
Tylidae				
<i>Tylos niveus</i>	1	0.04	1	0.05
Coleoptera				
sp. 1	5	0.20	9	0.43
larvae sp. 1	44	1.82	106	5.09
Tenebrionidae				
<i>Phaleria testacea</i>	149	6.17	2	0.10
Tenebrionid larvae	51	2.11	1	0.05
Staphylinidae				
<i>Bledius bonariensis</i>	17	0.70	678	32.53
<i>Bledius hermani</i>	22	0.91	–	–
<i>Bledius</i> sp. 1	16	0.66	35	1.68
<i>Bledius</i> sp. 2	–	–	19	0.24
<i>Gabronthus</i> sp. 1	5	0.20	–	–
Heteroceridae				
<i>Efflagitatus freudei</i>	–	–	6	0.29
<i>E. freudei</i> larvae	–	–	50	2.40
Cleridae	300	12.41	31	1.49
Carabidae	–	–	280	13.44
Nitidulidae	394	16.30	55	2.64
Scarabeidae				
Aphodinae sp. 1	9	0.36	4	0.19
Curculionidae	2	0.08	–	–
Araneae				
<i>Allocosa brasiliensis</i>	9	0.37	20	0.96
Araneae sp. 1	19	0.78	8	0.39
Araneae sp. 2	6	0.25	–	–
Araneae sp. 3	–	–	3	0.14
Araneae sp. 4	–	–	–	–
Araneae sp. 5	1	0.04	–	–
Diptera	83	3.44	19	0.91
Total density	2416		2084	
Total number of species	19		17	

Table S4. Total abundance (number of individuals) and percentage composition (percentage of community) of arthropods found in the wrack deposits on beaches of south-western Spain (Levante and Cortadura)

Taxa not collected on the beach are represented by en-dashes

Taxa	Levante		Cortadura	
	Total abundance	Percentage of community	Total abundance	Percentage of community
Amphipoda				
Talitridae				
<i>Talitrus saltator</i>	813	48.25	4569	74.23
Isopoda				
Armadillidae				
<i>Armadillium</i> sp. 1	4	0.24	–	–
Tylidae				
<i>Tylos europaeus</i>	–	–	40	0.65
Coleoptera				
Tenebrionidae				
<i>Phaleria bimaculata</i>	33	1.96	37	0.60
Tenebrionid larvae	69	4.09	125	2.03
Staphylinidae				
<i>Myrmecopora sulcata</i>	1	0.06	2	0.03
<i>Hydrosmeeta thinobioides</i>	7	0.42	–	–
<i>Tachyporus pusillus</i>	1	0.06	1	0.02
<i>Aleochara bipustulata</i>	1	0.18	–	–
<i>Acrotona orbata</i>	17	1.00	17	0.27
<i>Aloconota gregaria</i>	27	1.60	14	0.22
<i>Phytosus spinifer</i>	52	3.09	571	9.27
<i>Carpelimus rivularis</i>	13	0.77	8	0.13
<i>Anotylus nitidulus</i>	24	1.42	6	0.10
<i>Remus sericeus</i>	2	0.12	12	0.19
<i>Cafius xantholoma</i>	11	0.65	14	0.23
Curculionidae	7	0.42	6	0.11
Carabidae	15	0.89	5	0.09
Chrysomelidae	8	0.47	1	0.02
Elateroidae	2	0.12	–	–
Scarabidae	3	0.18	–	–
Histeridae	8	0.47	6	0.11
Araneae				
Lynphiidae	37	2.20	9	0.16
Agelinidae	1	0.06	–	–
Salticidae	2	0.12	–	–
Diptera				
Adults	276	16.38	49	0.89
Larvae sp. 1	153	9.08	9	0.16
Pupae sp. 1	24	1.42	5	0.09
Hymenoptera				
Pteromalidae	15	0.89	–	–
Hemiptera				
Psylloidea	39	2.31	2	0.04
Saldidae				
<i>Saldula saltoria</i>	15	0.89	–	–
Thysanoptera	2	0.12	–	–
Total abundance	1685		5508	
Total number of species	29		20	

Table S5. Temporal variation of macroinvertebrate taxa based on abundance classes (4th root transformed) for manipulated plots on sandy beaches on both studied regions

Pla, *Platorchestia monodi*; Pha, *Phaleria testacea*; Dip, Diptera; Tal, *Talitrus saltator*; Tyl, *Tylos europaeus*; Dip, Diptera; Bon, *Bledius bonariensis*; Her, *Bledius hermani*; Cle, Cleridae; Pha, *Phaleria bimaculata*; DipLv, dipteran larvae; Nit, Nitidulidae; TenLv, tenebrionid larvae; Ble, *Bledius* sp. 1; Alo, *Aloconota gregaria*; ColLv, coleopteran larvae sp. 1; Allo, *Allocosa brasiliensis*; Phy, *Phytosus spinifer*; Caf, *Cafius xantholoma*; Lyn, Lynphiidae; Ara, Arachnidae sp. 1; Eff, *Efflagitatus* larvae; Car, Carabidae; Acro, *Acrotona orbata*; Psy, Psylloidea; Car, Carabidae. Bold names relate to Assenodi Beach and Cortadura Beach

Abundance class	Southern Brazil Manipulated (days)						South-western Spain Manipulated (days)					
	1	3	6	16	32	47	1	3	6	16	32	47
4.5–5.0								Tal	Tal			
4.0–4.5												
3.5–4.0		Bon		Pla			Tal		Tal		Tal	
3.0–3.5		Pla	Bon		Pla	Pla			Phy	Tal		Tal
2.5–3.0	Bon	Car	Pla	Cle	Pla	Pla	Tal			Tal		
			Nit	Pla								
			Car									
2.0–2.5	Eff	Cle	Cle	Nit	Bon	ColLv		Tal		Phy	Dip	Tal
		Nit		Bon	ColLv	Nit		Dip			Phy	Lyn
				ColLv								
				Car								
1.5–2.0	Ble	Pha	Ble	Pha	Pla	Dip	Pha	TenLv	Dip	DipLv	Tal	Dip
	ColLv	TenLv	Pla	Eff	Cle	Car	TenLv		Pha	Phy	Phy	Phy
	Car	Dip			Pha		TenLv		TenLv	TenLv	Psy	Psy
		Pla			Dip		Phy			TenLv		Dip
					Ble							Phy
					Car							
1.0–1.5	Cle	Bon	Pha	Dip	Her	Cle	Dip	Pha	Alo	Dip	Alo	Ano
	TenLv	Ble	TenLv	Dip	TenLv	Pha	DipLv	Dip	Dip	Pha	Ano	Tyl
	Her	Ara	Dip		Cle	Nit	Alo	Tyl	Tyl	Alo	Lavt	TenLv
		ColLv	Allo		Nit	Bon	Dip	Alo	Alo	Caf	Caf	Car
		Eff			Eff	Dip		Phy	Caf	Pha		Lyn
					Allo	ColLv		DipLv		DipLv		
					Dip							
0.5–1.0	Bon	Her	Ara	Cle	ColLv	Bon	Ano	DipLv	DipLv	DipLv	Caf	Pha
	ColLv	Allo	ColLv	Allo	Allo	Ble		Phy	TenLv		Lyn	Alo
	Pla	Ble	Eff			TenLv		Lyn			Acro	Caf
		Allo				Ble		TenLv			Lyn	
		Dip				Allo		Lyn				
		ColLv						Car				
								Caf				

Table S6. PERMANOVA results and pairwise comparisons performed to compare macroinvertebrates assemblages for each geographical region (southern Brazil and south-western Spain)

Degrees of freedom (d.f.), mean square (m.s.) and pseudo-*F* are shown. Pairwise test: C, Control; T, Treatment. Bold values indicate significant results. The data were fourth-root-transformed.

Source	d.f.	South-western Spain		Southern Brazil	
		m.s.	Pseudo- <i>F</i>	m.s.	Pseudo- <i>F</i>
Treatment (Tr)	1	2242.00	5.63*	22956.00	22.43**
Beach (Be)	1	44534.00	202.49***	105740.00	70.10***
Time (Ti)	5	7407.90	9.77***	9762.00	11.96***
Block (Bl)(Be)	4	398.24	0.73	1508.60	2.15*
Tr × Be	1	1110.40	5.05*	4012.50	3.92*
Tr × Ti	5	920.26	1.21	5758.00	9.46***
Be × Ti	5	9281.90	17.77***	11075.00	13.56***
Tr × Bl(Be)	4	219.93	0.41	1023.70	1.46
Ti × Bl(Be)	20	758.16	1.40*	816.54	1.16
Tr × Ti × Be	5	1313.20	2.51**	711.85	1.17
Tr × Ti × Bl(Be)	20	522.18	0.96	608.87	0.87
Residual	360	540.34		703.15	

Pairwise test	Time (T)	Condition (C)	<i>P</i> (MC)		Condition	<i>P</i> (MC)
Tr × Ti × Be	T1	Lev × C v. T	0.0090	Tr × Ti	C v. T	0.0002
		Cort × C v. T	0.0077			
	T3	Lev × C v. T	0.1103		C v. T	0.0094
		Cort × C v. T	0.8303			
	T6	Lev × C v. T	0.5265		C v. T	0.0238
		Cort × C v. T	0.3123			
	T16	Lev × C v. T	0.4613		C v. T	0.2019
		Cort × C v. T	0.9243			
	T32	Lev × C v. T	0.3778		C v. T	0.7199
		Cort × C v. T	0.3911			
	T47	Lev × C v. T	0.1551		C v. T	0.2023
		Cort × C v. T	0.3857			

Table S7. SIMPER (Similarity Percentage) analysis listing species that contribute collectively to at least 70% of total assemblage dissimilarity between treatments (control and manipulated) at the sampling times (T1–T16)

Codes for higher taxa: AMP, Amphipods; COL, Coleoptera

(a) Southern Brazil		Average abundance		Contrib. %	Cum.%
		Manipulated	Control		
T1: 90.19% dissimilarity					
<i>P. monodi</i>	AMP	0.03	1.38	35.53	35.53
<i>B. bonariensis</i>	COL	0.59	0.46	21.05	57.09
Nitidulidae	COL	0.00	0.85	20.07	77.16
Cleridae	COL	0.06	0.39	9.42	83.19
<i>P. testacea</i>	COL	0.00	0.36	6.43	93.01
T3: 60.01% dissimilarity					
<i>P. monodi</i>	AMP	0.69	1.44	26.99	26.99
<i>B. bonariensis</i>	COL	0.99	0.80	24.69	51.68
Nitidulidae	COL	0.45	0.82	17.71	69.38
Cleridae	COL	0.32	0.52	12.38	81.76
<i>P. testacea</i>	COL	0.28	0.35	9.93	91.69
T6: 68.48% dissimilarity					
<i>P. monodi</i>	AMP	0.56	1.17	28.33	28.33
<i>B. bonariensis</i>	COL	0.72	0.44	25.80	54.14
Nitidulidae	COL	0.42	0.64	19.27	73.41
Cleridae	COL	0.34	0.43	13.69	87.09
<i>P. testacea</i>	COL	0.09	0.24	7.21	94.30
T16: 66.85% dissimilarity					
<i>P. monodi</i>	AMP	0.98	1.27	31.37	31.37
<i>B. bonariensis</i>	COL	0.37	0.21	20.45	51.83
Cleridae	COL	0.39	0.51	19.18	71.01
Nitidulidae	COL	0.32	0.31	14.94	85.95
<i>P. testacea</i>	COL	0.24	0.13	7.54	93.49
(b) South-western Spain		Average abundance		Contrib. %	Cum.%
		Manipulated	Control		
T1 – Levante: 53.58% dissimilarity					
<i>T. saltator</i>	AMP	0.98	1.69	43.18	43.18
Tenebrionid larvae	COL	0.53	0.00	22.69	65.88
Diptera	DIP	0.18	0.17	10.89	76.76
<i>P. bimaculata</i>	COL	0.25	0.00	9.10	85.86
T3 – Levante: 51.95% dissimilarity					
Diptera	DIP	0.54	1.23	28.34	28.34
<i>T. saltator</i>	AMP	0.76	0.82	22.73	51.07
Tenebrionid larvae	COL	0.59	0.65	18.09	69.16
<i>P. bimaculata</i>	COL	0.12	0.32	9.28	78.44
<i>P. spinifer</i>	COL	0.06	0.22	7.10	85.54
T1 – Cortadura: 44.32% dissimilarity					
<i>T. saltator</i>	AMP	1.49	2.12	39.51	39.51
Tenebrionid larvae	COL	0.22	0.62	22.05	61.57
<i>P. spinifer</i>	COL	0.21	0.56	19.29	80.86
Diptera	DIP	0.11	0.33	13.16	94.02
T3 – Cortadura: 44.32% dissimilarity					
<i>T. saltator</i>	AMP	2.26	2.46	42.17	42.17
Diptera	DIP	0.28	0.17	17.42	59.59
<i>P. spinifer</i>	COL	0.17	0.19	13.71	73.30