

Macrobenthic functional trait diversity at multiple scales along a subtropical estuarine gradient

Gisele C. Morais*, Joao B. Gusmao, Verônica M. Oliveira, Paulo Lana

*Corresponding author: gisellymorais@gmail.com

Marine Ecology Progress Series 624: 23–37 (2019)

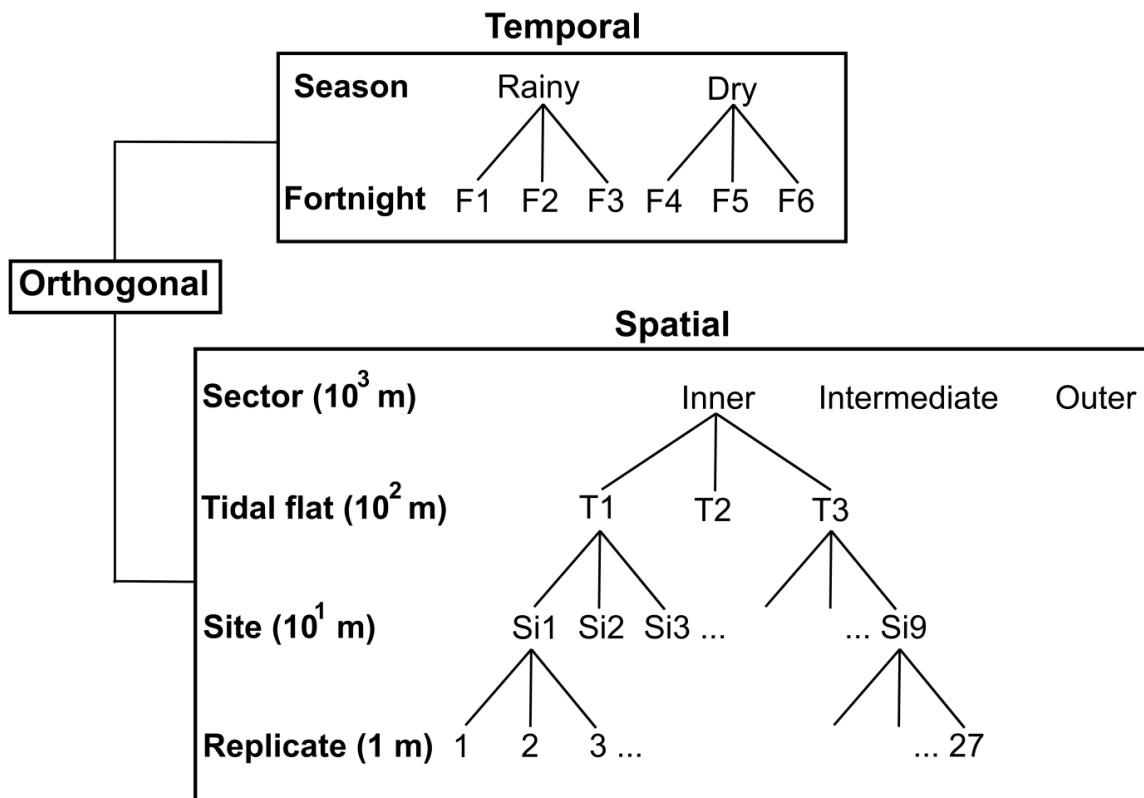


Fig. S1. Diagram of the experimental design and scales of temporal and spatial variability: Seasons (Rainy and Dry); Fortnights (F1 to F6); Sectors (Inner, Intermediate and Outer); Tidal flats (T1 to T9); and Sites (Si1 to Si27), with three replicate each

Table S1. Matrix “taxa by traits” for macrobenthic assemblages sampled in the subtropical estuarine system during rainy (March-April 2012) and dry (October-November 2012) seasons. Categories are coded by letters following an increasing order and according to descriptions presented in Table 1.

Taxa	Bioturbation type						Depth (cm)						Adult body size (mm)					
	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
Gammaridea sp.3	3	0	0	0	0	0	1.5	1.5	0	0	0	0	2	1	0	0	0	0
Corophiidae sp.1	0	1.5	1.5	0	0	0	1.5	1.5	0	0	0	0	1.5	1.5	0	0	0	0
Gammaridea sp.1	3	0	0	0	0	0	1.5	1.5	0	0	0	0	1.5	1.5	0	0	0	0
Monocorophium acherusicum	0	1.5	1.5	0	0	0	1.5	1.5	0	0	0	0	1.5	1.5	0	0	0	0
Senticaudata sp.1	3	0	0	0	0	0	1.5	1.5	0	0	0	0	1.5	1.5	0	0	0	0
Anomalocardia flexuosa	0	3	0	0	0	0	0	0	0.5	2	0.5	0	0.5	1	1	0.5	0	0
Phacoides pectinatus	0	3	0	0	0	0	0	1	2	0	0	0	1.5	1.5	0	0	0	0
Macoma constricta	0	3	0	0	0	0	0	1	1	1	0	0	0	0	1.5	1.5	0	0
Macoma tenta	0	3	0	0	0	0	0	1	1	1	0	0	2	1	0	0	0	0
Mytella guayanensis	3	0	0	0	0	0	3	0	0	0	0	0	2	1	0	0	0	0
Tagelus cf. plebeius	0	3	0	0	0	0	0	1	1	1	0	0	1.5	1	0.5	0	0	0
Tagelus divisus	0	3	0	0	0	0	0	1	1	1	0	0	1.5	1	0.5	0	0	0
Tellina cf. versicolor	0	3	0	0	0	0	0	1	1	1	0	0	0	0.5	2	0.5	0	0
Tellina sp.1	0	3	0	0	0	0	0	1	1	1	0	0	2	1	0	0	0	0
Brachyura Megalopa	3	0	0	0	0	0	3	0	0	0	0	0	1.5	1.5	0	0	0	0
Callinectes sp.1 (juvenile)	0	2.5	0	0.5	0	0	0	0.5	0.5	1	1	0	1	2	0	0	0	0
Uca thayeri	0	0	3	0	0	0	0	0	0	0	0.5	2.5	0	1	2	0	0	0
Panopeidae_sp.1	0	1	1	1	0	0	1	1	1	0	0	0	0.5	2	0.5	0	0	0
Alpheus sp.1	0	0	3	0	0	0	0.5	0.5	0.5	0.5	0.5	0.5	0	0	1	1	1	0
Edwardisiidae sp.1	3	0	0	0	0	0	1.5	1.5	0	0	0	0	1	1	1	0	0	0

Taxa	Bioturbation type						Depth (cm)						Adult body size (mm)					
	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
Harpacticoida sp.2	3	0	0	0	0	0	3	0	0	0	0	0	3	0	0	0	0	0
Cumacea sp.1	3	0	0	0	0	0	3	0	0	0	0	0	2.5	0.5	0	0	0	0
Bulla sp.1	0	3	0	0	0	0	1	2	0	0	0	0	1.5	1.5	0	0	0	0
Heleobia australis	3	0	0	0	0	0	2.5	0.5	0	0	0	0	2.5	0.5	0	0	0	0
Solarioorbis shumoi	0	3	0	0	0	0	1.5	1.5	0	0	0	0	3	0	0	0	0	0
Hirudinea sp.1	3	0	0	0	0	0	3	0	0	0	0	0	1.5	1.5	0	0	0	0
Trichoptera sp.1	0	0	0	0	3	0	3	0	0	0	0	0	1.5	1.5	0	0	0	0
Ceratopogonidae sp.1	3	0	0	0	0	0	3	0	0	0	0	0	3	0	0	0	0	0
Chironomidae sp.1	3	0	0	0	0	0	1.5	1.5	0	0	0	0	1.5	1.5	0	0	0	0
pupae of Diptera	3	0	0	0	0	0	1.5	1.5	0	0	0	0	1.5	1.5	0	0	0	0
Insect larva sp.1	3	0	0	0	0	0	1.5	1.5	0	0	0	0	1.5	1.5	0	0	0	0
Cassinidea fluminensis	1.5	1.5	0	0	0	0	2.5	0.5	0	0	0	0.5	3	0	0	0	0	0
Uromunna cf. peterseni	1.5	1.5	0	0	0	0	2.5	0.5	0	0	0	0.5	3	0	0	0	0	0
Pseudosphaeroma cf. jakobii	1.5	1.5	0	0	0	0	2.5	0.5	0	0	0	0.5	3	0	0	0	0	0
Nemertea sp.1	0	3	0	0	0	0	1	1	1	0	0	0	0	0	1	1	1	0
Nemertea sp.2	0	3	0	0	0	0	1	1	1	0	0	0	0	0	1	1	1	0
Oligochaeta	0	3	0	0	0	0	0	2	1	0	0	0	1.5	1	0.5	0	0	0
Ostracoda	3	0	0	0	0	0	3	0	0	0	0	0	3	0	0	0	0	0
Phoronis sp.1	0	0	0	0	3	0	0	1	1	1	0	0	1	1	1	0	0	0
Plathelminthes sp.1	3	0	0	0	0	0	3	0	0	0	0	0	1.5	1.5	0	0	0	0
Alitta succinea	0	1	2	0	0	0	0	0	0	1.5	1.5	0	0	0	0.5	0.5	1	1
Aricidea cf. albatrossae, Aricidea cf. fragilis, Aricidea sp.	0	1	2	0	0	0	0	0	0	1.5	1.5	0	0	0	0	0.5	1	1
Armandia hossfeldi	0	3	0	0	0	0	0	1.5	1.5	0	0	0	0	2	0.5	0.5	0	0
Boccardiella cf. truncata	0	1.5	1.5	0	0	0	0	0	1	1	1	0	0	3	0	0	0	0
Capitella cf. capitata	0	0	0	3	0	0	0	1.5	1.5	0	0	0	0	0.5	2	0.5	0	0
Dipolydora socialis	0	0	0	1.5	1.5	0	1	2	0	0	0	0	0	3	0	0	0	0

Taxa	Bioturbation type						Depth (cm)						Adult body size (mm)					
	A	B	C	D	E	F	A	B	C	D	E	F	A	B	C	D	E	F
<i>Exogone</i> sp.1	0	3	0	0	0	0	2	1	0	0	0	0	3	0	0	0	0	0
<i>Glycinde multidentis</i>	0	3	0	0	0	0	0.5	1	1.5	0	0	0	0	1	0.5	1	0.5	0
<i>Heteromastus</i> cf. <i>similis</i>	0	0	0	2	0	1	0	0	0	0	3	0	0	0.5	2	0.5	0	0
<i>Isolda pulchella</i>	0	0	0	0	3	0	0	1.5	1.5	0	0	0	0	0.5	2.5	0	0	0
<i>Laeonereis pandoensis</i>	0	3	0	0	0	0	0	2	1	0	0	0	0	0.5	0.5	1	0.5	0.5
<i>Hermundura tricuspis</i>	0	3	0	0	0	0	0	0	1	1	1	0	0	0.5	0.5	1.5	0.5	0
Lumbrineridae sp.1	0	3	0	0	0	0	0	0	0	1.5	1.5	0	0	1.5	1.5	0	0	0
<i>Magelona papillicornis</i>	0	0	3	0	0	0	0	1	1	1	0	0	0	0.5	1	1	0.5	0
<i>Mediomastus</i> sp.1	0	0	0	2	0	1	0	0	0	0	3	0	0	0.5	2	0.5	0	0
<i>Nephtys fluviatilis</i>	0	3	0	0	0	0	0	0.5	1.5	1	0	0	0	0.5	1	1	0.5	0
<i>Nereis</i> sp.1	0	3	0	0	0	0	0	1	1	1	0	0	0	0.5	1	1	0.5	0
<i>Oxydromus</i> sp.1	0	3	0	0	0	0	1.5	1.5	0	0	0	0	0.5	1	1.5	0	0	0
<i>Phyllodoce tamoya nomen nudum</i>	0	2	1	0	0	0	0.5	0.5	0.5	0.5	0.5	0.5	0	1.5	1.5	0	0	0
<i>Prionospio multibranchiata</i>	0	0	0	0	3	0	0	2	1	0	0	0	0	1	2	0	0	0
<i>Scoloplos</i> cf. <i>rubra</i>	0	3	0	0	0	0	0	0.5	1.5	1	0	0	0	0	0	1	1	1
<i>Sigambra grubii</i>	0	3	0	0	0	0	0	2	1	0	0	0	0	0.5	2	0.5	0	0
<i>Spiophanes missionensis</i>	0	0	0	0	3	0	0	1	1	1	0	0	0	1	1	1	0	0
<i>Streblospio</i> cf. <i>benedicti</i>	0	0	0	1.5	1.5	0	0	3	0	0	0	0	0	3	0	0	0	0
<i>Monokalliapseudes schubarti</i>	0	0	0.5	0	0	2.5	0.5	2.5	0	0	0	0	0	0.5	2	0.5	0	0
<i>Sinelobus stanfordi</i>	0	0	0.5	0	0	2.5	0.5	2.5	0	0	0	0	2	1	0	0	0	0

Taxa	Feeding type					Movement type				Body design			
	A	B	C	D	E	A	B	C	D	A	B	C	D
Gammaridea sp.3	2	1	0	0	0	0	0.5	2	0.5	0	0	3	0
Corophiidae sp.1	2	1	0	0	0	0	0	1	2	0	0	3	0
Gammaridea sp.1	2	1	0	0	0	0	0.5	2	0.5	0	0	3	0
Monocorophium acherusicum	2	1	0	0	0	0	0	1	2	0	1.5	1.5	0
Senticaudata sp.1	2	1	0	0	0	0	0	3	0	0	0	3	0
Anomalocardia flexuosa	0	3	0	0	0	0	0	0	3	0	0	0	3
Phacoides pectinatus	0	3	0	0	0	2	0	0	1	0	0	0	3
Macoma constricta	1.5	1.5	0	0	0	0	0	0	3	0	0	0	3
Macoma tenta	1.5	1.5	0	0	0	0	0	0	3	0	0	0	3
Mytella guayanensis	0	3	0	0	0	3	0	0	0	0	0	0	3
Tagelus cf. plebeius	3	0	0	0	0	0	0	1	2	0	0	0	3
Tagelus divisus	3	0	0	0	0	0	0	1	2	0	0	0	3
Tellina cf. versicolor	1.5	1.5	0	0	0	0	0	0	3	0	0	0	3
Tellina sp.1	1.5	1.5	0	0	0	0	0	0	3	0	0	0	3
Brachyura Megalopa	0	0	0	0	0	0	1.5	1.5	0	0	0	3	0
Callinectes sp.1 (juvenile)	0	0	1.5	0	1.5	0	1.5	1.5	0	0	0	3	0
Uca thayeri	3	0	0	0	0	0	0	1.5	1.5	0	0	3	0
Panopeidae_sp.1	0	0	0	0	0	0	0	1.5	1.5	0	0	3	0
Alpheus sp.1	0	0	0.5	0	2.5	0	0.5	1.25	1.25	0	0	3	0
Edwardisiidae sp.1	0	0	0	0	3	3	0	0	0	3	0	0	0
Cnidaria – simple Polyp sp.1	0	0	0	0	3	3	0	0	0	3	0	0	0
Cnidaria – branched Polyp sp.1	0	0	0	0	3	3	0	0	0	3	0	0	0
Harpacticoida sp.1	1.5	0	0	0	1.5	0	3	0	0	0	0	3	0
Harpacticoida sp.2	1.5	0	0	0	1.5	0	3	0	0	0	0	3	0
Cumacea sp.1	0	3	0	0	0	0	3	0	0	0	0	3	0

Taxa	Feeding type					Movement type				Body design			
	A	B	C	D	E	A	B	C	D	A	B	C	D
<i>Bulla</i> sp.1	0	0	1	1	1	0	0	3	0	0	0	0	3
<i>Heleobia australis</i>	3	0	0	0	0	0	1.5	1.5	0	0	0	0	3
<i>Solariorbis shumoi</i>	0	0	0	0	3	0	0	3	0	0	0	0	3
<i>Hirudinea</i> sp.1	0	0	1	0	2	0	1.5	1.5	0	3	0	0	0
<i>Trichoptera</i> sp.1	0	1	0	0	2	0	1.5	1.5	0	0	1.5	1.5	0
<i>Ceratopogonidae</i> sp.1	0	0	0	0	3	0	1	1	1	0	1	2	0
<i>Chironomidae</i> sp.1	1.5	0	0	0	1.5	0	0	3	0	0	1	2	0
pupae of <i>Diptera</i>	0	0	0	0	3	0	0	3	0	0	1	2	0
<i>Insect larva</i> sp.1	0	0	0	0	3	0	0	3	0	0	1	2	0
<i>Cassidinidea fluminensis</i>	0	0	0	3	0	0	1.5	1.5	0	0	0	3	0
<i>Uromunna</i> cf. <i>peterseni</i>	0	0	0	3	0	0	1.5	1.5	0	0	0	3	0
<i>Pseudosphaeroma</i> cf. <i>jakobii</i>	0	0	0	3	0	0	1.5	1.5	0	0	0	3	0
<i>Nemertea</i> sp.1	0	0	1.5	0	1.5	0	0	3	0	3	0	0	0
<i>Nemertea</i> sp.2	0	0	1.5	0	1.5	0	0	3	0	3	0	0	0
<i>Oligochaeta</i>	1.5	0	0	1.5	0	0	0	1	2	3	0	0	0
<i>Ostracoda</i>	0	3	0	0	0	0	3	0	0	0	0	1.5	1.5
<i>Phoronis</i> sp.1	0	3	0	0	0	1	0	0	2	0	3	0	0
<i>Plathelminthes</i> sp.1	0	0	1.5	0	1.5	0	0	3	0	3	0	0	0
<i>Alitta succinea</i>	1.5	0.5	0.5	0	0.5	0	1.5	0	1.5	3	0	0	0
<i>Aricidea</i> cf. <i>albatrossae</i> , <i>Aricidea</i> cf. <i>fragilis</i> , <i>Aricidea</i> sp.	1.5	0.5	0.5	0	0.5	0	1.5	0	1.5	3	0	0	0
<i>Armandia hossalfieldi</i>	3	0	0	0	0	0	0	3	0	3	0	0	0
<i>Boccardiella</i> cf. <i>truncata</i>	3	0	0	0	0	0	0	1	2	1.5	1.5	0	0
<i>Capitella</i> cf. <i>capitata</i>	2.5	0	0	0.5	0	0	0	0	3	1.5	1.5	0	0
<i>Dipolydora socialis</i>	1	1	0	1	0	1	0	0	2	1.5	1.5	0	0
<i>Exogone</i> sp.1	1	0	1	0	1	0	0	3	0	3	0	0	0

Taxa	Feeding type					Movement type				Body design			
	A	B	C	D	E	A	B	C	D	A	B	C	D
<i>Glycinde multidentis</i>	0	0	0	0	3	0	0	3	0	3	0	0	0
<i>Heteromastus cf. similis</i>	3	0	0	0	0	0	0	0	3	3	0	0	0
<i>Isolda pulchella</i>	3	0	0	0	0	0	0	0	3	0	3	0	0
<i>Laeonereis pandoensis</i>	3	0	0	0	0	0	0	2.5	0.5	1.5	1.5	0	0
<i>Hermundura tricuspis</i>	1	1	1	0	0	0	0	1	2	3	0	0	0
<i>Lumbrineridae sp.1</i>	1	0	1	0	1	0	0.5	1.25	1.25	3	0	0	0
<i>Magelona papillicornis</i>	1.5	1.5	0	0	0	0	0	1.5	1.5	3	0	0	0
<i>Mediomastus sp.1</i>	3	0	0	0	0	0	0	0	3	3	0	0	0
<i>Nephtys fluviatilis</i>	0	0	0	0	3	0	1.5	1.5	0	3	0	0	0
<i>Nereis sp.1</i>	1	0	1	0.5	0.5	0	0	1	2	3	0	0	0
<i>Oxydromus sp.1</i>	0	0	0	0	3	0	0	3	0	3	0	0	0
<i>Phyllodoce tamoya nomen nudum</i>	0.5	0	1	0	1.5	0	0	2	1	3	0	0	0
<i>Prionospio multibranchiata</i>	3	0	0	0	0	0	0	0	3	0	3	0	0
<i>Scoloplos cf. rubra</i>	3	0	0	0	0	0	0	0	3	3	0	0	0
<i>Sigambra grubei</i>	0	0	0.5	0	2.5	0	0	3	0	3	0	0	0
<i>Spiophanes missionensis</i>	1.5	1.5	0	0	0	0	0	0	3	0	3	0	0
<i>Streblospio cf. benedicti</i>	1.5	0.5	0	1	0	0	0	0	3	1.5	1.5	0	0
<i>Monokalliapseudes schubarti</i>	0	3	0	0	0	0	1	1	1	0	1	2	0
<i>Sinelobus stanfordi</i>	1.5	0	0	0	1.5	0	1	1	1	0	0.5	2.5	0

Table S2. Mean values (\pm SE) of environmental variables along a subtropical estuarine system in each sector and season.

Environmental variables	Rainy			Dry		
	Inner	Intermediate	Outer	Inner	Intermediate	Outer
Temperature ($^{\circ}$ C)	26.53 \pm 0.29	27.27 \pm 0.41	25.84 \pm 0.14	22.65 \pm 0.24	24.64 \pm 0.38	23.61 \pm 0.31
Salinity	8.33 \pm 0.53	23.33 \pm 0.83	31.48 \pm 0.28	2.07 \pm 0.38	18.93 \pm 0.83	27.85 \pm 0.56
pH	6.75 \pm 0.06	6.99 \pm 0.03	7.12 \pm 0.03	6.75 \pm 0.03	7.03 \pm 0.03	7.27 \pm 0.04
Chlorophyll-a (μ g.g $^{-1}$)	9.42 \pm 0.76	26.13 \pm 2.96	16.06 \pm 1.87	11.35 \pm 1.19	9.27 \pm 0.94	13.59 \pm 1.35
Phaeopigments (μ g.g $^{-1}$)	5.29 \pm 0.92	17.5 \pm 1.24	9.69 \pm 1.11	7.6 \pm 0.52	6.3 \pm 0.61	3.52 \pm 0.53
PAP ratio (μ g.g $^{-1}$)	0.31 \pm 0.04	0.44 \pm 0.03	0.38 \pm 0.03	0.42 \pm 0.02	0.42 \pm 0.03	0.19 \pm 0.02
Nitrogen (mg N/g dry weight)	0.56 \pm 0.11	0.86 \pm 0.08	0.94 \pm 0.15	4.64 \pm 0.67	0.56 \pm 0.13	0.17 \pm 0.04
Phosphorus (mg P/g dry weight)	1.15 \pm 0.07	2.22 \pm 0.1	1.4 \pm 0.17	2.14 \pm 0.14	2.2 \pm 0.26	1.72 \pm 0.21
N:P ratio (μ mol/g dry weight)	0.97 \pm 0.19	0.84 \pm 0.06	1.52 \pm 0.27	5.02 \pm 0.61	0.97 \pm 0.23	0.3 \pm 0.08
C:N ratio (μ mol/g dry weight)	8.41 \pm 2.45	29.07 \pm 2.39	17.04 \pm 7.03	6.18 \pm 0.53	21.56 \pm 4.45	88.38 \pm 36.9
Organic matter (%)	1.56 \pm 0.28	8.55 \pm 0.82	2.68 \pm 0.63	1.74 \pm 0.2	2.78 \pm 0.25	2.54 \pm 0.22
Redox discontinuity layer (cm)	9.94 \pm 1.06	1.84 \pm 0.18	1.87 \pm 0.12	12.59 \pm 0.64	1.21 \pm 0.1	1.7 \pm 0.11
Grain size (μ m)	218.32 \pm 14.82	69.4 \pm 5.79	117.58 \pm 7.7	197.46 \pm 16.4	94.94 \pm 2.44	113.32 \pm 3.19

Table S3: Results of the RLQ analysis relating macrobenthic species traits and environmental variables for the rainy season (only 3 dimensions (out of 13) are shown).

	Axis 1	Axis 2	Axis 3
Eigenvalues:	11.61	1.11	0.14
Proj. inertia (%):	89.6	8.58	1.1
Cum. proj. inertia (%):	89.6	98.18	99.29
Total inertia:	12.96		

Eigenvalues decomposition:				
	covar.	sd.R	sd.Q	corr.
Axis 1:	3.408	1.962	2.453	0.708
Axis 2:	1.055	1.096	1.989	0.484

Inertia & coinertia R (PCA):			
	inertia	max.	ratio
Axis 1:	3.8493	4.285	0.898
Axis 1 and 2:	5.0498	6.75	0.748

Inertia & coinertia Q (PCA):			
	inertia	max.	ratio
Axis 1:	6.016	7.511	0.801
Axis 1 and 2:	9.97	13.965	0.712

Correlation L (CA):			
	corr.	max.	ratio
Axis 1:	0.708	0.954	0.743
Axis 2:	0.484	0.877	0.552

Table S4: Results of the RLQ analysis relating macrobenthic species traits and environmental variables for the dry season (only 3 dimensions (out of 13) are shown).

	Axis 1	Axis 2	Axis 3
Eigenvalues:	8.72	0.67	0.39
Proj. inertia (%):	88.06	6.77	3.89
Cum. proj. inertia (%):	88.06	94.83	98.72
Total inertia:	9.91		

Eigenvalues decomposition:

	covar.	sd.R	sd.Q	corr.
Axis 1:	2.954	1.860	2.375	0.669
Axis 2:	0.819	1.656	2.241	0.221

Inertia & coinertia R (PCA):

	inertia	max.	ratio
Axis 1:	3.460	3.669	0.943
Axis 1 and 2:	6.203	6.733	0.921

Inertia & coinertia Q (PCA):

	inertia	max.	ratio
Axis 1:	5.639	6.037	0.934
Axis 1 and 2:	10.660	11.623	0.917

Correlation L (CA):

	corr.	max.	ratio
Axis 1:	0.669	0.870	0.769
Axis 2:	0.221	0.662	0.333