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Evaluation of Beach Wrack for Use as an Organic Fertilizer: Temporal Survey in Different Areas

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Abstract We analysed the chemical composition of beach wrack (drift seaweed) to evaluate its potential for use as an organic fertilizer. For this purpose, two very different areas were selected for collecting samples of the material: a partially enclosed bay that is subjected to a high level of anthropogenic pressure and an open sea area. We sampled 13 beaches in these sites over a period of 1 year and analysed both the bulk (unseparated) samples and the constituent species. Beach wrack appears to be a potentially good material for producing high quality organic fertilizers, and the concentrations of N and K (especially in brown seaweeds) and of micronutrients (such as B) were particularly high. However, systematic collection of drift seaweed is difficult because of the seasonal variability in its presence. Furthermore, the low concentrations of P and the presence of extraneous matter in beach wrack collected in areas affected by anthropogenic pressure may limit use of the material. The temporal variability in the concentrations of certain nutrients must also be taken into account when using the beach wrack as a fertilizer. The concentrations of toxic metals in the material must be evaluated, particularly in areas subjected to high levels of anthropogenic pressure. Finally, the sustainability of beach wrack exploitation must be considered, as the material fulfils an ecological function as a habitat and resource for some beach-dwelling species.

Keywords Seaweed · Seagrass · Nutrients · Metals · Temporal variability · Fertilizing potential

Introduction

The use of drift seaweed present in the beach wrack as a natural fertilizer on agricultural land is a frequent activity in coastal areas throughout the world, although the practice has fallen into disuse in many areas (Stephenson 1968; Chapman 1970; Blunden 1991; Guiry and Blunden 1991; Zemke-White and Ohno 1999; McHugh 2003; Han et al. 2014). Several studies have shown the benefits that seaweed and seaweed extracts have on different crops. Thus, in addition to increasing crop production (Hong et al. 2007; Khan et al. 2009; Papenfus et al. 2013; Omar et al. 2015), the use of seaweed as a fertilizer improves crop resistance to biotic and abiotic stressors, improves the rooting rate and increases the nutrient concentrations in plant parts of commercial interest (Wu et al. 1997; Craigie 2011). Application of these organisms can also improve soil structure and fertility and can also have a liming effect on acid soils (Crouch et al. 1990; Blunden 1991; Cassan et al. 1992; Crouch and Van Staden 1992; Verkleij 1992; Patier et al. 1993; López-Mosquera and Pazos 1997). The absence of pathogens and the seeds of weed species that are usually present in other types of organic fertilizer is a further advantage.

Beach wrack, which is a natural component of coastal ecosystems, represents a source of allochthonous organic matter that maintains a large variety of primary and secondary consumers and after decomposition provides nutrients to coastal plants (Spiller et al. 2010; Mellbrand et al. 2011). Harvesting beach wrack must therefore be carried out sustainably. However, this valuable resource is sometimes problematical as eutrophication of coastal

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areas has become a worldwide problem (Nixon 1995; Ye et al. 2011; Zhang et al. 2013). In the study area (Galicia, NW Spain), the presence of large amounts of seaweed in intertidal areas can lead to asphyxiation and death of commercial populations of bivalves, such as clams and cockles (Niell et al. 1996). Beach wrack also affects the tourist sector in the summer months as its presence hinders recreational use of beaches. Large quantities of beach wrack are therefore removed from beaches in the study area every year. The material is not utilized and is dumped in rubbish tips, thus generating economic and environmental costs.

The use of beach wrack as a fertilizer has largely fallen into disuse in Galicia because of the widespread use of chemical fertilizers and the expense associated with collecting and transporting the material. However, the increased cost of industrial fertilizers and the increasing tendency to use organic or natural fertilizers have generated new interest in this traditional practice, especially for application in integrated ecological agricultural systems.

The aim of the present study was to obtain information about the properties of beach wrack as a raw material for elaborating fertilizers. For this purpose, we carried out a survey of the beach wrack collected from 13 beaches in two areas with very different characteristics, during a period of 1 year. We studied the quantities of beach wrack present and identified the main component plant species. We determined the chemical composition of both the unseparated material and the component species, paying particular attention to elements of particular importance for fertilizing agricultural soils (macro- and micronutrients) and to toxic metals, which must be evaluated in all material destined for agricultural use. This is essential information required for the assessment of organic material for possible commercial development as a fertilizer.

Material and Methods

Characteristics of the Study Areas

The study was carried out in two coastal areas in Galicia (NW Spain) with very different characteristics. In both areas, beach wrack was traditionally used as an organic fertilizer, although the practice is no longer common. In each of the areas, beaches relatively close to each other and also close to a possible processing point were chosen as sampling sites. One of the areas (San Simón Bay) is a fairly enclosed shallow bay (on average less than 7 m deep), situated at end of the Ría de Vigo (Fig. 1). Clams and cockles are cultivated in the intertidal zone, and mussels are cultivated on floating rafts in the deeper zone at the south end of the bay. The main population centre in the bay is Redondela, with approximately 30,000 inhabitants, although the whole area is densely populated, particularly towards the central and outer parts of the Ría de Vigo, with some 400,000 inhabitants. The zone is highly industrialized, and the entrance of contaminants from the outermost areas of the Ría de Vigo is favoured by the fact that approximately half of the volume of water in the bay is renewed during each tidal cycle (Romero and Prego 1995). The bays in this area are highly productive due to upwelling events that usually occur between April and October (Álvarez-Salgado et al. 1993). We selected six beaches in the San Simón Bay for fortnightly sampling (coinciding with spring tides) between November 2004 and October 2005. The frequency of sampling was established in consultation with farmers and fishermen in the area, who informed us that larger quantities of beach wrack were washed up on the beaches after spring tides.

The other study area comprised seven beaches exposed to the open sea in a scarcely industrialized zone with a much lower density of population. All except one of these beaches are situated between the towns of Foz and Burela, each of which have fewer than 10,000 inhabitants. Upwelling events are not frequent in the area, and shellfish cultivation is minimal. Sampling in the area was carried out between January and December 2006. Our experience in the first sampling area led us to reduce the sampling frequency in the second area (from fortnightly to monthly), although three replicate samples from each point were analysed. Hereafter, we will refer to this sampling area as the Foz beaches.

Sampling Strategy

We collected samples of fresh beach wrack (i.e. not dry or decomposed). In addition to seaweed and marine spermatophytes, the samples often contained other types of material, which we denominated extraneous matter. We classified this matter as organic (e.g. remains of terrestrial plants washed into the sea) and inorganic (highly diverse material derived from human activity). We estimated the percentage of extraneous material visually as follows: (1) <5 %, (2) 5–20 %, (3) 20–35 %, (4) 35–50 % and (5) >50 %.

We measured the entire length of each pile of beach wrack as well as the width and the height of the pile at each of six points selected at random. We also weighed the material (with a dynamometer, Electrosamson Salter Weigh-Tronix, capacity 25 kg) within a square of side 33 cm at each of the six points. Before weighing these samples, we removed all inorganic extraneous matter as well as large pieces of organic waste, although we left all small pieces of organic waste that would not need to be triturated prior to composting (a possible treatment for processing the material). We then used these data to determine the fresh weight and the total volume of wrack.

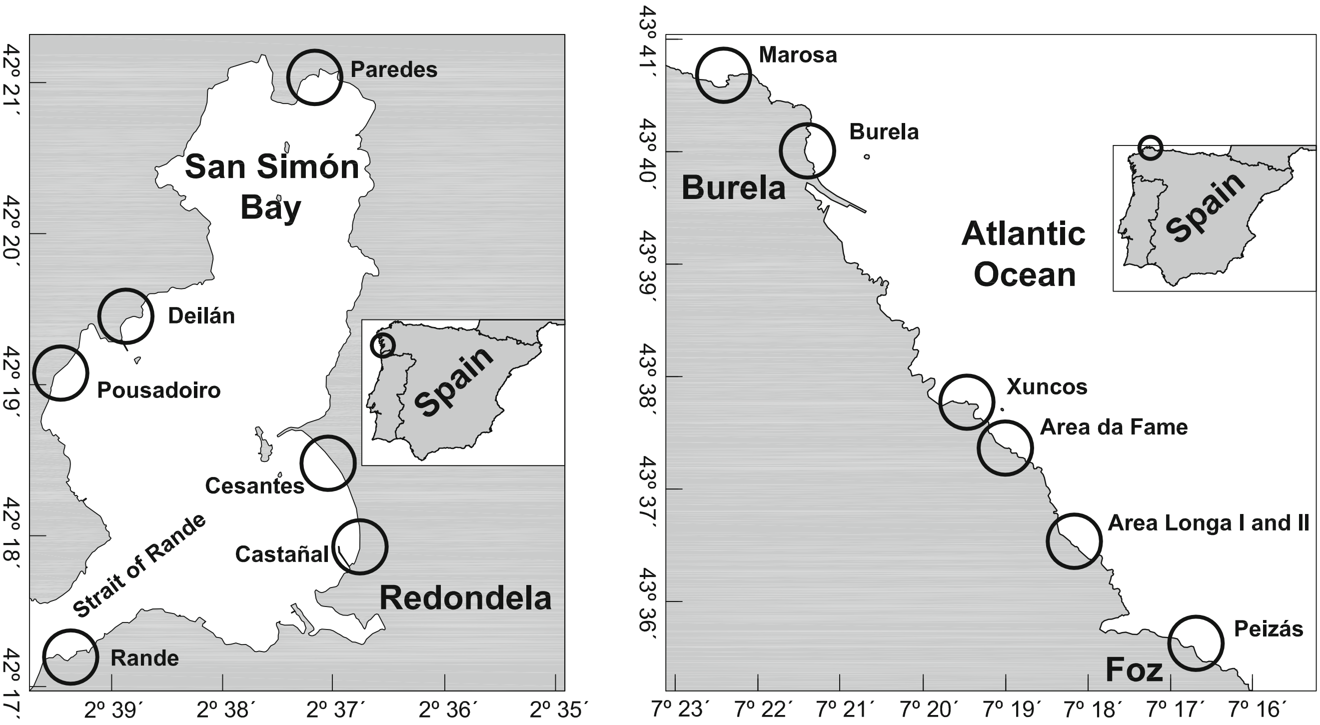


Fig. 1 Location of the sampling points

The sample from each beach was made by mixing the six replicate samples together.

During the study, the cleaning carried out between July and September to prepare the beaches for the tourist season and to prevent problems in clam and cockle nurseries hampered sampling and measurement of the drift seaweed. The data collected during this period therefore underestimate the quantities of beach wrack present.

Laboratory Work

The samples were transported in cool boxes to the laboratory and refrigerated at 4 °C (for less than 48 h) until processing. The samples were then washed with distilled water to remove sand. Two subsamples (each 500 g) were removed from each sample. One of these was dried in an oven at 105 °C until constant weight to enable determination of the percentage of dry matter. The other subsample was examined to determine the botanical composition. For the chemical analysis of each species, only those species of fresh weight more than 30 g were considered. Only the least damaged material was identified to species level, as in many cases identification by morphological characteristics was not possible due to fragmentation of the material and, given the nature of the study, identification by microscopic examination was not viable. We denominated species of the genus *Ulva* with laminar morphology as *Ulva* spp. 1 and species with tubular morphology, previously considered as belonging to the genus *Enteromorpha* (see Hayden et al. 2003) as *Ulva* spp. 2.

The samples were then dried in an oven at 60 °C until constant weight before being ground with an agate mill to particles <0.5 mm. All chemical analyses were carried out on samples dried at 60 °C, although an aliquot of each sample was further dried at 105 °C to enable determination of the percentage moisture in the samples and to correct the final concentrations.

The concentrations of C, N and S were determined in an elemental analyser (LECO CNS-2000). For measurement of P, K, Ca, Mg, Na, Fe, Mn, Cu and Zn, the samples were first digested with H_2SO_4 and H_2O_2 in a block digester (Thomas et al. 1967). P was determined colourimetrically (Chapman and Pratt 1984) in a Jenway 6300 spectrophotometer. Na and K were determined by flame atomic emission spectrometry and Ca, Mg, Fe, Mn, Cu and Zn by flame atomic absorption spectrometry (Varian SpectrAA 220FS). Ni, Cr, Cd and Pb were determined by flame atomic absorption spectrometry (Varian SpectrAA 220FS) after microwave-assisted digestion (ETHOS 900) of the sample with HNO_3. Borum in the samples from Foz was also determined by inductively coupled plasma after microwave-assisted digestion of the sample with HNO_3. In total, 16 elements (17 in Foz) were measured in a total of 506 samples. Certified reference materials BCR-279 (*Ulva lactuca*, a green seaweed) and BCR 381 (rye flour) from the Institute for Reference Materials and Measurements (European Commission) were used for quality control.

Results

Quantities of Beach Wrack

The total weight of beach wrack on the San Simón beaches ranged between the 12 tonnes estimated in March and the 95 tonnes estimated in October (Fig. 2); the total annual weight was estimated to be 512 tonnes. Larger amounts were generally collected from the Foz beaches, reaching a maximum of almost 4000 tonnes in November, and the total annual weight in the zone was 8094 tonnes. The variation in volume was similar to the variation in weight, i.e. there was little seasonal variation in the density of beach wrack in each area. However, there were differences between each zone: the mean density of beach wrack on the San Simón beaches was 162 kg m^{-3} and on the Foz beaches 295 kg m^{-3}. The abundance of beach wrack varied on the different beaches, and the largest amounts were found on Castañal and Rande beaches (San Simón Bay) and on Area Longa (I and II) and Area da Fame (Foz) (Fig. 3). As indicated in "Material and Methods", these figures do not include the beach wrack that was removed from the beaches during the summer, and the amounts are therefore underestimated. No beach wrack was found on any of the Foz beaches sampled in August.

The beach wrack from San Simón Bay contained large amounts of extraneous matter (Fig. 4), with slightly more organic than inorganic matter. In the beach wrack from Foz, the amount of extraneous matter was negligible throughout the entire study period (data not shown).

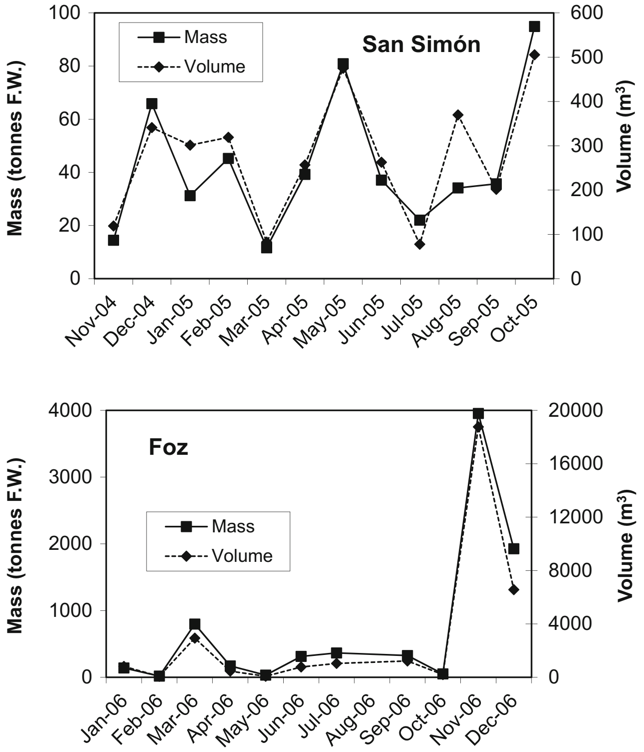


Fig. 2 Temporal variation in the weight and volume of the beach wrack

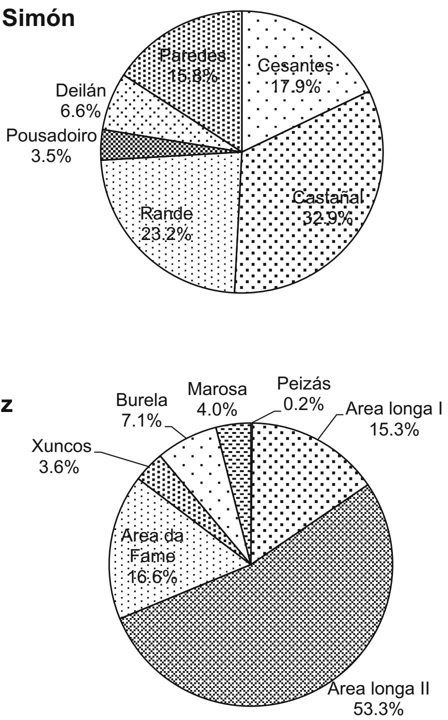


Fig. 3 Percentage weight of beach wrack at each sampling point, relative to the total weight in each sampling area

Floristic Composition

In the beach wrack from San Simón Bay, green algae predominated in winter and spring, and marine spermatophytes (*Zostera* spp.) predominated in summer (Fig. 5). In Foz, spermatophytes were negligible and the beach wrack consisted almost exclusively of brown algae. Green alga, *Codium* spp., appeared in January and April (only), although the amount only represented around 3 % of the weight of the material. During most of the year, more than half of the weight of the beach wrack consisted of two genera, *Laminaria* and *Cystoseira*.

Secondary species in San Simón included *Ascophyllum nodosum*, *Codium* spp., *Gelidium* spp., *Gracilaria verrucosa*, *Himanthalia elongata*, *Laminaria ochroleuca*, *Laminaria hyperborea*, *Pelvetia canaliculata*, *Saccorhiza polyschides* and *Sargasum* spp. (Fig. 5: "other species"). The part of the beach wrack formed by the least abundant species represented 37 % of the total in April. In Foz, the secondary species included *Ulva* spp., *Chondrus crispus*, *Gracilaria verrucosa*, *Calliblepharis jubata* and *Corallina* spp. In this sampling area in June, the algae comprised pieces that were so small that it was impossible to identify them, and we categorised the whole sample as "other species".

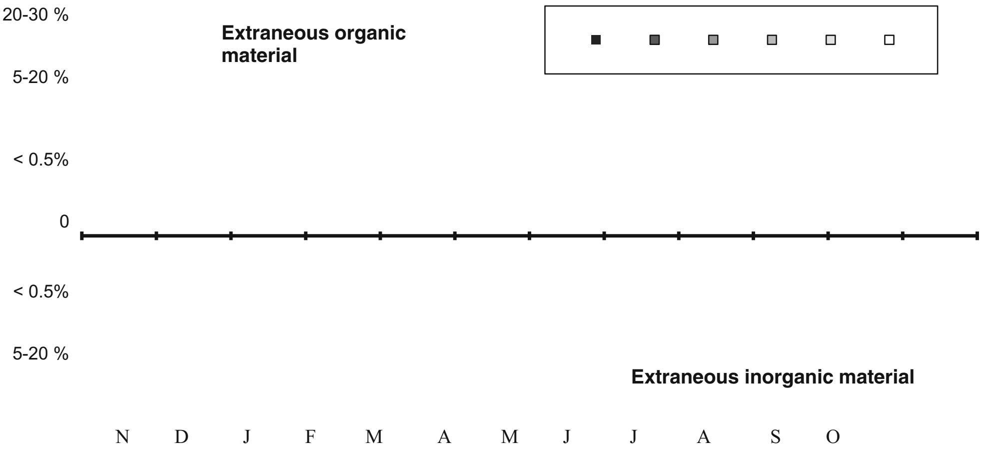


Fig. 4 Presence of extraneous matter (other than seaweed and marine spermatophytes) in the beach wrack from San Simón Bay in the period between November 2004 and October 2005

Chemical Composition

The annual mean percentage dry matter was higher in the San Simón material than in the Foz material: 25 % in the bulk samples and >20 % in the different species and genera. In Foz, the mean value in the entire beach wrack was 15 % and it was slightly higher than 20 % in only two species (Tables 1 and 2). The annual mean value of the C/N ratio was higher in both the entire beach wrack and in the individual algae in Foz, which was due to the higher concentration of C as the concentrations of N were similar in both sites (around 2 %). The concentrations of P were also similar, although slightly higher in San Simón, ranging between mean values of 0.40 % for *Zostera marina* and 0.53 % for *Fucus* spp., whereas in Foz, they ranged between a minimum of 0.24 % in *Codium* spp. and a maximum of 0.51 % in *Himanthalia elongata*. There were large differences in K and Ca, which were generally higher in the material from Foz. The mean concentration of Mg was about 1 % (slightly lower than this in Foz and slightly higher in San Simón). The mean concentrations of Na and S were slightly higher in San Simón. The elements for which the differences were greatest were all metals, and the mean levels of Fe, Mn, Cu, Cr, Ni and Pb were generally much higher in San Simón, and in Foz, the concentrations of Cr, Ni and Pb were not detectable in most of the samples (data not shown). The concentrations of Cd were below the limit of detection in samples from both sites and on most occasions (data not shown).

We applied analysis of variance to test for significant differences in the mean concentrations of the different elements in the beach wrack from the different zones. As the data represent consecutive temporal samples from the sampling zone, they are not independent replicates, thus violating one of the important assumptions of ANOVA. We therefore considered the mean annual values for each sampling point as replicates. The only elements for which there were no significant differences ($p > 0.05$) between the two sampling areas were N, P and Zn.

The least variable element in relation to the coefficient of variation in the beach wrack was C (in both San Simón and Foz) in direct contrast to the highly variable levels of Cu (Tables 1 and 2). The temporal variation differed in each case (Figs. 6, 7, 8 and 9). For some elements (e.g. for K in San Simón), there was no clear trend, and although there were sometimes important differences between months, there was no clearly defined pattern of increase or decrease throughout the year. In other cases, there was a seasonal trend, such as in N and P in both zones, with minimum values in summer and maximum values in winter, and in Cr and Ni in San Simón (in Foz these metals were almost always below the limit of detection), with maximum values in spring–summer.

Discussion

The presence and quantities of drift seaweed on beaches depend on factors such as wind strength and direction, tidal action and the orientation, slope and shape of the beaches. This explains why seaweed was not always found on all beaches at all sampling times and also why the amounts of seaweed varied from 1 month to another. Planning the systematic collection of the drift seaweed is difficult as the timing depends on weather conditions and is further complicated by the temporal and site-related variations in the amounts of material present.

The amounts of beach wrack on the Foz beaches were similar to those reported by Piriz et al. (2002)

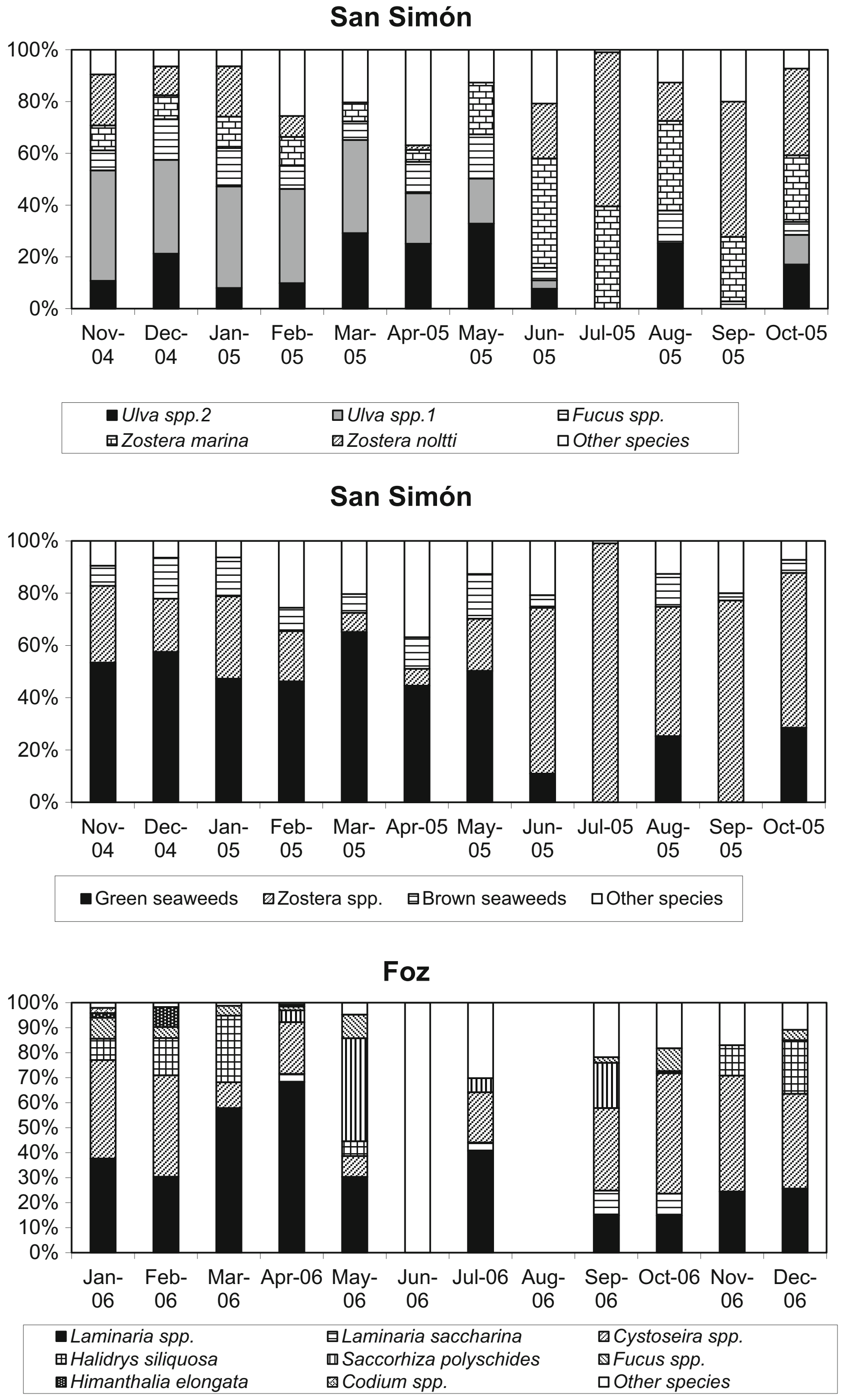


Fig. 5 Percentage of each genus or species relative to the total weight. *Fucus* spp. (*F. vesiculosus*, *F. spiralis*, *F. serratus*, *F. ceranoides*), *Laminaria* spp. (*L. ochroleuca*, *L. hyperborea*), *Cystoseira* spp. (*C. baccata*, *C. tamariscifolia*), *Codium* spp. (*C. tomentosum*, *C. fragile*)

for open sea zones and were higher than the amounts on the San Simón beaches, although these still represent a useful (free) source of raw material for making agricultural fertilizers. Because of the importance of the wind direction in relation to the presence of beach wrack and because of the San Simón Bay is partially enclosed, there will always be some beach wrack on one or other side of the bay.

The beaches in the San Simón Bay with the largest quantities of beach wrack coincided with the main traditional areas of extraction of algae for agricultural use. Of the total volume of algae and higher plants pulled up and swept along by the sea, it has been estimated that only 30 % is washed up on the beaches, and the rest of the material accumulates in underwater sinks (De Andrés et al. 1991). In addition to the material collected from the

Table 1 Descriptive statistics for the samples of macroalgae and marine spermatophytes collected during 1 year from the beaches in San Simón Bay

		Bulk beach wrack	*Fucus* spp.	*Ulva* spp. 1	*Ulva* spp. 2	*Zostera marina*	*Zostera noltii*
	n	50	19	26	26	35	32
Dry matter (%)	Mean	25.17	25.20	24.12	20.70	22.59	28.20
	Median	22.29	24.12	23.26	18.57	21.23	24.84
	S.D.	8.72	7.83	8.10	7.55	6.59	9.13
	C.V.	34.65	31.07	33.59	36.50	29.17	32.38
C (%)	Mean	28.74	37.96	23.64	22.36	32.98	30.93
	Median	27.75	38.36	25.80	24.08	33.85	31.31
	S.D.	5.91	2.52	6.19	5.72	4.73	6.27
	C.V.	20.55	6.64	26.19	25.57	14.34	20.27
N (%)	Mean	2.02	2.11	2.13	2.04	2.04	2.13
	Median	2.00	2.16	2.10	1.85	2.04	2.10
	S.D.	0.53	0.37	0.78	0.86	0.48	0.51
	C.V.	26.33	17.55	36.60	41.84	23.27	24.12
C/N (wt ratio)	Mean	14.72	18.46	12.15	11.74	16.57	14.85
	Median	15.32	18.19	10.26	11.21	16.95	15.19
	S.D.	2.87	3.25	4.23	2.66	2.52	2.57
	C.V.	19.49	17.63	34.80	22.68	15.22	17.33
P (%)	Mean	0.42	0.53	0.45	0.50	0.40	0.47
	Median	0.35	0.45	0.44	0.45	0.30	0.38
	S.D.	0.19	0.25	0.19	0.22	0.25	0.22
	C.V.	46.15	46.71	42.51	44.11	61.03	46.31
K (%)	Mean	2.37	3.52	2.20	2.44	2.15	2.04
	Median	2.25	3.62	2.17	2.18	2.08	2.01
	S.D.	0.81	0.95	0.72	1.01	0.91	0.81
	C.V.	34.08	26.98	33.01	41.57	42.25	39.64
Ca (%)	Mean	0.80	0.77	0.62	0.69	1.09	0.71
	Median	0.70	0.75	0.53	0.53	0.75	0.74
	S.D.	0.33	0.15	0.32	0.51	0.96	0.17
	C.V.	41.80	19.97	51.95	74.03	87.93	23.33
Mg (%)	Mean	1.35	1.06	1.87	1.29	1.20	1.14
	Median	1.23	0.97	1.76	1.19	1.20	1.16
	S.D.	0.52	0.33	0.61	0.41	0.20	0.28
	C.V.	38.97	31.44	32.42	31.48	16.78	24.92
Na (%)	Mean	4.75	4.55	4.30	4.45	5.51	5.03
	Median	4.91	4.33	4.31	4.38	5.96	5.56
	S.D.	1.46	1.14	1.55	1.74	1.62	1.66
	C.V.	30.87	24.95	36.04	39.02	29.37	33.04
S (%)	Mean	1.46	1.80	3.09	1.69	0.86	0.84
	Median	1.08	1.93	3.01	1.56	0.87	0.75
	S.D.	1.09	0.71	1.52	0.87	0.30	0.29
	C.V.	74.86	39.29	49.18	51.26	34.68	34.56
Fe (μg g^{-1})	Mean	4157.30	1901.73	5563.11	6732.62	2695.65	3949.94
	Median	3912.54	1748.49	4794.09	6433.22	2274.77	3814.96
	S.D.	2394.42	1538.93	2987.84	3007.91	1331.16	2465.79
	C.V.	57.60	80.92	53.71	44.68	49.38	62.43
Mn (μg g^{-1})	Mean	154.11	193.21	92.87	132.76	131.42	221.69
	Median	143.60	159.67	87.89	129.96	123.07	206.92
	S.D.	66.11	75.47	31.00	57.83	49.43	97.44

Table 1 (continued)

		Bulk beach wrack	*Fucus* spp.	*Ulva* spp. 1	*Ulva* spp. 2	*Zostera marina*	*Zostera noltii*
	C.V.	42.89	39.06	33.38	43.56	37.62	43.95
Cu (μg g^{-1})	Mean	87.99	24.07	30.18	38.14	35.79	59.07
	Median	25.73	18.02	24.27	22.71	19.72	25.18
	S.D.	284.81	19.01	26.79	73.45	31.96	90.71
	C.V.	323.68	78.98	88.78	192.60	89.32	153.56
Zn (μg g^{-1})	Mean	54.70	106.42	44.70	40.84	49.49	63.27
	Median	48.38	84.19	36.52	37.84	39.90	54.37
	S.D.	31.43	63.20	40.38	16.54	25.71	30.72
	C.V.	57.45	59.38	90.34	40.50	51.95	48.56
Cr (μg g^{-1})	Mean	79.49	74.21	96.93	116.19	73.98	137.83
	Median	38.07	48.31	28.04	53.66	47.24	51.11
	S.D.	93.21	87.52	177.43	153.45	68.94	225.01
	C.V.	117.26	117.94	183.05	132.07	93.18	163.26
Ni (μg g^{-1})	Mean	25.98	22.45	25.98	37.89	27.91	45.22
	Median	13.05	12.14	8.35	18.44	18.37	16.16
	S.D.	29.98	24.45	59.87	53.06	29.57	73.25
	C.V.	115.38	108.90	230.43	140.01	105.97	161.99
Pb (μg g^{-1})	Mean	12.75	10.07	14.72	15.57	13.71	16.69
	Median	13.75	7.83	14.74	13.19	13.26	17.43
	S.D.	6.67	9.46	8.99	9.66	7.25	6.98
	C.V.	52.35	93.97	61.05	62.02	52.91	41.81

S.D. standard deviation, *C.V.* coefficient of variation

beaches, seaweed used to be collected from underwater sinks in San Simón Bay with different types of traditional equipment.

In San Simón Bay, the extraneous matter makes up a large proportion of the beach wrack. The presence of inorganic elements may render the beach wrack unsuitable for agricultural purposes as such elements might affect the composting process (Kopeć et al. 2013) or damage soil. This fraction would therefore have to be removed before the material could be used to make fertilizer, thus adding to the cost of the process. As already mentioned, the presence of extraneous material was almost negligible in the beach wrack from the Foz sites.

The floral composition of the beach wrack was very different in both areas, as expected from the different characteristics. The most common species in San Simón Bay were species typical of sheltered or semi-exposed areas, whereas in Foz species that are characteristic of exposed or semi-exposed environments prevail (Bárbara and Cremades 1987; Lüning 1990; Otero-Schmitt et al. 2002). A large proportion of opportunistic species of the genus *Ulva* commonly associated to eutrophication events (Teichberg et al. 2010) were found in San Simón Bay.

Beach wrack can be used directly as fertilizing material or it can first be washed, dried or subjected to different degrees of composting (Stephenson 1968; Chapman 1970; Blunden 1991; Guiry and Blunden 1991; Jablonski 2006). The mean dry matter content of the beach wrack from San Simón is consistent with the lower levels reported by different authors for sheep and cattle manure (Table 3), and it was even lower in the material from Foz. The high water content of seaweed makes handling of the material difficult, and therefore the material would have to be dried before use.

The mean value of the C/N ratio in the San Simón material was slightly lower than 15 (Table 1), which is the maximum limit established by Spanish legislation regarding commercialization of organic nitrogenous fertilizers (RD 824/2005 2005). In Foz, the mean value of this ratio was slightly lower than 20 (Table 2) probably because most algae in this zone are brown algae, which are richer in C than green algae.

The mean N content in the beach wrack from both sites was similar to the mean concentrations of N in animal manure (e.g. sheep and cattle manure), although it was much lower than in chicken manure and dairy sludge, which are particularly rich in this element (Table 3).

Table 2 Descriptive statistics for the samples of macroalgae collected during 1 year from the Foz beaches

		Bulk beach wrack	*Laminaria* spp.	*Laminaria saccharina*	*Cystoseira* spp.	*Halidrys siliquosa*	*Saccorhiza polyschides*	*Fucus* spp.	*Himanthalia elongata*	*Codium* spp.
	n	93	68	16	69	30	19	18	3	2
Dry matter (%)	Mean	15.21	15.09	19.14	19.30	20.71	12.36	20.39	19.45	6.18
	Median	15.09	14.33	19.72	19.57	20.54	9.59	21.23	20.56	6.18
	S.D.	3.40	5.67	4.22	3.38	3.22	10.45	5.15	2.31	0.12
	C.V.	22.35	37.60	22.05	17.51	15.53	84.56	25.23	11.88	1.89
C (%)	Mean	37.34	38.36	41.17	41.07	43.10	32.02	43.16	40.86	29.10
	Median	37.84	38.68	42.84	41.29	43.26	31.30	42.96	41.65	29.10
	S.D.	3.57	3.98	3.82	1.74	1.17	3.07	1.49	4.81	2.61
	C.V.	9.55	10.37	9.28	4.24	2.72	9.59	3.46	11.77	8.97
N (%)	Mean	1.96	1.87	1.63	1.66	1.31	1.65	2.10	1.98	2.71
	Median	2.01	1.88	1.73	1.67	1.27	1.46	2.32	1.88	2.71
	S.D.	0.37	0.36	0.31	0.34	0.20	0.53	0.72	0.42	0.52
	C.V.	18.73	19.12	19.19	20.70	15.25	32.06	34.46	20.93	19.23
C/N (wt ratio)	Mean	19.79	21.54	27.08	26.03	33.67	21.30	23.72	20.72	10.83
	Median	19.11	19.31	24.85	24.32	34.35	20.57	18.13	21.23	10.83
	S.D.	4.64	6.26	9.99	6.65	5.27	6.73	10.06	7.26	1.12
	C.V.	23.46	29.06	36.88	25.53	15.65	31.61	42.41	35.02	10.35
P (%)	Mean	0.36	0.38	0.40	0.38	0.43	0.27	0.43	0.51	0.24
	Median	0.34	0.39	0.37	0.40	0.45	0.28	0.42	0.53	0.24
	S.D.	0.14	0.14	0.14	0.13	0.13	0.13	0.14	0.14	0.03
	C.V.	38.57	37.23	34.22	35.35	30.98	46.89	31.77	28.62	14.31
K (%)	Mean	5.80	7.99	5.09	5.26	5.58	12.10	3.96	5.50	1.25
	Median	5.58	7.54	4.26	5.11	5.67	11.76	3.99	5.58	1.25
	S.D.	1.87	3.03	2.50	1.30	1.53	3.05	0.88	3.67	0.19
	C.V.	32.23	37.84	49.06	24.72	27.34	25.23	22.25	66.72	15.51
Ca (%)	Mean	2.93	1.36	1.14	1.70	1.22	1.62	1.42	0.90	0.97
	Median	2.19	1.28	0.90	1.59	1.24	1.40	1.52	0.83	0.97
	S.D.	2.02	0.61	0.65	0.60	0.35	0.85	0.40	0.67	0.23
	C.V.	68.84	44.68	57.25	35.14	28.92	52.75	28.12	74.13	23.36
Mg (%)	Mean	0.98	0.71	0.60	0.95	0.82	0.83	0.78	0.57	1.51
	Median	0.99	0.70	0.57	0.95	0.78	0.79	0.76	0.49	1.51
	S.D.	0.19	0.18	0.15	0.12	0.15	0.13	0.08	0.21	0.12
	C.V.	19.70	24.64	24.21	12.60	18.29	15.83	9.99	36.21	7.68
Na (%)	Mean	3.00	3.05	2.80	2.52	2.38	4.04	2.88	2.20	10.83
	Median	2.92	3.00	2.85	2.41	2.25	4.06	2.86	1.98	10.83
	S.D.	0.76	0.82	0.57	0.64	0.58	0.75	0.55	1.36	0.58

Table 2 (continued)

		Bulk beach wrack	*Laminaria* spp.	*Laminaria saccharina*	*Cystoseira* spp.	*Halidrys siliquosa*	*Saccorhiza polyschides*	*Fucus* spp.	*Himanthalia elongata*	*Codium* spp.
	C.V.	25.46	26.82	20.25	25.36	24.27	18.63	19.23	61.70	5.34
S (%)	Mean	0.84	0.58	0.33	0.60	0.86	0.52	0.79	0.65	2.41
	Median	0.75	0.57	0.27	0.62	0.86	0.49	0.72	0.54	2.41
	S.D.	0.38	0.21	0.19	0.20	0.28	0.18	0.35	0.33	0.18
	C.V.	45.63	35.60	57.68	34.07	32.18	33.90	44.53	51.37	7.33
Fe (μg g^{-1})	Mean	418.13	205.35	133.80	329.21	291.53	222.34	220.10	69.28	188.62
	Median	368.31	139.68	108.59	240.68	125.04	132.98	136.06	82.56	188.62
	S.D.	346.06	175.28	76.39	215.58	307.36	193.26	206.16	166.01	24.83
	C.V.	82.76	85.36	57.09	65.48	105.43	86.92	93.67	239.62	13.16
Mn (μg g^{-1})	Mean	22.92	16.70	18.49	22.11	12.77	19.27	94.98	13.72	11.34
	Median	26.78	21.12	21.87	22.91	2.13	24.69	77.83	13.72	11.34
	S.D.	16.57	15.25	8.19	33.40	14.76	14.10	71.15	13.98	2.40
	C.V.	72.31	91.32	44.32	151.05	115.62	73.15	74.91	101.90	21.16
B (μg g^{-1})	Mean	168.18	129.59	106.30	211.04	275.51	124.75	157.35	88.37	144.16
	Median	166.60	110.14	102.00	213.88	279.52	118.39	151.30	100.17	144.16
	S.D.	50.58	62.53	8.98	55.33	116.06	15.28	49.46	56.40	122.93
	C.V.	30.07	48.25	8.45	26.22	42.13	12.25	31.43	63.82	85.27
Cu (μg g^{-1})	Mean	3.23	1.55	1.29	2.97	1.63	1.48	2.53	0.77	1.98
	Median	2.67	1.25	1.31	2.84	1.33	1.67	2.36	0.72	1.98
	S.D.	6.67	1.60	0.50	1.30	0.94	0.75	1.15	1.32	0.11
	C.V.	206.62	103.12	38.73	43.80	57.88	50.63	45.30	172.49	5.55
Zn (μg g^{-1})	Mean	42.58	44.51	45.36	24.03	19.73	40.46	83.19	57.85	33.59
	Median	42.03	43.90	46.00	20.88	17.89	29.11	78.77	57.22	33.59
	S.D.	14.83	18.14	10.45	12.26	8.43	17.88	43.96	17.34	40.53
	C.V.	34.83	40.75	23.03	51.03	42.71	44.18	52.84	29.97	120.67

S.D. standard deviation, *C.V.* coefficient of variation

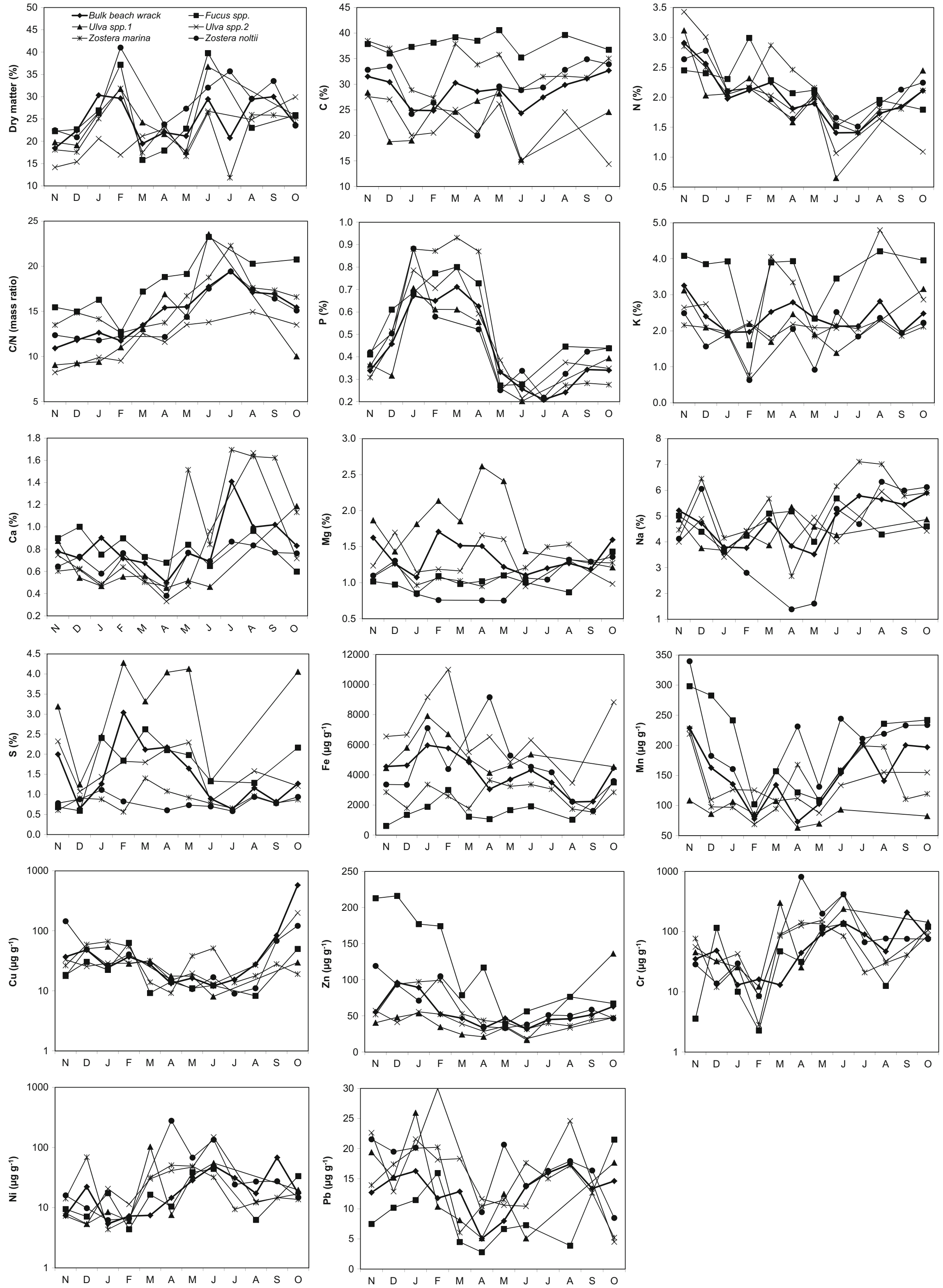


Fig. 6 Temporal variation (November 2004 to October 2005) in the concentrations of the elements analysed and of dry matter percentage in the beach wrack from San Simón Bay. The results for the bulk samples and for the main component species of algae and higher plants are shown. The data are monthly means for samples collected fortnightly at six sampling points. Note that for Cu, Cr and Ni, the scale of the *y* axis is logarithmic

Fig. 7 Temporal variation (January 2006 to December 2006) in the concentrations of C, N, P, K; C/N ratio and of dry matter percentage in the beach wrack from the Foz beaches. The results for the bulk samples and for the main component species are shown. The data are monthly mean values for samples from seven sampling points

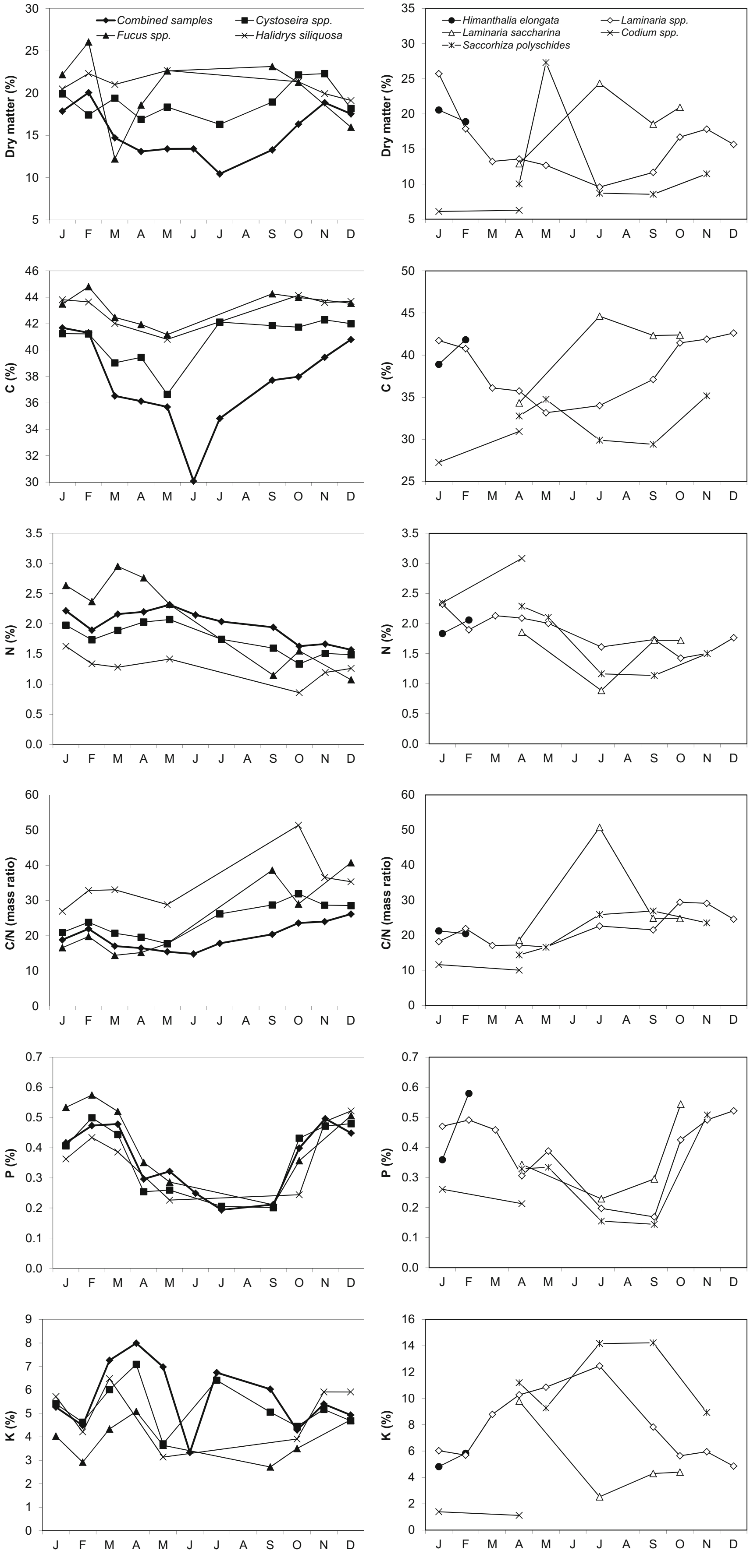


Fig. 8 Temporal variation (January 2006 to December 2006) in the concentrations of Ca, Mg, Na, S, B and Fe in the beach wrack from the Foz beaches. The results for the bulk samples and for the main component species are shown. The data are monthly mean values for samples from seven sampling points

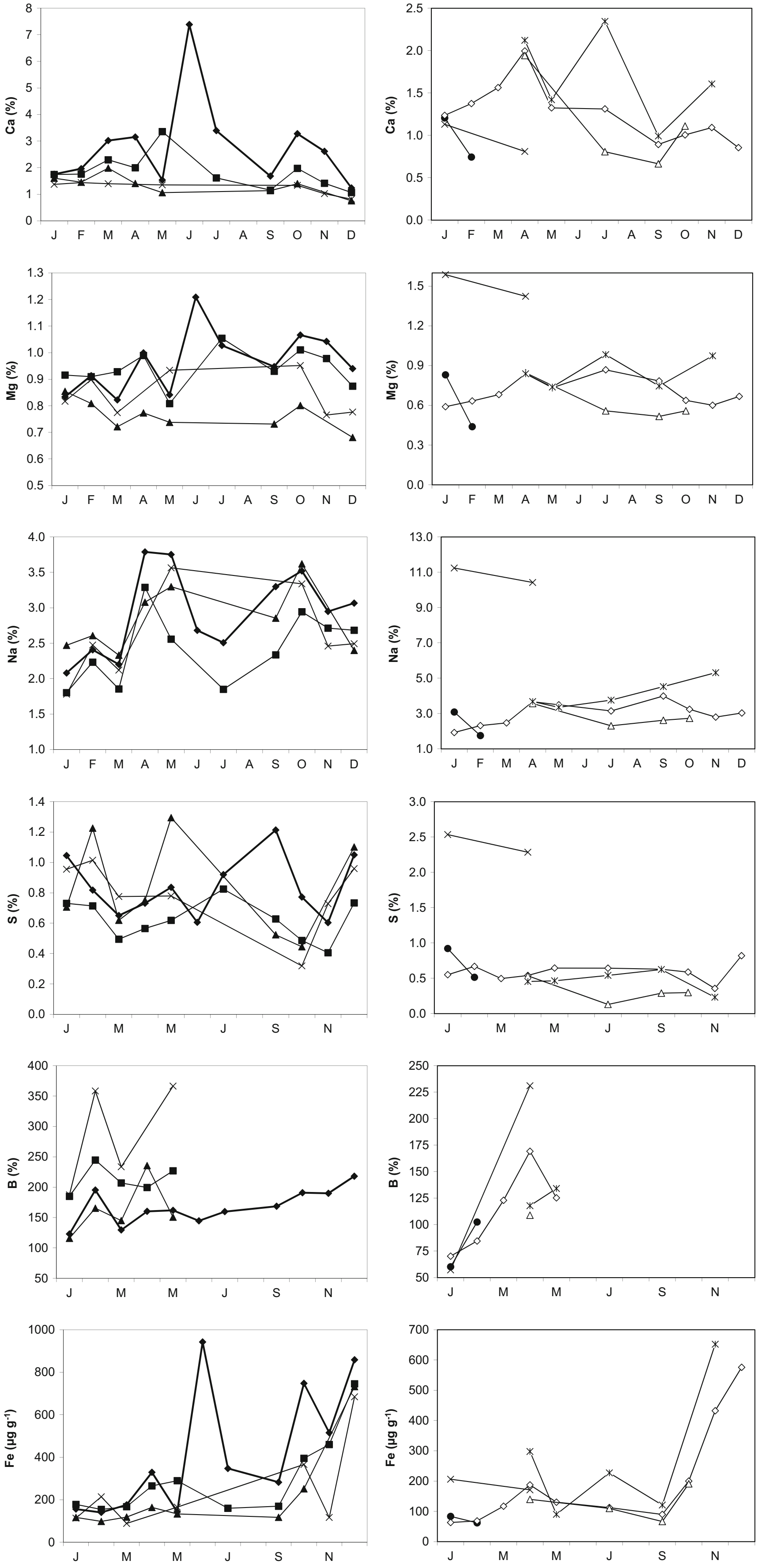
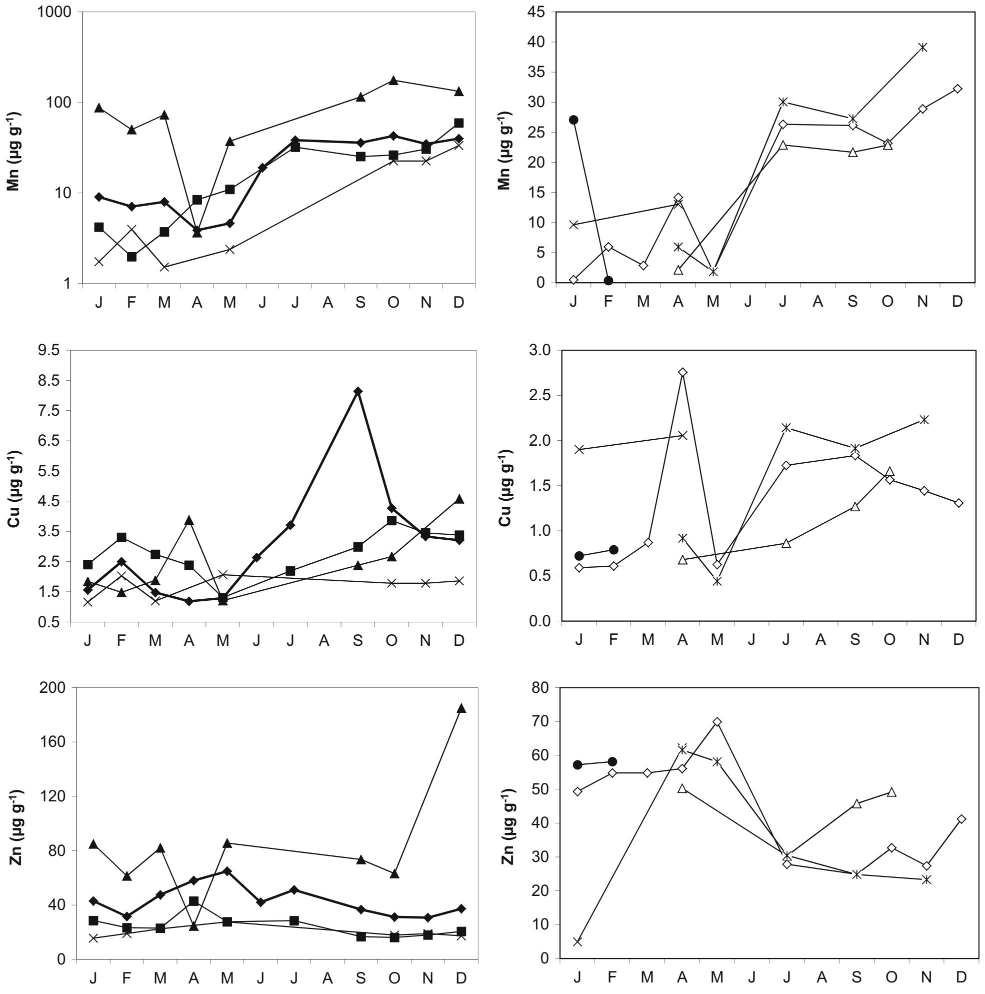


Fig. 9 Temporal variation (January 2006 to December 2006) in the concentrations of C, N, P, K; C/N ratio and of dry matter percentage in the beach wrack from the Foz beaches. The results for the bulk samples and for the main component species are shown. The data are monthly mean values for samples from seven sampling points



However, the levels of P were generally low (on average 0.4 % and slightly higher in the San Simón material), although similar to those in composted urban solid waste, urban sewage sludge and sheep and cattle manure. However, brown algae contain large amounts of alginic acid, a polymer that decreases the concentration of the ions that cause precipitation of phosphates (Al^{+3} and Fe^{+3}), thus increasing the P available to plants (Caiozzi et al. 1986). Fertilization of soil with seaweed also improves P availability in acid soils as a result of the increased soil pH and displacement of Al from exchange sites (López-Mosquera and Pazos 1997). Although the anthropogenic influence is greater in San Simón Bay, the concentrations of N and P were not significantly different from those in the samples from the Foz beaches.

The K content in the beach wrack was much higher than in other types of organic fertilizer (Table 3), and the K content of the material from Foz was more than twice that of the material from San Simón Bay. The lower concentrations of this element in the San Simón material may be due to the greater fluvial influence in this partially enclosed bay, as concentrations of K are higher in seawater than in river water (Meybeck et al. 1996; Bruland and Lohan 2006). The concentrations of K are also higher in brown algae, which are much more abundant in Foz than in San Simón. The concentrations of Ca in the Foz material were similar to those in other organic fertilizers (Table 3), and the San Simón beach wrack contained rather low amounts of this element. The concentrations of Mg in the beach wrack from both sites were similar to or higher than those in other organic fertilizers. Magnesium is a component of the chlorophyll molecule, which may explain the higher concentrations of this element found in the green algae than in the brown algae.

Contrary to the abovementioned benefits, the high content of Na in beach wrack (due to its marine origin) may be a drawback. The concentration of this element may

Table 3 Characteristics of other organic fertilizers

	Units	Fresh chicken manure[a]	Dried chicken manure[a]	Sheep manure[b]	Cow manure[b]	Pig manure[b]	Sewage sludge[c]	Dairy sludge[d]	Composted sewage sludge[b]
C/N		6.0	7.3	10.6–14.1	3.7–7.5	5.0	–	5.7	–
Dry matter	%	74.0	89.9	25–63	23–65	11.1	–	–	94.6–54.1
C	%	38.2	36.8	37.2–40.4	23.8–38.4	38.4	–	37.2	9.0–39.4
N	%	6.5	5.2	2.5–2.7	1.1–1.8	7.6	0.1–17.6	6.5	0.4–1.8
P	%	1.7	1.6	0.4–0.5	0.3–0.8	2.6	0.1–14.3	2.4	0.1–0.6
K	%	2.8	2.6	2.1–2.3	1.9–2.6	3.6	0.02–2.6	0.9	0.2–1.0
Ca	%	2.0	1.9	4.2–5.5	2.7–5.3	3.9	0.01–3.1	2.1	5.4–12.7
Mg	%	0.7	0.6	0.6–0.9	0.6–0.7	1.1	0.03–2.0	0.4	0.4–1.4
Na	%	1.6	1.2	0.3–0.6	0.6–0.7	0.7	0.01–3.1	2.4	0.3–1.0
S	%	0.5	0.6	–	–	–	0.6–1.5	–	–
Fe	$\mu g\ g^{-1}$	737.6	792.2	3400–4906	4100–7574	3752	0.1–15.3	–	–
Cu	$\mu g\ g^{-1}$	71.3	63.6	27–72	33–36	624	80–10,400	40.0	80.7–1200
Zn	$\mu g\ g^{-1}$	261.2	259.8	82–120	113–133	658	100–27,800	339.1	199–1455
Mn	$\mu g\ g^{-1}$	349.6	187.0	222–306	172–193	407	20–7100	–	–
B	$\mu g\ g^{-1}$	20.1	13.9	–	–	–	4–760	–	–
Cr	$\mu g\ g^{-1}$	27.3	7.4	16–23	24–30	–	–	15.5	12–662
Pb	$\mu g\ g^{-1}$	<0.1	26.6	10–16	11–14	–	–	20.3	54–457
Ni	$\mu g\ g^{-1}$	<0.1	<0.1	15–32	20–22	–	–	11.1	7–78

[a] López-Mosquera et al. (2008)

[b] Pomares and Canet (2001)

[c] Sommers (1977)

[d] López-Mosquera et al. (2005)

limit the use of beach wrack as fertilizer. Jablonski (2006) reported that in the San Simón Bay area, piles of beach wrack were traditionally left for some time in the open to allow the rain to wash off the salt, and the material was only used in plots that were irrigated. López-Mosquera and Pazos (1997) found that after fertilization of a potato crop with fresh drift seaweeds, the soils became enriched in Na, although the exchange complex did not become saturated to limiting levels. In addition, if the seaweed is applied to well-drained land, the Na will be quickly washed off in rainy areas and will not have a negative effect on the soil properties.

The mean values of S in the beach wrack from both sites were higher than those in other types of organic fertilizer, although there is relatively little information about this element in the relevant literature. There is currently some interest in this element as the reduction in atmospheric depositions produced in the past few decades and the use of fertilizers containing fewer impurities in intensive agriculture has led to several studies indicating the need for fertilizers to contain this element (e.g. Sarda et al. 2014), particularly for growing sulphur-demanding crops such as brassicas and lilies.

Regarding the micronutrients, the mean concentrations of Fe and Mn in the beach wrack from San Simón Bay were similar to those in other organic fertilizers (Table 3), whereas the concentrations in the beach wrack from Foz were approximately one order of magnitude lower. The difference between both sites can be explained by the well-known behaviour of these metals in estuary water, in which the concentrations decrease as the salinity increases (Roux et al. 1998; Escoube et al. 2009). San Simón Bay is a more estuarine environment than Foz because it is partially enclosed and receives larger fluvial inputs and the water is therefore less saline (Pérez et al. 1992). The beach wrack from Foz was rich in B, and the concentrations in the bulk material and in the component species were close to or higher than 100 $mg\ kg^{-1}$, the minimum content required by Spanish law on fertilizers (RD 824/2005 2005) for a fertilizer to be declared as rich in this element. The concentrations of B were not measured in the samples from San Simón Bay.

The concentrations of toxic metals were almost always higher in the samples from San Simón, as expected given the high level of anthropogenic pressure in this area. The greater fluvial influence and the consequent lower salinity may also contribute to the accumulation of metals (Wang and Dei 1999). The mean annual concentrations of these toxic elements in the bulk material did not surpass the threshold levels established in the EU ecolabelling scheme for soil amendments (EC Council 799/2006 2006) and plant growth substrates (EC Council 64/2006 2006).

The temporal variation in nutrients such as N and P in macroalgae and seagrasses has been well studied (e.g. Alcoverro et al. 1995; Chopin et al. 1996; Brenchley et al. 1998; Campbell et al. 1999; Lehvo et al. 2001; Martínez and Rico 2002; Villares and Carballeira 2003; Walker et al. 2004) as these elements are often limiting for growth. These studies demonstrate that minimal concentrations are usually reached during the period of greatest growth, which is what we observed for P in the bulk material for both sampling areas. A similar pattern was observed for N only in the samples from San Simón, in the samples from Foz the concentrations of this element were maximal in spring and summer. The variation in the C/N ratio in San Simón was mainly a consequence of the variation in N, as the C contents were generally less variable. From an agronomic point of view, the temporal variability in the concentrations of nutrients is problematical as a homogeneous supply of nutrients is required throughout the year. For example, the mean concentrations of P in the bulk material from San Simón Bay were more than twice as high in winter than in summer; the differences were slightly less in the samples from Foz. As already mentioned, the concentrations of this element were not very high in any of the samples. To obtain a product that is richer in P, the beach wrack could be co-composted with other material such as sea fish waste, which is usually rich in P, as proposed by Illera-Vives et al. (2013).

Although, as mentioned above, the annual mean concentrations of toxic metals in the bulk samples of beach wrack never surpassed the threshold established in the European thresholds, and in San Simón, the threshold levels of Cr and Ni were exceeded at certain times during spring and summer and those of Cu in October. In the samples from Foz, the threshold levels were not exceeded at any time for any of the metals in either the unseparated samples or any of the component species. Macroalgae are commonly used to biomonitor metal contamination, amongst other reasons because of their high capacity to bioconcentrate metals extracted from the water in their shoots (Bryan et al. 1985), and therefore it is not unusual, particularly in areas affected by anthropogenic pressure, for these elements to be present at high concentrations in the algae. This characteristic, which is useful for environment monitoring, may be problematical for exploitation of the algae for agricultural use (Greger et al. 2007).

In the present study, the open sea zone appeared to be the most suitable for collecting drift seaweed, given the large quantities and the lack of either extraneous inorganic material or inacceptable levels of toxic metals in the samples. Regarding the main nutrients that a fertilizer must contain (N, P, K), the concentrations of K were significantly higher in the samples from this site and the concentrations of the other two elements did not differ between the sites.

In summary, beach wrack appears to be a good material for producing high quality organic fertilizer containing large amounts of N, K and micronutrients such as B. However, because of the high variability in the quantities of material that appear on the beaches, a detailed collection plan would be required. Another aspect that must be considered is the presence of extraneous matter, which is common in the areas affected by anthropogenic pressure. Large quantities of such material would make the beach wrack unsuitable for agricultural use given the high cost of removal. The temporal variability in certain nutrients must also be taken into account. The final aspect that must be considered is the presence of toxic metals, which may be present at high levels in areas affected by anthropogenic pressure and at certain times of the year. Testing the raw material to evaluate the presence of such metals would have to be carried out before the material could be used to produce fertilizer.

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