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Relation between the type of wave exposure and seagrass losses (*Cymodocea nodosa*) in the south of Gran Canaria (Canary Islands – Spain)

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Key words: *Cymodocea nodosa*, seagrass, wave forces, swell, wind waves, storms

Abstract

Effects of different types of wave events on *Cymodocea nodosa* seagrass meadows were observed and investigated by quantitative and qualitative evaluation of material washed ashore a few days after the events. The studied seagrass meadows are located on the south coast of the island of Gran Canaria (Canary Islands – Spain) and they are protected from frequent swells arriving from the North Atlantic. However, sporadic phenomena associated with winter storms occasionally hit this coastline, causing the loss of entire plants (fresh leaves with rhizomes and roots attached). An unusual type of southern swells generated in the South Atlantic also reaches the Islands in spring and summer. A clear relation was observed between the wave events (southern swells and storm waves) and the material cast ashore over the following days, with differences in composition (fresh vs. decaying leaves) depending on the type of event. After southern swells, detached portions of *C. nodosa* consisted mostly of decaying leaves shed after senescence. These old swells cause frictional drag with moderate oscillations over a wider range at greater depths, removing only decaying leaves from the seagrass meadows and favoring the natural clean-up process.

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INTRODUCTION

Seagrass accumulations have been documented on beaches in several locations around the world, such as East Africa (Hemminga and Nieuwenhuize 1990, Ochieng and Erftemeijer 1999), Australia (Kirkman and Kendrick 1997), Europe (Milchakova 1999, Mateo et al. 2003, Duarte 2004, Roig and Martín 2005, Kotwicki et al. 2005, Ballestri et al. 2006, De Falco et al. 2008, Portillo 2008, Mateo 2010, Cocozza et al. 2011, Mossbauer et al 2012, Simeone and De Falco 2012) and North America (Behbehani and Croker 1981, Roman and Able 1988), but little has been published about their relation to wave exposure (Ochieng and Erftemeijer 1999, Ballestri et al. 2006).

Strong hydrodynamics and sudden disturbances in the sea can snap off leaves and uproot whole plants from seagrass meadows (Preen et al. 1995, Fourqurean and Rutten 2004, Ballestri et al. 2006), which results in massive accumulations of material on beaches in certain parts of the Mediterranean (Duarte 2004, Medina et al. 2001) and Australia (Department of the Environment and Heritage, 2004).

Earlier studies of interaction between waves and seagrasses addressed only wave height (Fonseca and Cahalan 1992, Granata et al. 2001, Koch et al. 2006) and the effect of seagrass meadows on wave propagation and attenuation (Bradley 2009, Stratigaki et al. 2011, Hansen and Reidenbach 2012, Infantes et al. 2012, Paul et al. 2012). Nothing has been mentioned about the effects of different types of waves (swells and wind waves) and whether they could determine high rates of canopy defoliation (shedding leaves) or uprooting of entire plants (fresh leaves with rhizomes and roots attached).

Seagrass meadows are particularly vulnerable to direct and indirect effects of human impact

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(Boudouresque et al. 2009), making their presence a good indicator of the health of the water in the area. Any change in their distribution, such as a decrease in beach-cast material on neighbouring beaches, would indicate serious changes in the ecosystem. This is why seagrass meadows act as "coastal canaries", because they indicate any degradation, disturbance or contamination in the marine ecosystem (Orth et al. 2006).

The main aims of this investigation were to answer the following research question: Is there any relation between the quantity and the composition (shed leaves or entire plants) of these depositions of beach-cast seagrass and the type of wave (swell and wind waves) or the type of material present in the meadow at the time of the wave event?

The study was conducted at Playa del Inglés and Maspalomas beaches, in the south of the island of Gran Canaria (Canary Islands – Spain). Through quantitative and qualitative assessment, a study was conducted of the relation between the beach-cast seagrass collected by the local beach cleaning service and the wave type preceding each event, from January 2004 to January 2007.

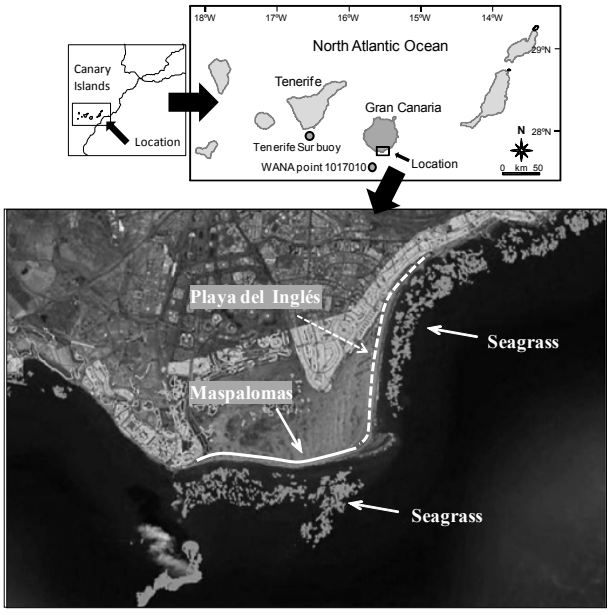

Fig. 1. Map of the Canary Islands showing the Tenerife Sur buoy, WANA Point 1017010, the locations of Playa del Inglés and Maspalomas beaches with maps of the seagrass meadows

MATERIALS AND METHODS

Study site and meteorological and oceanographic conditions

The Canary Islands are an Atlantic Archipelago of seven volcanic islands off the northwest coast of Africa (Fig. 1). The seagrass *Cymodocea nodosa* (Ucria) Ascherson is the most abundant marine phanerogam in the Archipelago and forms extensive sub-tidal meadows (Barberá et al. 2005, Tuya et al. 2006). The largest *C. nodosa* seagrass meadows in Gran Canaria are in the southern coastal region of the island, at Playa del Inglés and Maspalomas beaches (Fig. 1), occupying shallow sandy bottoms at depths from 5 to 21 m, with an average seagrass cover of 50% in a total area of 525 ha and a mean density of 848 shoots per m^2 (Espino et al. 2003). This southern location with a gentle beach slope of 0.016 is protected from frequent swells arriving from the North Atlantic (Haroun et al. 2003, Tuya and Haroun 2006) and wind waves generated by high pressure systems, which occur in all seasons in the Canary Islands with prevalent NE winds known as trade winds (the most common wind system on these islands). The gentle beach slope and the protected shore of the area explain why it is home to sandy sea bottoms and therefore how the seagrass meadows (known locally as *sebadales*) can settle and grow without disturbance from waves or currents, constituting the island's largest seagrass meadow. For this reason, the entire area has been made a Special Area of Conservation (SAC) under the name of *Sebadales de Playa del Inglés* (ES7010056) (BOE 2009).

Nevertheless, natural and sporadic phenomena associated with significant wave events cause seagrass losses in the area.

On the one hand, severe winter storms near the Canary Islands (Bullón 2003, Yanes et al. 2006) occasionally reach the south of Gran Canaria, crossing the area and battering it with west-south-west (WSW) to east-south-east winds (ESE) (8-9 Beaufort scale) from the sea (Medina et al. 2007), directly hitting the seagrass meadows. The predominant direction and height of the wind waves generated depend on the strength, path and spread of the storm. Additionally, wind waves generated by powerful high pressure systems, which can occur sporadically in winter and summer usually extend eastward, generating E to ESE wind waves, and could also affect this protected shoreline.

On the other hand, in spring and summer, a southern swell occasionally arrives in the Canary Islands from deep low pressure systems in the South Atlantic (austral autumn and winter). This strong

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depression, with a tendency to generate travelling fetch, sporadically results in waves up to 9 m high that head for the Canary Islands through the small passage between eastern South America and western North Africa (Portillo et al. 2007). The swells produced travel more than 5000 nmi for 6 to 8 days until they reach the southern shores of the Canary Islands. As a result, they show good internal organization (sets of up to 8 waves and a standard "wait-time" of 10-20 minutes) when they reach the shoreline, with high peak periods of 15-20 seconds and low significant wave heights of 1-1.5 m in deep waters, although up to 3 m in some breakers (Portillo et al. 2007).

Wave forecast and data

Wind waves and southern swells were forecast by the third generation wave model WAVEWATCHIII (WW3), developed at NOAA/NCEP and run on the Fleet Numerical Meteorology and Oceanography Center (FNMOC), and the WAM wave model, developed by the WAMDI Group (WAMDI 1988) and provided by the Spanish Meteorological Agency. The Spanish Ports System, attached to the Ministry of Public Works, provided the archived directional wave data from the Ports System deep sea Measurement Networks taken from the *Tenerife Sur* buoy, located at 28ºN 16º34.8'W at a depth of 781 m, very close to the beaches of Playa del Inglés and Maspalomas (Fig. 1). As the buoy was inoperative on 28 November 2005 during cyclone Delta, wave data were recorded by the WANA Point located in the closest proximity to these beaches (WANA Point 1017010) from the WANA data set, which comes from the WAM model output.

Wave power was determined in deep water, through extrapolation of the Airy wave theory (1845), where the water depth is greater than half the wavelength (the region of the Tenerife Sur buoy). In this case, wave power can be presented using the following formula $P \approx 0.5\ Hs^2Tp$ (kw m^{-1}) (Brooke 2003).

Sampling and data analysis

Sampling was carried out on beach-cast seagrass collected on the two beaches by the cleaning service URBASER SA, which removes debris every morning. As Playa del Inglés and Maspalomas are very important beaches for tourism, the cleaning service is responsible for clearing any beach-cast accumulation in this area. We were notified only when the collected beach-cast material was more than 1 ton fresh weight, i.e. when tractors and lorries are normally required for removal. However, after significant wave events that did not require collection of beach-cast material, we visited these beaches to determine the type of *C. nodosa* material washed ashore (decaying or fresh leaves).

The collected beach-cast material was randomly removed from a lorry until 1 m^3 was obtained and washed in seawater tanks to remove sand. During this process, the collected material was immersed in floating sifters, favoring decantation and separation of the sand downward through the net, then dried in a solar/wind drying area to determine dry weight. Stones and other residue (plastic, wood, remnants of clothing, etc.) were easily removed from the dried material and various components (sand, stones, seagrass, seaweed, other residue, etc.) were weighed separately. The variation in the weight of salt content in the dried seagrass material was considered constant, as the local salinity (oceanic waters) is quite stable. Once the percentages were determined, the total amount of beach-cast seagrass collected was quantified by the number and capacity of the lorries used. The 5 kg samples of washed beach-cast material were sorted by species before drying at 60ºC to constant weight. Percentages of the taxonomic composition of the samples were estimated from dry weights.

C. nodosa leaves were defined as "decaying" when their cover was dark brown and no rhizomes or roots were attached, and "fresh" when their cover had a fresh green color and rhizomes and roots were attached.

RESULTS

Composition of beach-cast material

All beach-cast material collected from Playa del Inglés and Maspalomas by the cleaning service contained up to 84% of detached portions (leaves, rhizomes, roots, etc.) of *C. nodosa* (Table 1) cast ashore anywhere on the two beaches. The entire submerged area in the vicinity is covered by large seagrass meadows of *C. nodosa* (Fig. 1), so the small amount of the remaining material included a variety of seaweeds that occur in the seagrass meadows (*Caulerpa racemosa*, *Caulerpa prolifera*, *Sporochnus pedunculatus*, etc.) or grow on the rocky substrate of the surrounding areas (*Haliptilon virgatum*, *Halopithys*

Table 1

Composition of beach-cast material during the period: A) January 2004 − December 2005, B) January 2006 − January 2007. Data shown as a percentage of the total dry weight of beach-cast material.

A)

	Maspalomas	Inglés and Maspalomas	Inglés	Inglés	Inglés	Inglés and Maspalomas
	6 June 2004	5 Sept 2004	13 Feb 2005	9 April 2005	6 May 2005	29 Nov 2005
Seaweed material						
Caulerpa prolifera	0.4	3.1	0.8	1.2	3.1	1
Caulerpa racemosa	0.1	1.8	0.2	0.9	2.1	0.4
Dictyota spp.				0.2		
Enteromorpha sp.		0.2		0.2	0.2	
Haliptilon virgatum	2.5		1.5		0.2	
Halopithys incurva	5.1	1	1		1.5	0.2
Halopteris filicina				0.5		
Jania rubens				0.3	0.3	
Liagora spp.					0.1	0.2
Lobophora variegata	0.3	0.1				
Sporochnus pedunculatus	3.3	1	1	0.2	1	0.2
Ulva sp.				0.1		
Seagrass material						
Cymodocea nodosa	88.3	92.8	95.5	96.4	91.5	98
Total	100	100	100	100	100	100

B)

	Inglés and Maspalomas	Inglés and Maspalomas	Maspalomas	Maspalomas	Inglés	Inglés and Maspalomas	Inglés
	10 Feb 2006	8 May 2006	11 June 2006	6 July 2006	12 Sept 2006	13 Jan 2007	28 Jan 2007
Seaweed material							
Caulerpa prolifera	0.4	1.4	0.8	2.1	1.3	0.4	0.8
Caulerpa racemosa	0.8	0.2	0.3	1.8	1.4	0.2	0.2
Dictyota spp.	0.3		0.3		0.6		
Enteromorpha sp.	0.2				0.2		
Haliptilon virgatum		1.1		0.1			
Halopithys incurva	0.8	8	1.1	3.8	1.5	0.1	
Halopteris filicina		0.4			0.2		
Jania rubens		0.1			0.3	0.3	
Liagora spp.			2		0.2		
Lobophora variegata	0.5		0.2		0.1		
Sporochnus pedunculatus	0.7	4	1	0.4			
Ulva sp.	0.3		0.1		0.1		
Seagrass material							
Cymodocea nodosa	96	84.8	94.2	91.8	94.1	99	99
Total	100	100	100	100	100	100	100

incurva, Halopteris filicina, *Jania rubens*, *Liagora* spp., etc.). The highest percentages reached *H. incurva* among the red algae, *S. pedunculatus* among the brown algae and two green algae, *C. prolifera* and *C. racemosa*. Percentages varied during the study, but no differences in relation to season or beach were observed.

Quantitative and qualitative assessment (fresh or decaying leaves) of beach-cast seagrass collected and wave events

Significant wave events (with high energy), consisting in southern swells and storm wind waves (but not from powerful anticyclones), presented a clear relation to beach-cast seagrass collected some days after these events (Fig. 2 and Table 2). Seagrass accumulations occurred only when preceded by significant wave episodes a few days earlier: southern swells in spring-summer and wind waves caused by storms in winter. The collected beach-cast material was associated with the wave power of significant wave events during the whole period of the study, as shown in Figure 3. The trend type and equation that best fitted this relation was the linear form with a determination coefficient higher than 0.85. This type of relation indicated that the increased wave power has a proportional linear effect increase on the amount of beach-cast material collected.

On the one hand, the phenomenon of deposition of beach-cast seagrass preceded by southern swells occurred only when these swells had reached the Canary Islands with a wave height of more than 1.4 m and a peak period of more than 15 s some days earlier (wave power ≥15 kW m^{-1}) (Fig. 2 and Table 2). Beach-cast material was collected at one or both of the beaches and in all cases the material was mostly decaying *C. nodosa* leaves (>97%) (Fig. 4). The

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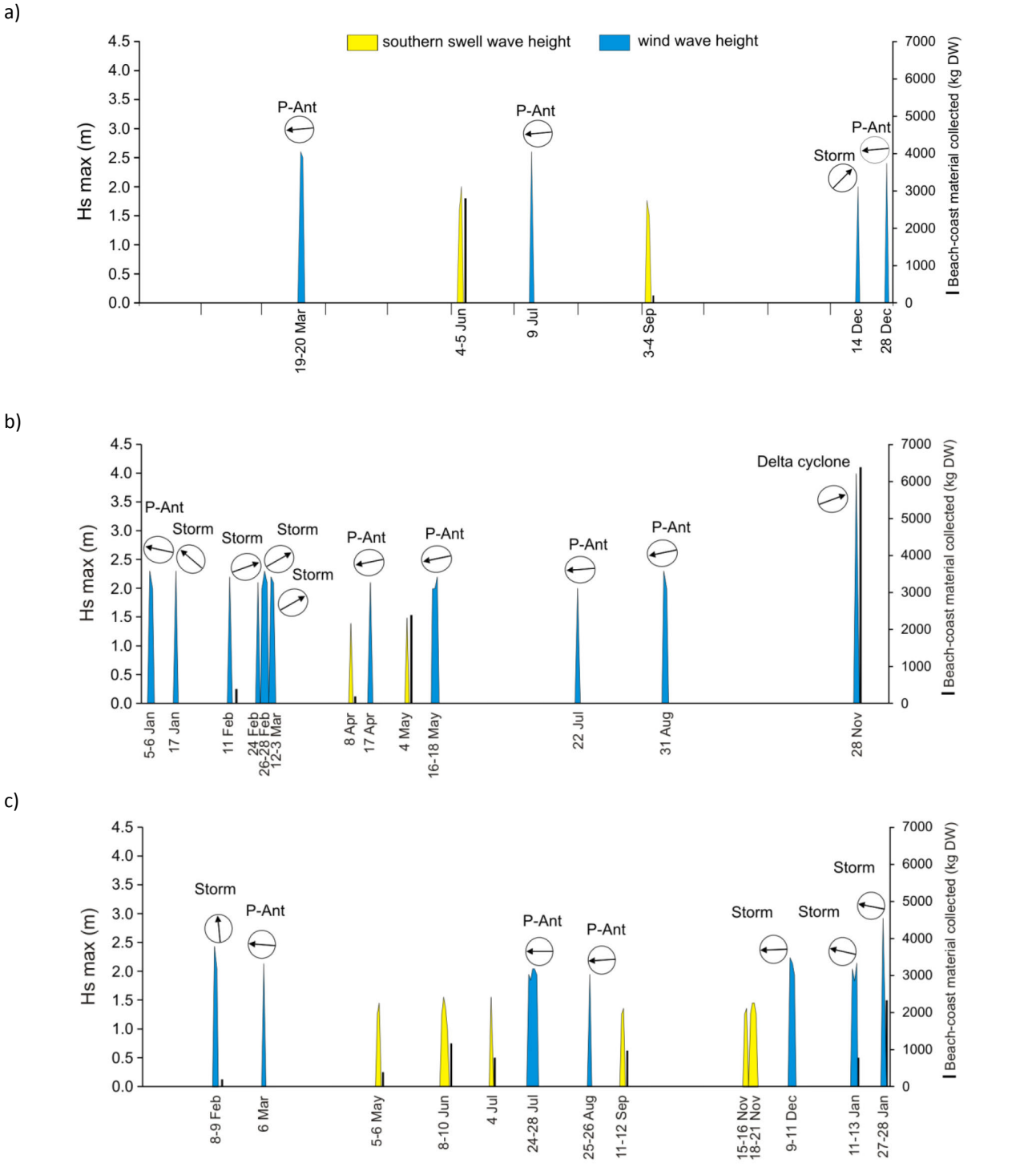

Fig. 2. Seasonal variation (X-axis: date) of the collected beach-cast material showing the quantity in kg dry weight (kg DW) at Playa del Inglés and Maspalomas and the maximum significant wave height of the day (Hs max) with the origin, southern swells or wind waves (from Storm (*Storm*) or Powerful Anticyclones (*P-Ant*)), and the direction in a) January 2004 − December 2004, b) January 2005 − December 2005, c) January 2006 − January 2007. Only wind wave heights above 2 m generated by storms (direction: WSW-ESE; *Storm*) and powerful anticyclones (direction: ENE-ESE; *P-Ant*) and only southern swell wave heights above 1.3 m with peak periods of more than 15 s are shown (direction: SSW-S; *southern swell*).

Table 2

Maximum significant wave height of the day (Hs max), peak period (s), direction (°), type of wave (with origin) and wave power of all significant wave events occurred from January 2004 to January 2007. Beach-cast material collected some days after these events (kg DW) at Playa del Inglés and Maspalomas.

Date	Hs max (m)	Tp (s)	Direction (°)	Type of wave / Origin	Wave Power (kW m^{-1})	Beach-cast material collected (kg DW)
20/03/2004	2.5	10	82	wind waves / anticyclone	31.3	0
05/06/2004	1.9	15.4	214	southern swells	27.8	2800
09/07/2004	2.6	7.6	79	wind waves / anticyclone	25.7	0
03/09/2004	1.7	15	210	southern swells	21.7	200
14/12/2004	2	6.7	237	wind waves / storm	13.4	0
28/12/2004	2.4	6.4	80	wind waves / anticyclone	18.4	0
05/01/2005	2.3	6.5	120	wind waves / anticyclone	17.2	0
17/01/2005	2.3	6.1	153	wind waves / storm	16.1	0
11/02/2005	2.2	8.4	115	wind waves / storm	20.3	400
24/02/2005	2.1	8.4	231	wind waves / storm	18.5	0
27/02/2005	2.3	6.6	225	wind waves / storm	17.5	0
02/03/2005	2.2	7.2	239	wind waves / storm	17.4	0
08/04/2005	1.4	15.4	217	southern swells	15.1	200
17/04/2005	2.1	11.1	76	wind waves / anticyclone	24.5	0
04/05/2005	1.8	15	205	southern swells	24.3	2400
18/05/2005	2.2	5.9	90	wind waves / anticyclone	14.3	0
22/07/2005	2	6.2	75	wind waves / anticyclone	12.4	0
31/08/2005	2.1	6.2	83	wind waves / anticyclone	13.7	0
28/11/2005	4	9	225	wind waves / Delta cyclone	72.0	6400
08/02/2006	2.5	7.6	158	wind waves / storm	23.8	200
06/03/2006	2.2	6.2	101	wind waves / anticyclone	15.0	0
06/05/2006	1.5	15.4	217	southern swells	17.3	400
09/06/2006	1.6	15.4	208	southern swells	19.7	1200
04/07/2006	1.6	15.4	214	southern swells	19.7	800
26/07/2006	2.1	7.2	84	wind waves / anticyclone	15.9	0
25/08/2006	2	5.5	87	wind waves / anticyclone	11.0	0
12/09/2006	1.4	15.4	217	southern swells	15.1	1000
15/11/2006	1.3	15.4	208	southern swells	13.0	0
19/11/2006	1.5	15.4	211	southern swells	17.3	0
09/12/2006	2.3	7.2	87	wind waves / storm	19.0	0
13/01/2007	2.2	6.6	124	wind waves / storm	16.0	800
27/01/2007	2.8	8.4	127	wind waves / storm	32.9	2400

largest amount collected was preceded by the largest southern swell during the study period. An estimated 2800 kg dry weight of collected beach-cast seagrass was preceded by the strongest event − on 5 June 2004 (Hs max: 1.9 m; 27.8 kW m^{-1}) and in 2005, after the largest southern swell for the year (4 May; Hs max: 1.8 m and wave power of 24.3 kW m^{-1}), when 2400 kg dry weight was collected. Three days after the major swells in 2006, i.e. on 9 June (Hs max: 1.6 m; 19.7 kW m^{-1}), the cleaning service collected 1200 kg dry weight, the largest landing of beach-cast seagrass for the year. As an exception, southern swell events on 19 November 2006, with the maximum significant wave heights of 1.5 m (wave power of 17.3 kW m^{-1}), hit the area in autumn (austral spring), but no beach-cast material was collected in Playa del

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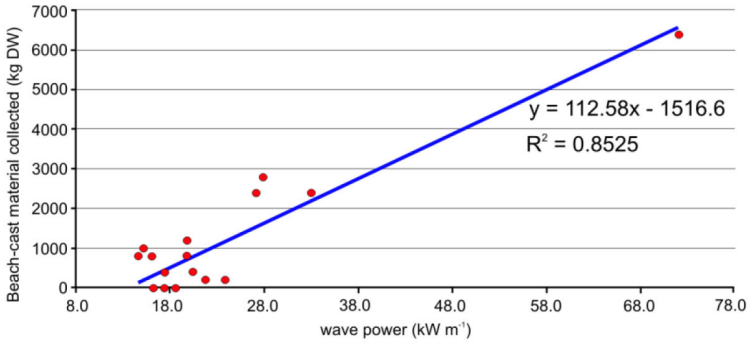

Fig. 3. Relation between wave power (kW m^{-1}) for significant wave events occurred from January 2004 to January 2007 with southern direction (from 115° to 225°) and beach-cast material collected some days after (kg DW) at Playa del Inglés and Maspalomas.

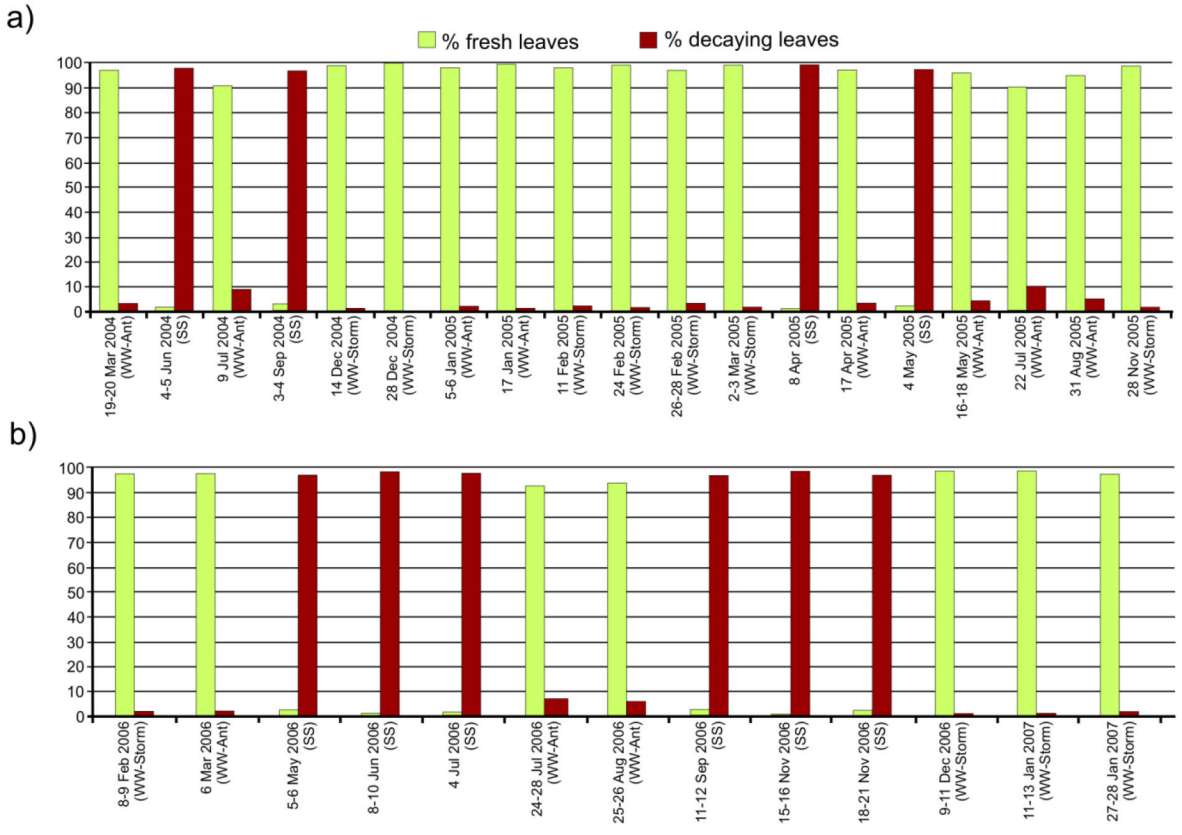

Fig. 4. Dates of beach-cast seagrass and types of wave events (southern swells (SS), wind waves generated by storms (WW-Storm) and wind waves generated by powerful anticyclones (WW-Ant)) preceding each deposition of beach-cast material during the study period (X-axis), showing the composition as a percentage of decaying and fresh leaves: a) From January 2004 to December 2005, b) From January 2006 to January 2007.

Inglés or Maspalomas. However, *C. nodosa* remains found on the shore after both southern swells consisted mainly of decaying leaves.

On the other hand, the phenomenon of material cast ashore after wind waves occurs in winter (January and February), only when southerly (115° to 225°) storm waves reach the islands with wave power greater than 14.6 kW m^{-1}. Approximately 99% of the seagrass material collected after these severe storms during the study period was fresh *C. nodosa* leaves

(Fig. 4). After the severe storms of 11 February 2005 (Hs max: 2.2 m; 20.3 kW m^{-1}), 8 February 2006 (Hs max: 2.5 m; 23.8 kW m^{-1}) and 13 January 2007 (Hs max: 2.2 m; 16 kW m^{-1}), the cleaning company collected 400, 200 and 800 kg dry weight, respectively. The highest amount (2400 kg dry weight) corresponded to the largest wave event generated in the heaviest squall of 27 January 2007 (Hs max: 3 m; 32.9 kW m^{-1}). Other winter storms with similar characteristics, e.g. those on 17 January 2005 (16.1 kW m^{-1}) and 27 February 2005 (17.5 kW m^{-1}), were not followed by accumulations of beach-cast seagrass, but the detached portions of *C. nodosa* observed on the beaches after all these events were fresh leaves with rhizomes and roots attached (Fig. 4). Conversely, wind waves originating from strong anticyclones (P-Ant), in both winter and summer, were not associated in any way with beach-cast seagrass (when tractors and lorries are normally required for removal), even though in some cases the generated wave power was more than 14.6 kW m^{-1}. However, the seagrass material observed on the shore consisted of fresh leaves in approximately 90%.

An exceptional event occurred on 28 November 2005, in mid autumn, with the unusually severe tropical cyclone Delta, which was accompanied by the largest amount of beach-cast material collected in the whole study period (6400 kg dry weight). No wave data were recorded at this time as the *Tenerife Sur* buoy was inoperative, so the specified wave height of 4 m and peak period of 9 s was predicted by the WAM model, incorporating the wind field generated by the HIRLAM model.

DISCUSSION

Quantifying the beach-cast material collected on these types of tourist beaches is one approach to estimate and assess the loss of marine plants in this area, as the cleaning service always removes any material washed ashore, and this is one way to estimate the condition of the surrounding seagrass meadows (growth, stability or regression) (Orth et al. 2006). However, mechanical removal of this material is not an environmentally friendly practice, as seagrass remains help to maintain the shoreline by reducing the wave forces and favor sedimentation processes (Hemminga and Nieuwenhuize 1990). Similarly, a large amount of sand is lost (>80%) when seagrass is collected mechanically (Portillo 2008).

The considerable southern swell and wind waves generated by storms normally coincided with a large volume of beach-cast material on the beaches of Playa del Inglés and Maspalomas several days later, but similar sea conditions were not always followed by depositions of beach-cast material. The quantity of beach-cast material depended on the force of incident wave events (Fig. 3), although other factors were also involved: whether stronger or similar events had previously occurred; the plant cover existing at that time of year; and in particular, whether, as a result of the local hydrodynamic conditions (currents, tides, residual waves and wave type, etc.) occurring immediately after these wave events, the material was washed up on nearby beaches or drifted to submerged areas (Portillo 2008).

In spring-summer, after southern swells with wave power higher than 15 kW m^{-1}, all the beach-cast material collected at these beaches consisted of decaying *C. nodosa* leaves. An exception occurred with the swell event in autumn 2006, which did not result in beach-cast accumulations even though its wave power exceeded 15 kW m^{-1}. This could be related to the explanation given above, as the southern swell events occurring in spring and summer could have removed all the leaves shed by the seagrass meadow, and leaf production begins to decline in autumn, with less frequent defoliation. Nevertheless, the limited materials found at these beaches after the two swell episodes in autumn 2006 consisted of decaying *C. nodosa* leaves, whereas only fresh leaves were observed in the same season (late November) after tropical storm Delta.

In winter, storms that hit the Canary Islands and generated southern wind waves (from 115° to 225°; Table 2) (Storm; Fig. 2) with high wave power (up to 14.6 kW m^{-1}; Table 2) clearly caused erosion of the seagrass bed as all the seagrass material collected after these events consisted of fresh *C. nodosa* leaves (with rhizomes and roots attached). Other storm events with high wave power of up to 14.6 kW m^{-1} have occurred without subsequent collection of beach-cast material, although this does not mean that canopy uprooting did not occur as we found remains of fresh leaves washed ashore. Throughout the study, wind waves generated by powerful high pressure systems (P-Ant; Fig. 2) with high wave power of up to 14.6 kW m^{-1} (Table 2) were not associated with beach-cast seagrass material. This type of wind wave never resulted in beach casts, even in winter, spring or summer (when southern swells normally wash the

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decaying *C. nodosa* leaves ashore). These wind waves generated by powerful anticyclones usually arrive on the shore with more easterly directions (wind wave directions from *P-Ant* varied from 75° to 120°, whereas wind wave directions from *Storms,* which caused beach-cast accumulation, varied from 115° to 225°; Fig. 2 and Table 2), and therefore they hit this coastline less directly than storm wind waves. However, the small accumulations of material that appeared on the beaches after these wind waves generated by powerful anticyclone systems were fresh *C. nodosa* leaves in all seasons, with no decaying leaves. For this reason, a clear difference was observed in spring-summer between the different types of wave events (southern swells vs. wind waves) and the amount and composition of beach-cast material (whole plants vs. senescent leaves).

The first consideration is that the differences observed in the type of seagrass cast ashore (whole plants vs. senescent leaves) could be related to seasonal changes in the abundance and growth stage of *C. nodosa*. In spring-summer, when southern swells normally wash the decaying *C. nodosa* leaves ashore, the leaf shedding process occurs which involves the highest frequency of new leaf production per shoot and leaf loss, and senescence of plants due to cooler waters and shorter days in winter (Reyes et al. 1995, Espino et al. 2006, Tuya et al. 2006), resulting in considerable replacement of old leaves. Moreover, the winter period, when storms cause the loss of entire plants, coincides with more limited development of rhizomes and roots (Reyes 1993), which could facilitate the uprooting.

The second consideration is whether the wave type could be related to rates of canopy defoliation (shedding leaves) or uprooting of entire plants (fresh leaves with rhizomes and roots attached). A clear difference was observed in the composition of beach-cast material (whole plants vs. senescent leaves) when different types of wave events (southern swells vs. wind waves) occurred in the same seasons. Wind waves always uproot the whole plants, whereas southern swells detach only decaying leaves from seagrass meadows, regardless of the season. Southern swells are old swells resulting from long distances travelled and therefore start to touch the bottom at a deeper level of the sea floor than wind waves do (Open University Course Team 1989). As a result, *C. nodosa* meadows feel the drag effect over a wide range of deep depths. These old swells can therefore be related to harmonic movements over a wider range of greater depths compared to wind waves and are referred to as monami (Ackerman and Okubo 1993), which could produce slight drag forces, strong enough to detach decaying leaves from seagrass meadows. In contrast, high wind waves normally interact with the sea floor at a narrow range of low depths in comparison with southern swells, but inside the seagrass meadow (at depths of more than 5 m). Moreover, as this type of surface wave consists of many short, steep waves of varying heights, the frictional drag in shallow waters may be associated with irregular, strong rips and movements over this shorter range of lower depths. There is a maximum horizontal water particle velocity at breaking under the wave crest (Le Roux 2008) and for such severe storm waves the increased effect of wave setup and setdown causes pressure differences and undertows that tend to exceed landward particle velocities under the wave crest and are capable of eroding the bottom (Davis and Fitzgerald 2004) and uprooting the whole plants at these breaking depths. Therefore, wind waves could generate near-bottom turbulence frictional drags at lower depths of the seagrass meadows capable of uprooting the entire plants (fresh leaves with rhizomes and roots attached) and consequently result in high rates of canopy uprooting.

This is one of the first studies attempting to link the wave type to seagrass uprooting or "leaf cleaning", as the few earlier studies accounted only for wave height. However, a variety of new approaches are needed to corroborate that different types of waves determine high rates of canopy defoliation or uprooting, such as *in situ* wave measurements with hydrodynamic force instruments (dynamometers) and studies of seasonal seagrass cover (dynamics of biomass and phenology of seagrass populations) before and after significant wave events.

The following can be concluded from this study:

- The occurrence of wave events (wind waves generated by storms and southern swells) is a *sine non qua* condition for the appearance of landings of beach-cast seagrass.
- In spring and summer, when plants are senesced and leaf loss reaches the highest frequency, southern swells detach only the decaying leaves from the seagrass meadows (favoring the natural clean-up process, which results in accumulations of beach-cast seagrasses); however, southern swells never uproot the whole plant, even in other seasons (i.e. autumn).

- In winter, when sporadic winter storms occasionally hit this coastline, the southern wind waves cause uprooting of whole plants (fresh leaves with rhizomes and roots attached) and accumulations of beach-cast seagrasses.
- Significant wind waves generated by powerful anticyclones tend to uproot the entire plant regardless of the season, but do not produce accumulations of beach-cast seagrasses.
- The present approach of sampling beach-cast material collected by a cleaning service is innovative and provides a useful context for evaluating the relation between the type of wave exposure and seagrass losses in the south of Gran Canaria.

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