Taxonomic Guide to Pelagic *Sargassum* in the Caribbean Sea and North Atlantic

Guide Taxonomique de *Sargassum* Pélagique dans la Mer des Caraïbes et de l'Atlantique Nord

Guía Taxonómica de *Sargassum* Pelágico en el Mar Caribe y el Atlántico Nort

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EXTENDED ABSTRACT

Sargassum is a pelagic seaweed found in the Sargasso Sea, Caribbean Sea, Gulf of Mexico and greater North Atlantic Ocean. In recent years, Caribbean islands and the west African coast have experienced massive influxes of *Sargassum*. Much of the seaweed that washed ashore during the 2014 - 2015 inundation period was identified as *S. natans VIII (SnVIII),* arriving from the North Equatorial Recirculation Region (Johnson et al. 2012) which expanded the known range of *Sargassum* beyond historical patterns. In contrast, other *Sargassum* forms traditionally found in the Caribbean are transported from the Sargasso Sea, such as the quintessential *S. natans I* (*SnI*) and widespread *S. fluitans III* (*SfIII*; Gower and King 2011, Schell et al. 2015). Reliable taxonomic identification of *Sargassum* in the field (land or sea) is crucial to indicate the seaweed's predicted source region and forecasted movement, as emphasized by inundation events within the last decade.

Many *Sargassum* forms have been identified, with initial morphological descriptions provided in taxonomic classification manuscripts (Winge 1923, Parr 1939). These authors relied solely upon visual differences between forms, although the details of their specimen origins, identification techniques, and dichotomous system have been lost over time. *Sargassum* has since been generalized as one entity in most reports and field investigations, minimizing information and clarity about diversity and identification available to interested parties.

It was hypothesized that statistically significant differences existed between morphological characteristics of common *Sargassum* forms. The physical traits focused on here are conservative, respective to each form. If these characteristics were non-conservative, species or form identification would be impossible without genetic information; visual identification and field guides would have no purpose. By encompassing a wide spatial area, this study has purposefully mixed samples from many locations to confirm the morphology as conservative.

Fresh samples of pelagic *Sargassum* (*SnI, S. natans II (SnII), SnVIII* and *SfIII*) were collected by neuston tow, dip net and hand grab from the North Atlantic Ocean and Caribbean Sea on five Sea Education Association cruises onboard the *SSV Corwith Cramer* between December 2014 and March 2016 (Figure 1). To maintain form and sample longevity, all specimens were dried and pressed, using coffee filters and manilla folders within textbooks. Initial drying occurred in the *Corwith Cramer* shipboard library, thereafter the Sea Education Association campus lab. Blade length and width, float diameter, and distance between branching foliation were measured in millimeters using calipers (Figure 1). These measurements were combined respectively into averages and examined through t-tests and ANOVAs.

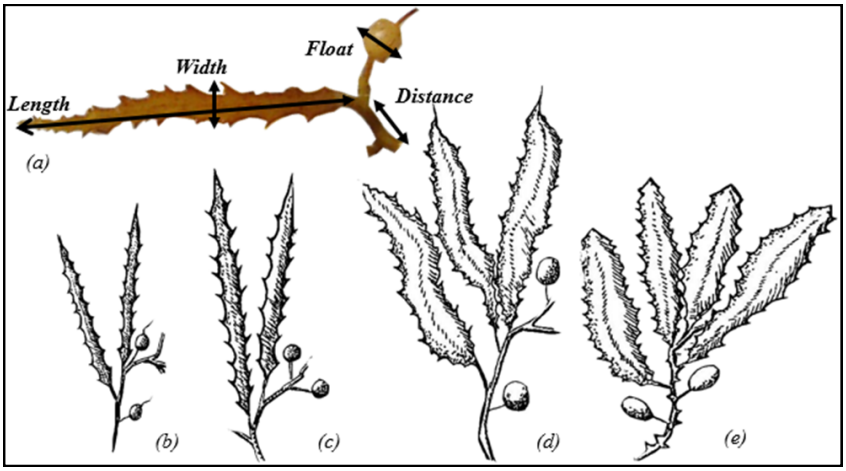

Figure 1. (a) Measurement parameters, Four Sargassum forms, (b) S. natans I, (c) S. natans II, (d) S. natans VIII, (e) S. fluitans III
Photo credit: Jeffery Schell, sketches by Corey Wrinn 2016

Of the common *Sargassum* forms examined in this project, two pairs are most often confused. Nearly uniform in appearance, *SnI* and *SnII* are difficult to tell apart and best distinguished by *SnI*'s singular superficial spine found on the float. Likewise, the broad blades of *SnVIII* and *SfIII* hinder accurate identification; the presence of stem thorns only on *SfIII* is key.

SnI (n = 6) has long (14.82 mm ± 0.45 mm) and thin (0.96 mm ± 0.06 mm) blades, with spherical floats (1.93 mm ± 0.6 mm) each with a singular superficial spine. The appearance of *SnII* (n = 10) is very similar to *SnI*, with longer (21.8 mm ± 1.67 mm) blades not as thin (2.19 mm ± 0.3 mm), and spherical floats (2.02 mm ± 0.08 mm) without any spine. A key morphological similarity between these two *S. natans* forms is their foliage pattern (Table 1), with nearly equal stem distances between branching (*SnI* average 2.96 mm ± 0.23 mm; *SnII* average 3.93 mm ± 0.26 mm). Neither *SnI* nor *SnII* have stem thorns.

SfIII (n = 10) has short (14.3 mm ± 0.65 mm) and comparatively broad (2.52 mm ± 0.09 mm) blades, and oblong floats (2.4 mm ± 0.08 mm). Visually similar, *SnVIII* (n = 10) produces longer (24.29 mm ± 0.8 mm) leaves with broader (4.49 mm ± 0.15 mm) blades; *SnVIII* floats are spherical in shape (2.6 mm ± 0.06 mm). A key morphological difference between these two forms is their foliation pattern, where *SfIII* has an average (3.09 mm ± 0.12 mm) stem distance between densely-branching foliage with numerous thorns along the stems, compared to *SnVIII* with an average (5.27 mm ± 0.37 mm) space between sparsely-branching foliage and no thorns (Table 1).

Statistical analyses confirmed significant morphological differences observed between forms. While float size and foliage distances are very similar in *SnI* and *SnII*, blade length ($p < 0.004$) and width ($p < 0.003$) traits are significantly different. Additionally, *SnVIII* and *SfIII* blade length ($p < 0.001$) and width ($p < 0.001$) characteristics, as

Table 1. T-test results for comparison between measurements of morphological characters between Sargassum forms ($p < 0.05$).

Blade Length	SN1	Sn2	Sn8	Sf
vs S. Natans I		0.003559	2.93E-07	0.289176
vs S. Natans II	0.003559		0.09775	0.000282
vs S. Natans VIII	2.93E-07	0.09775		7.3E-09
vs S. Fluitans	0.289176	0.000282	7.3E-09	
Blade Width	SN1	Sn2	Sn8	Sf
vs S. Natans I		0.004076	5.42E-11	1.02E-08
vs S. Natans II	0.004076		1.17E-06	0.153635
vs S. Natans VIII	5.42E-11	1.17E-06		1.52E-09
vs S. Fluitans	1.02E-08	0.153635	1.52E-09	
W/L Ratio	SN1	Sn2	Sn8	Sf
vs S. Natans I		0.002182	5.91E-10	1.47E-07
vs S. Natans II	0.002182		5.25E-09	5.23E-07
vs S. Natans VIII	5.91E-10	5.25E-09		0.273966
vs S. Fluitans	1.47E-07	5.23E-07	0.273966	
Float Diameter	SN1	Sn2	Sn8	Sf
vs S. Natans I		0.258843	5.57E-06	0.001233
vs S. Natans II	0.258843		2.85E-05	0.00353
vs S. Natans VIII	5.57E-06	2.85E-05		0.046336
vs S. Fluitans	0.001233	0.00353	0.046336	
Foliage Distance	SN1	Sn2	Sn8	Sf
vs S. Natans I		0.013783	0.000303	0.295061
vs S. Natans II	0.013783		0.09775	0.005444
vs S. Natans VIII	0.000303	0.09775		1.61E-05
vs S. Fluitans	0.295061	0.005444	1.61E-05	

well as foliation distance ($p < 0.001$), are significantly different. Ratios of blade width-to-length varied, showing significant differences between *SnI* and *SnII* ($p < 0.01$) but not between *SnVIII* and *SfIII* (Table 1).

This research effort examined *Sargassum* collected from the open ocean, then dried for analysis. However, the general public and many scientists encounter the seaweed in a coastal setting, on the beach or in the intertidal zone, where all specimens are in the process of drying, and accurate identification is complicated. In order to monitor changes in key dimensions during the *Sargassum* transition from fresh to dried, fresh clumps of benthic *S. filipendula* were collected from the waters off Surf Drive Beach, Falmouth, MA in September 2016, and dried/pressed as those from offshore cruises. These samples are being measured periodically over many weeks to establish a correction based on percentage loss in each studied dimension. As this study continues, application of *S. filipendula*-based real-time insight into morphological changes during the transformation from fresh-to-dried will allow estimation of actual fresh dimensions for each examined *Sargassum* form. Comparisons to Winge (1923) and Parr's (1939) historic measurements and updates to the field guide will be implemented. Pressed and dried *Sargassum* samples continue to provide a reliable reference for future inquires, and are easily accessible for detailed study.

Description of *Sargassum* form morphology has not changed since early detailed explanations (Winge 1923, Parr 1939). Statistical analyses confirm physical differences between four *Sargassum* forms observed in the Sargasso and Caribbean Seas in recent years. Caliper measurements are more accurate than instruments used by field researchers in the early 20th century, giving this study more reliable and specific results. The four *Sargassum* forms here described are distinguished on the basis of morphological differences and identification cues given in original descriptive manuscripts. The examined traits are conservative in nature, distinct from each other, and maintain their significant differences over time.

SnI and *SnII* dominate the Sargasso Sea, *SfIII* occurs throughout the North Atlantic Ocean, and *SnVIII* appears to originate in the north Equatorial Zone off the coasts of South America and Western Africa, though newly abundant in the Caribbean Sea and Gulf of Mexico within the past five years (Johnson et al. 2012, Schell et al. 2015). Reported measurements reflect inherent variability in seaweed structure and character while highlighting differences useful for field identification in the open ocean or on land. With recent range expansion and inundation events, it is a critical time to once again pay attention to *Sargassum* morphological differences as they are important indicators of ecological changes occurring throughout the North Atlantic basin.

KEYWORDS: *Sargassum*, Caribbean, identification, morphology

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