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Short Communication

Shoalgrass *Halodule wrightii* (Ascherson, 1868) meadows in El Salvador: distribution and associated macroinvertebrates at the estuary complex of Bahía de Jiquilisco

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ABSTRACT. Seagrasses are aquatic angiosperms that grow submerged in shallow marine and estuarine environments worldwide. *Halodule wrightii* is a circumtropically distributed seagrass species found primarily in the Atlantic Ocean, but also in parts of the Indian Ocean and eastern Pacific Ocean. Along the Pacific coast of Central America, large swaths of the reported distribution of *H. wrightii* are assumptions based on interpolation between known seagrass point locations, and despite confirmation of *H. wrightii* occurrence in Bahía de Jiquilisco in El Salvador, little is known about its distribution and associated species, which can hamper efforts to conserve this seagrass ecosystem. To address these gaps in data, we provide the first assessment of *H. wrightii* distribution and associated macroinvertebrate species in Bahía de Jiquilisco. We identified six areas where seagrasses occurred and two of these were selected for monitoring. At the two sampled areas, heterogeneous patches of *H. wrightii* covered 27.1 km^2 with 22 associated macroinvertebrate species from three taxonomic groups in three phyla. We conclude by discussing local threats to *H. wrightii*, including implications for endangered hawksbill (*Eretmochelys imbricata* and green (*Chelonia mydas agassizii*) turtles that depend on these ecosystems, and describe opportunities for conservation in Bahía de Jiquilisco.

Keywords: *Halodule wrightii*, associated fauna, foundation species, mangroves, seagrass, biogeography, environmental policy.

Seagrasses are aquatic angiosperms that grow submerged in shallow marine and estuarine environments worldwide (Den Hartog & Kuo, 2006). Despite their global distribution and critical role as foundation species (Hughes *et al.*, 2009; Lefcheck *et al.*, 2017), growing evidence suggests that human activities are driving seagrass meadow fragmentation and degradation worldwide (Duarte, 2002; Cloern *et al.*, 2016). Given the major gaps in knowledge that exist regarding seagrass cover and distribution, particularly in low-income regions, there is an urgent need to address not only threats causing precipitous decline of known seagrass-based communities, but to simultaneously enhance understanding of seagrasses at unstudied sites (Orth *et al.*, 2006).

Halodule wrightii Ascherson is a circumtropically distributed species found on sandy to muddy bottoms in the lower intertidal and upper subtidal zones primarily in the Atlantic Ocean, but also in parts of the Indian Ocean and eastern Pacific Ocean (Short *et al.*, 2007). As with other species of seagrasses, the morphology, fitness, and distribution of *H. wrightii* can be strongly influenced by environmental factors, including temperature, salinity, and nutrient and light availability (Short & Duarte, 2001; Ralph *et al.*, 2007; Howard *et al.*, 2016). For example, light limitation can produce physiological stress that decreases plant growth and biomass production, diminishes density, increases shoot mortality, and limits depth distribution (Phillips & Meñez, 1988; Biber *et al.*, 2009). Given its high light requirements, the survival of *H. wrightii* is particularly vulnerable to declines in water quality from system-wide changes induced by natural events or cultural eutrophication (Tiling & Proffitt, 2017).

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Along the Pacific coast of Central America, large swaths of the reported distribution of *H. wrightii* are assumptions based on interpolation between known seagrass point locations (Spalding *et al.*, 2003; Short *et al.*, 2010), with its presence confirmed only at Corinto in Nicaragua; Jicarón Island, Punta Naranja and Taboga Island in Panama (Den Hartog, 1964, 1970); and Bahía de Jiquilisco in El Salvador (MARN, 2010). However, despite confirmation of *H. wrightii* occurrence in El Salvador, little is known about its distribution and associated species in Bahía de Jiquilisco, which can hamper efforts to conserve this seagrass ecosystem. For these reasons, we investigated the distribution and macroinvertebrate species associated with *H. wrightii* in Bahía de Jiquilisco, El Salvador. Based on our findings, we identify local threats to *H. wrightii* and describe opportunities for conservation.

Our study was conducted in the mangrove estuary complex of Bahía de Jiquilisco (13º15'N, 88º30'W), which is located on the south-central coast of El Salvador (Fig. 1). Bahía de Jiquilisco is the largest mangrove forest in El Salvador (635 km^2) and is a RAMSAR wetland, UNESCO Biosphere Reserve, and National Conservation Area (MARN, 2013). Water transparency is generally low (1-2 m), particularly during spring tides and the rainy season (May-November), and the marine bottom consists of primarily fine sand and mud.

Based on local residents' knowledge, we identified six areas where *H. wrightii* occurred and selected the two areas -Golfo La Perra (13º01'N, 88º29'W) and Corral de Mulas (13°11'N, 88°31'W)- that were most discernible for monitoring (Fig. 1). The seagrass meadow at Golfo La Perra is adjacent to relatively intact mangrove and tropical dry forest, whereas the seagrass meadow at Corral de Mulas borders fragmented tropical dry forest interspersed with human settlements.

We determined the distributional area of *H. wrightii* patches at Golfo La Perra and Corral de Mulas by delineating the perimeter at both areas using handheld Global Positioning System (GPS) receivers (eTrex, Garmin International, Olathe, KS, USA) coupled with aerial photographs (camera: GoPro, San Mateo, CA, USA; drone: DJI Phantom, Shenzhen, China). We established seven and two sampling points at Golfo La Perra and Corral de Mulas, respectively, in 2013 (Fig. 1). Logistical and economic limitations prevented us from taking morphometric measurements of all plants and from identifying belowground invertebrates that would enable a complete description of the seagrass beds (*e.g.*, above- and belowground biomass) at both sites. Therefore, at each sampling point, we collected only a small subset of plants and all visible aboveground macroinvertebrates in 50×50 cm quadrants (modified from Mostacedo & Fredericksen, 2000). Plants were identified by the description in Phillips & Meñez (1988). We photographed fresh and dried individuals, which were subsequently preserved as herbarium specimens in the Museum of Natural History of El Salvador (MUHNES). Collected macroinvertebrates were identified using the descriptions in Keen (1971) and Fisher *et al.* (1995).

Heterogeneous patches of *H. wrightii* were distributed across 27.1 km^2 in the two sampled areas of Bahía de Jiquilisco, with 26.0 and 1.1 km^2 at Golfo La Perra and Corral de Mulas, respectively (Fig. 1). We consider this to be an underestimate of total seagrass coverage, however, as we were unable to estimate seagrass distribution at the other four identified areas-Golfito, Rancho Viejo, La Chepona, and El Bajón (Fig. 1), which were less familiar locally.

Morphological characteristics of *H. wrightii* specimens from Bahía de Jiquilisco align with diagnostic features previously reported for the species (*e.g.*, Phillips & Meñez, 1988; Creed *et al.*, 2016): slender, creeping rhizomes 0.5-1.1 mm in diameter and stolons with internodes 5.0-15.5 mm long; each node produces 2-5 unbranched roots 1-5 cm long and 2-3 leaf-blades 3-20 cm long and 0.3-0.9 mm wide; leaf-blades arise from a translucent leaf sheath with blade apex bidentate measuring 0.01-0.03 mm between lateral teeth. No flowers or fruits were observed. Greater coverage and density of seagrass patches were observed at Golfo La Perra, where leaf-length reached 20 cm, than at Corral de Mulas, where seagrass coverage and density appeared lower and leaf-length was shorter (3-10 cm), possibly due to higher levels of freshwater run-off from degraded forest conditions surrounding the area. Although leaf-length values for *H. wrightii* from Bahía de Jiquilisco fall within the range of values reported in other regions (*e.g.*, Phillips & Meñez, 1988; Biber *et al.*, 2009; Sordo *et al.*, 2011), maximum leaf-length (20 cm) at our study area is more than double the maximum value (7.2 cm) at Cape Verde in the eastern Atlantic (Creed *et al.*, 2016). We observed an increased presence of unidentified species of macroalgae in *H. wrightii* patches at Corral de Mulas, presumably resulting from sustained nutrient loads from proximate land-based human activities. Macroalgae and epiphytes have been shown to attenuate light and impede growth of seagrass species (Dunton, 1990; Lapointe *et al.*, 1994; Reynolds *et al.*, 2014; Tiling & Proffitt, 2017), which may contribute to the shorter leaf-length of *H. wrightii* at Corral de Mulas than at Golfo La Perra.

Seagrass beds function as important nurseries for larval and juvenile stages of fish and invertebrates (Beck *et al.*, 2001; Bloomfield & Gillanders, 2005;

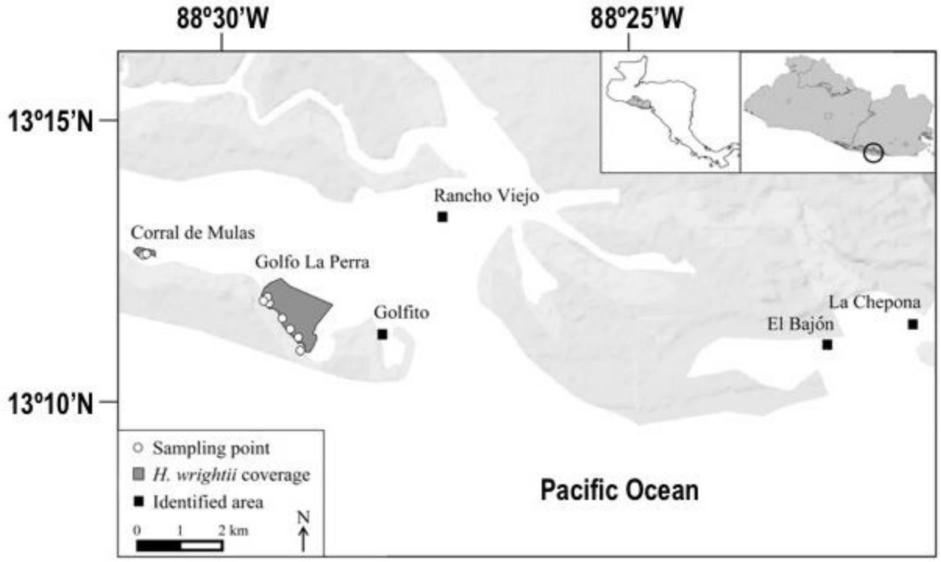

Figure 1. Locations and monitoring of *Halodule wrightii* and associated macroinvertebrates in Bahía de Jiquilisco in El Salvador, 2013.

Dorenbosch *et al.*, 2005), particularly in patchy rather than homogenous seagrass meadows (Holt *et al.*, 1983). In *H. wrightii* patches at Golfo La Perra and Corral de Mulas, we identified 22 macroinvertebrate species from three taxonomic groups (Crustaceans, Echinoderms, Molluscs) in three phyla (Table 1).

Many of these organisms are utilized by local communities as subsistence resources or sold commercially on local markets, including diverse species of mangrove cockles (*Anadara grandis*), clams (*Donax panamensis*, *Chione imbricata*, *Chione subrugosa*, *Dossinia* sp.) and crabs (*Callinectes* sp.). Other species have artisanal value, such as the shells of *Sanguinolaria* sp., *Theodoxus luteofasciatus*, *Rhinocoryne humboldti*, and *Olivella* sp. Given the high local value of macroinvertebrate species, increasing human populations and acute poverty in coastal areas have led to overexploitation of these resources and degradation of *H. wrightii* meadows. Additionally, domestic mammals, particularly pigs and dogs, roam *H. wrightii* patches during low tide and consume exposed invertebrates, which further impairs populations (Carlton & Hodder, 2003). The synergistic degradation and fragmentation of *H. wrightii* meadows in Bahía de Jiquilisco may also negatively impact endangered marine megafauna, such as green turtles (*Chelonia mydas agassizii*), that depend on these areas for foraging (Liles & Thomas, 2010; Meza-Ruiz *et al.*, 2015). Our next steps for future research will focus on demarcating the seagrass distribution at Golfito, Rancho Viejo, La Chepona, and El Bajón to provide a more accurate assessment of total seagrass coverage in Bahía de Jiquilisco. Additionally, we will characterize the population dynamics of these seagrass meadows, including above- and belowground seagrass biomass, shoot length and density, seasonality, and associated environmental parameters at Golfo La Perra and Corral de Mulas. Finally, we will measure the organic carbon content of seagrass biomass and underlying substrate in seagrass meadows in Bahía de Jiquilisco, as previous research demonstrates that organic carbon stored per unit area of seagrasses is similar to that of forests (Fourqurean e*t al.*, 2012), underscoring the potential importance of seagrasses in climate change mitigation (Trevathan-Tackett *et al.*, 2017).

Our findings provide the first assessment of *H. wrightii* distribution in Bahía de Jiquilisco, with seagrass meadows covering approximately 27 km^2 at Golfo La Perra and Corral de Mulas. However, delineating the species' distribution at the other four sites where *H. wrightii* was identified would likely increase total coverage in the estuary complex. Because seagrasses are foundation species, *H. wrightti* meadows provide critical areas for reproduction and maintenance of species with important ecological, economic, and cultural roles. Uncontrolled human activities, including the overexploitation of marine resources and coastal development, are persistent threats that synergistically stress the survival of *H. wrightii* and associated fauna in Bahía de Jiquilisco. Despite these multiple stressors, opportunities for conservation exist. Bahía de Jiquilisco is under the protection of diverse national laws and international agreements and is increasingly recognized for its importance as a refuge for critically endangered

Table 1. Macroinvertebrates associated with *Halodule wrightii* observed at Golfo La Perra and Corral de Mulas in Bahía de Jiquilisco in El Salvador, 2013.

Associated macroinvertebrates			Sampling area	
Group	Phylum	Species	Golfo La Perra	Corral de Mulas
Crustaceans	Arthropoda	*Callinectes arcuatus*	X	X
		Chthamalus sp.		X
		Leucosilia jurinii		X
Echinoderms	Echinodermata	*Ophiura* sp.	X	
Mollusks	Mollusca	*Anadara grandis*	X	
		Cerithium stercusmuscarum	X	X
		Chione imbricata	X	
		Chione subrugosa	X	X
		Cumingia sp.		X
		Donax panamensis	X	
		Dosinia sp.	X	
		Nassarius luteostomus	X	X
		Olivella sp.	X	X
		Polinices uber	X	
		Rhincoryne humboldti	X	X
		Sanguinolaria sp.	X	
		Tellina brevirostris		X
		Tellina sp.	X	
		Thais kioskiformis	X	
		Theodoxus luteofasciatus	X	X
		Tivela sp.	X	
		Turbo sp.	X	

species, such as hawksbill turtles (*Eretmochelys imbricata*) (Liles *et al.*, 2011, 2015), which further heightens its standing as a priority on the national conservation agenda. Additionally, when water conditions are suitable for its survival, *H. wrightii* is tolerant to disturbances and can quickly recolonize denuded areas, which underscores its potential for recovery and offers opportunities to extend its distribution in Bahía de Jiquilisco.

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