Rapid Communication

First record and putative introduction of the subtropical brown alga *Padina durvillei* Bory (Phaeophyceae, Dictyotales) in southern California, USA

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Abstract

The subtropical brown alga, *Padina durvillei* Bory, is common in the intertidal and shallow subtidal habitats in Baja California, Mexico, in both the Gulf of California and on the Pacific coastline. Here we report the first record of this genus in temperate waters of California, USA, in the heavily urbanized, man-made harbor of Marina del Rey in Los Angeles County, located more than 550 km from its northernmost recorded range. A population of several hundred individuals was found in April 2016 in shallow waters attached to silt-covered concrete adjacent to a public boat ramp. The isolated population has persisted through June 2019. Given that the observed *P. durvillei* population is located near a heavily trafficked public boat ramp, the alga was likely transported from the Baja California region via recreational boating activities, either attached to the hull of a boat or carried on-board and disposed of in the water. Two other locations in the marina were surveyed in 2016 and 2017 with no *Padina* individuals found, although further sampling and continued monitoring is needed to ensure the alga has not spread. Ideally, an effort should be undertaken to eradicate this species given its isolated distribution and the relatively small spatial extent of the population.

Key words: introduced seaweed, recreational boating vector, non-native species

Introduction

Padina durvillei Bory de Saint-Vincent is a perennial marine brown alga (Ochrophyta, Phaeophyceae; Dictyotales) and, much like all *Padina* species, is typically found in subtropical and tropical waters. *Padina* species, with a few exceptions, are isomorphic and diplohaplonts with dioecious gametophytes (Win et al. 2013). *P. durvillei* ranges from Baja California, Mexico (Gulf of California and Pacific coast), Costa Rica, and Panama in Central America to Chile, Columbia, Ecuador, and the Galapagos Islands in South America (Dawson 1961; Avila-Ortiz and Pedroche 2005; Norris 2010; Guiry and Guiry 2016). Its type locality is Concepción, Chile (Guiry and Guiry 2016). In the Gulf of California and along the western shoreline of Baja California (Figure 1), this species is common on sand-covered rocks and platforms in the mid intertidal zone to 3.3 m in depth (Norris 2010). Historically, this

species has not been found north of the offshore island Isla Guadalupe and El Cardón, Punta María on the Baja California mainland coast (Dawson 1961; Avila-Ortiz and Pedroche 2005; Pedroche et al. 2008; Norris 2010). Herein, we describe the first known detection of *P. durvillei* (as well as any *Padina* representatives) in the temperate waters of California, USA, in Marina del Rey, a wave-sheltered, man-made harbor in Los Angeles County, located more than 550 km from its known northern limit. Although a possible natural range expansion, dispersing potentially via rafting, we provide evidence for the population being a putative result of anthropogenic transport and introduction through recreational boating.

Materials and methods

Marina del Rey is a man-made, small craft harbor located along the coast of central Los Angeles County in southern California, USA (Figure 1). The harbor was built in the mid-1960s at the mouth of the historic Ballona Creek Estuary and currently houses more than 6,000 recreational boat slips and several public boat launching ramps that provide water access to over 100,000 public, trailer-class boats annually (http://www.marinadelrey.com/history.html; accessed October 2019). The 3.2 km^2 (800 acre) harbor is protected from wave activity by a rocky riprap breakwater located just offshore of the harbor mouth (Figure 1). The harbor is open to continuous, but likely impeded, tidal exchange with the salinity relatively similar to open coast conditions (ca. 33 PSU; Aquatic Bioassay and Consulting Laboratories, Inc. 2001). Water temperature information is limited but typically ranges annually from approximately 14 °C to 24 °C (Aquatic Bioassay and Consulting Laboratories, Inc. 2001), warmer than the adjacent open coast (Santa Monica Pier annual range of approximately 13–21 °C; Southern California Coastal Ocean Observing System; http://www.sccoos.org) likely due to relatively limited water exchange and shallow conditions. The harbor bottom consists primarily of fine sediment grains (fine sand, silt and clay) with sporadic hard substrate found in shallow zones, consisting of riprap, concrete bulkheads, and cement or plastic pilings and dock materials.

Specimens of the initially unknown brown alga, *Padina durvillei,* were first detected on April 15, 2016, at the public boat ramp in the Marina del Rey Harbor (Figure 1; 33.977480°; −118.441543°) during SCUBA surveys assessing biotic presence (particularly focusing on species of concern, including eelgrass *Zostera marina* and the invasive seaweed *Caulerpa taxifolia*) using swim transects near the boat ramp as part of a dock re-development project (Ecomarine Consulting LLC and Anghera Environmental 2016). The site was revisited on May 28, 2016 for specimen collection during a low tide (0.0 m) with the shallow habitat surveyed without SCUBA. Specimens were photographed, collected, and archived as herbarium presses and in

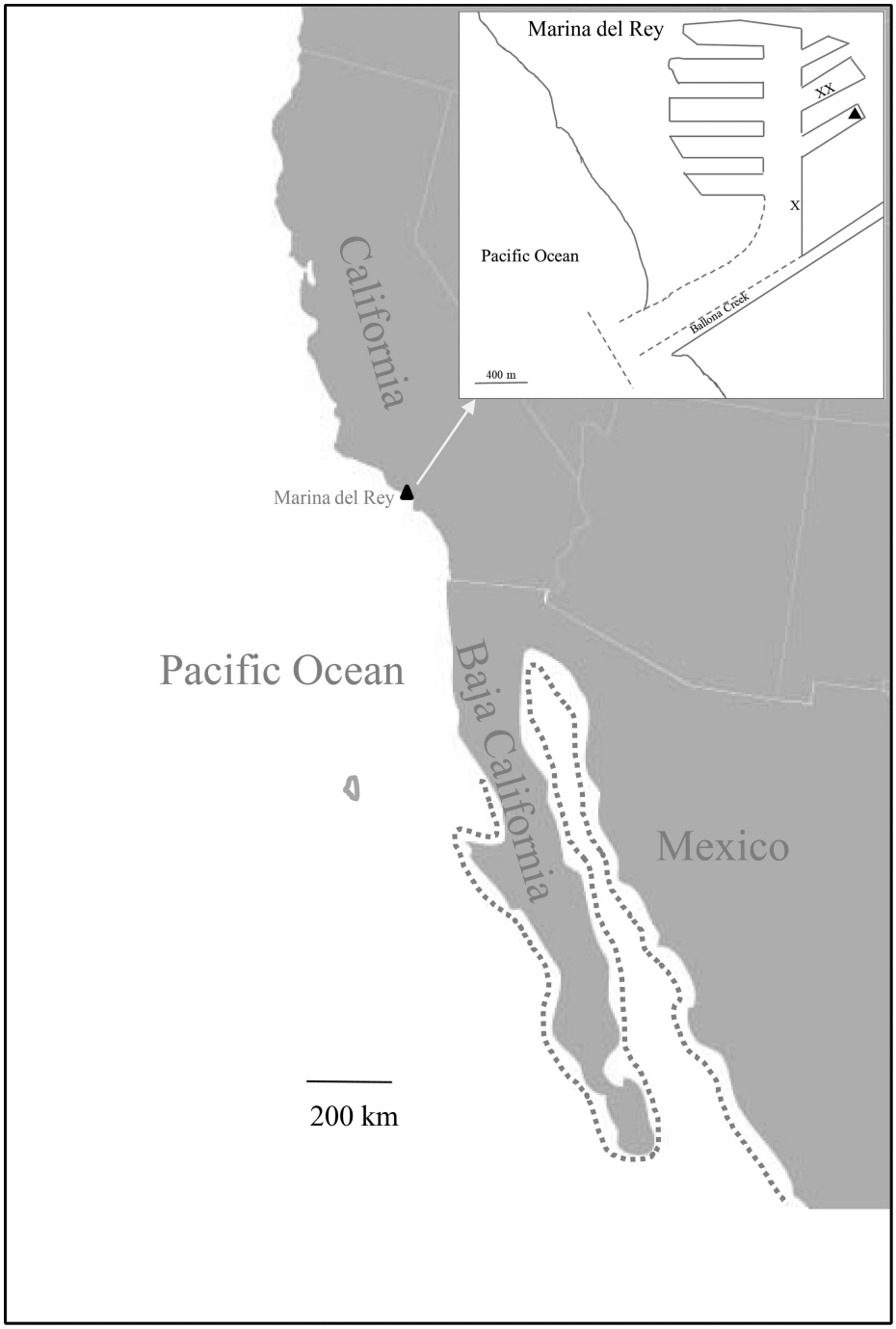

Figure 1. Approximate native range (dashed line) of *Padina durvillei* in the Gulf of California, Pacific coast of Baja California, and offshore island Isla Guadalupe based on published records and herbarium samples. Also indicated is the location of the first record of this species in southern California, USA in Marina del Rey. An inset map shows the details of Marina del Rey with man-made breakwaters indicated with dashed lines and the location of *Padina* demarcated in the lower right inlet branch. *Padina* was not found in additional surveys elsewhere in the marina in 2016 ("XX") and 2017 ("X").

silica gel. The population extent was measured roughly using a transect tape, and the number of individuals were crudely estimated visually from the surface and through underwater photographs. To identify the specimens, live material was returned to the laboratory, examined under a microscope, and keyed out using several resources, primarily Norris (2010).

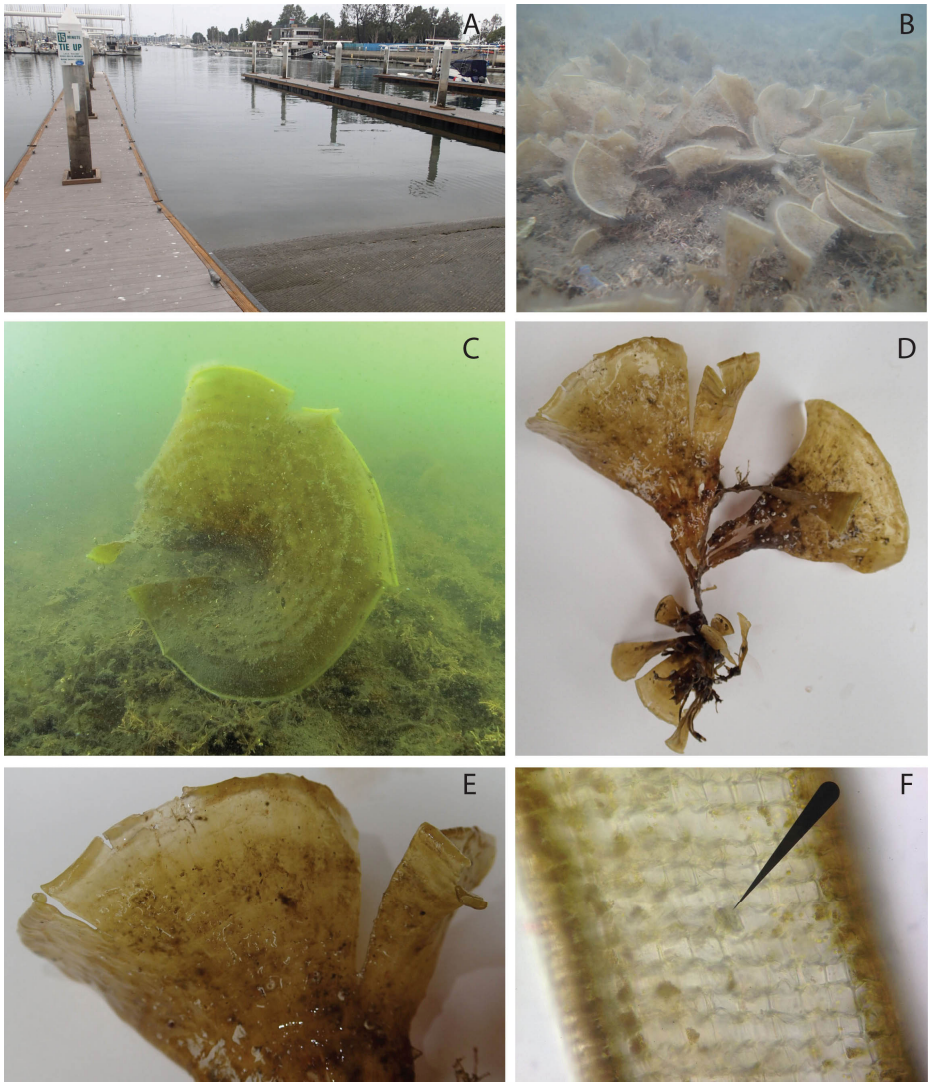

Figure 2. The *Padina durvillei* population was located in the shallow (0–0.3 m depth) zone attached to the cement of the public boat launch ramp in Marina del Rey (A). The population density was high (B) and individuals were large (~ 5–10 cm in height), non-calcified, and originating from a holdfast consisting of stupose rhizoids (C). Individuals were characterized with wide blades (3–4 cm) with divisions becoming laciniate (D). The tips of blades were curled (E), and the thallus consisted of 7–10 medullary cells and 2 cortical cells (F). Photos by JRS (A, B, D, E, F) and AKM (C).

Results

During SCUBA surveys on April 15, 2016, only a few *Padina durvillei* individuals were observed and photographed; however, limited water visibility prevented adequate enumeration of the overall abundance and spatial distribution of the species. Individuals were attached subtidally to man-made corrugated cement substrate at the end of the Marina del Rey public launch ramp (Figure 2A). During the subsequent May 2016 visit, the extent of *P. durvillei* appeared to have increased after initial observation and consisted of two patches of approximately 6 m^2 on both sides of one of three public docks, with several hundred individuals, estimated visually, present. The algae, as well as the concrete substrate, were covered with a light sediment film (Figure 2B, C). The observed population was located at

a depth of ~ 0.3 to 1 m of water (0.0 m low tide); the population thinned at the deeper extent of the patches, but poor visibility limited our ability to determine if more individuals were in deeper waters. The cement ramp that *P. durvillei* was attached to ends at ~ 1 m in depth, where the substrate changes to a fine sediment bottom. Collected specimens were heavily epiphytized by spirorbid polychaetes, encrusting bryozoans, and other small fouling organisms.

Specimens were identified as *P. durvillei* using Norris (2010). Individuals were erect with a holdfast, stipe, and flabellate blades, reaching ~ 10–15 cm tall. The thallus was non-calcified and described as thick and leathery. The blades were often divided, with divisions becoming laciniate. Concentric rings were located on the blade surface (Figure 2C, D, E), many with conspicuous hair zones. The apical portion of the blades were curled (Figure 2E). The holdfast was moderately sized, arising from stupose rhizoids (Figure 2D). Cross sections of the blades revealed 7–10 medullary cells and 2 cortical cells (Figure 2F). Pressed specimens were sent for identification confirmation and curation to Dr. Kathy Ann Miller, Curator of Algae at the University Herbarium, UC Berkley, Silva Center for Phycological Documentation (voucher UC 2050563).

The launch ramp at Marina del Rey Harbor was re-visited on June 11, 2019, and the population of *P. durvillei* was still present in similar abundance and covering the same general area. The temporal persistence of the population between sampling periods in 2016 and 2019 is unknown.

Discussion

The brown alga *Padina durvillei* is a subtropical species with a documented range from the offshore island Isla Guadalupe and Punta María, Baja California, Mexico, and south (Dawson 1961; Avila-Ortiz and Pedroche 2005; Pedroche et al. 2008; Norris 2010). To our knowledge, this species, nor any other *Padina* representatives, has not been previously detected north of the U.S. and Mexico border, thus the discovery of a *P. durvillei* population in Marina del Rey in Los Angeles is the first record of the alga in California. The discovery of the Marina del Rey population was well outside of its normal geographic range, more than 550 km north of its documented geographic limit. The coastline in southern California to the Mexican border is well studied by the following groups: 1) state agencies, including the California Department of Fish and Wildlife Marine Invasive Species Program (e.g. Ruiz and Gellar 2018; see reports/data at https://www.wildlife.ca.gov/OSPR/Science/Marine-Invasive-Species-Program), 2) regional monitoring groups or programs, such as the Multi-Agency Rocky Intertidal Network (MARINe; https://marine.ucsc.edu/), the Southern California Bight Monitoring Program (e.g. Schiff et al. 2016; see reports at http://www.sccwrp.org/), the Marine Protected Area Baseline Sampling Program (e.g.

Blanchette et al. 2015; see reports at https://www.wildlife.ca.gov/Conservation/Marine/MPAs/management/monitoring), and the Vantuna Research Group (https://www.oxy.edu/academics/vantuna-research-group), 3) regulatory agencies and consulting firms, such as monitoring of public and private receiving water dischargers (e.g. https://www.waterboards.ca.gov/ for annual reports for power generating stations and publicly-owned treatment works), 4) numerous local researchers with marine macroalgal expertise, including the authors, and 5) community-based organism observation reporting programs, such as https://www.inaturalist.org/. Despite frequent and intensive surveys by these groups collectively, *P. durvillei* has never previously been documented, thus Marina del Rey is very likely to be the only location in California where the species exists.

Due to natural phenomena or periodic anomalously warm ocean conditions, marine species have been documented to expand their ranges northward. Numerous examples of marine fish (Pondella and Craig 2001; Craig et al. 2006; Williams et al. 2011; Love et al. 2016) and invertebrate species (Fenberg et al. 2014; Rosenberg 2018) previously limited in distribution to Baja California, such as *P. durvillei*, have expanded their ranges into southern California, both over short and persistent time scales. From 2013–2016, the period of detection of *P. durvillei* in Marina del Rey, several range expansions of species were observed across multiple spatial scales along the Northeast Pacific, associated with anomalously warm ocean water conditions due to a persistent heat wave and an El Nino Southern Oscillation event (e.g. Freiwald et al. 2016; Tracy et al. 2017; Sadowski et al. 2018; Williams et al. 2018; Sanford et al. 2019). During this time, several warmer-water species from the south were observed in waters of southern California by the public and scientific communities, including pelagic red crabs, subtropical krill, spotfin burrfish, butterflyfish, hammerhead sharks, brown boobies, and yellow-bellied sea snakes, among others (e.g. Cavole et al. 2016). Despite numerous examples of range expansions from Baja California to southern California for fauna, documentation of range expansion of marine macroalgae from Baja appears to be absent. For similar reasons leading to northward range expansions of fauna, it would be expected for some seaweed taxa to also expand their range northward, although the distance over which an expansion could occur would likely be minimized due to the typically low spatial dispersal capabilities of macroalgal species (Santelices 1990; Gaylord et al. 2002). Most seaweeds disperse via propagules within a few meters to hundreds of meters from the parent, although a small proportion of taxa under certain oceanic conditions have been modelled to potentially disperse up to a few kilometers (Gaylord et al. 2002). Longer distance dispersal of seaweeds, on the other hand, can occur through occasional floating or rafting of reproductive individuals or of taxa that can propagate via fragmentation (van den Hoek 1987; Saunders 2014). However, this type of dispersal seems

unlikely in this case due to the location where *P. durvillei* was discovered, which was deep within a sheltered marina (Figure 1, inset) where floating materials are unlikely to accumulate.

Given the low dispersal rates of seaweeds and the large geographic jump in distribution in *P. durvillei* of at least 550 km, the population in Marina del Rey may be attributable to a human-mediated introduction. The location of *P. durvillei* at a public boat ramp suggests that transport was through recreational boating, either via boat hull fouling or other unintentional transport and release by boaters. The public boat launch in Marina del Rey provides water access to over 100,000 public boats annually (http://www.marinadelrey.com/) and is considered a highly trafficked cosmopolitan ocean access point for many private boat operators, thus the likelihood for non-native species transport and potential release is high. This may be why Marina del Rey is considered to be a heavily invaded area, comparable to other highly invaded bays and harbors in California (e.g. San Francisco Bay; Maloney et al. 2007; Lyman and Walton 2014; Ruiz and Gellar 2018). While there are no official public records of destinations of personal pleasure crafts into and out of Marina del Rey, presumably recreational travel from Marina del Rey to Baja California and the Gulf of California likely occurs. Thus, transport of species, such as *P. durvillei*, from southern areas is possible.

Marina del Rey Harbor has been moderately well studied for various reasons over the past several decades, thus some information is available on the historical composition of biota. Environmental surveys in the harbor are regularly conducted as part of ongoing harbor-wide monitoring efforts through various programs administered through the City of Los Angeles, Department of Beaches and Harbors, that include investigations of water characterization, bacteriology, sediment chemistry, and/or fish and benthic infauna diversity (e.g. Aquatic Bioassay and Consulting Laboratories, Inc. 2001; Stein et al. 2003; Weston Solution, Inc. 2008). Similar data are also recorded every four years as part of regional Bight-wide surveys (e.g. Ranasinghe et al. 2010; Schiff et al. 2016). In addition, other biological or ecological research has been conducted in the harbor, including studies of fishes (Stephens et al. 1991; Behrents Hartney and Tumyan 1998) and seabirds (e.g. Ryan and Vigallon 2013; Hamilton Biological, Inc. 2014). Periodically, localized survey efforts are conducted to meet a variety of regulatory requirements for construction, redevelopment, and dredging projects. Usually such survey efforts specifically target eelgrass (*Z. marina*) or the invasive alga *Caulerpa taxifolia*. Generally, these studies are not focused on observations of other non-indigenous macroalgae and may not include individuals with the expertise to properly identify other potentially non-native seaweed species. On the other hand, specific surveys for detection of non-native species by the California Department of Fish and Wildlife Marine Invasive Species Program have been conducted on numerous

occasions in the harbor with seaweed identification experts (Maloney et al. 2007; Lyman and Walton 2014; Ruiz and Gellar 2018), including ten locations surveyed in 2015 (Ruiz and Gellar 2018). Unfortunately, the specific location of the *P. durvillei* population was not sampled during that time. Author Morris conducted surveys at two additional sites in the marina in late 2016 and mid 2017 (Figure 1) and did not find *Padina,* despite specifically looking for the alga. Based on this information, there is moderate evidence that *P. durvillei* may be limited to the public dock area, though the potential timing of initial establishment is unknown.

Little is known about the temperature tolerance of *P. durvillei* in its native range, although Dawson (1944) anecdotally suggested a wide tolerance. Given its geographic distribution and the general temperature regimes for the Baja California Pacific coast and Gulf of California, it appears that this seaweed has a large thermal tolerance from approximately 17 °C to 29 °C, although this is complicated by the seasonal fluctuation of this perennial species and its unknown temporal population dynamics throughout its range. The literature suggests this species is more common in warmer regions of Baja California Sur and the Gulf of California, thus its realized temperature tolerance may be closer to the higher end of this range (e.g. > 20 °C). While Marina del Rey is several degrees warmer than the adjacent outer coast, the temperature only exceeds 20 °C during May through October months (Aquatic Bioassay and Consulting Laboratories, Inc. 2001). It is therefore likely that the Marina del Rey population may be stressed or, more likely, senescent during the colder months. The colder temperatures on the open coast near Marina del Rey may inhibit its spread in southern California waters.

Southern California has a long history of seaweed invasions, most notably the ochrophytes *Sargassum muticum* (Yendo) Fensholt, *Sargassum horneri* (Turner) C. Agardh, and *Undaria pinnatifida* (Harvey) Suringar, the chlorophyte *Caulerpa taxifolia* (M. Vahl) C. Agardh, and the rhodophyte *Caulacanthus ustulatus* (Mertens ex Turner) Kützing, among others (Miller 2004; Miller and Engle 2009; Miller et al. 2011; Smith et al. 2014; Marks et al. 2015; Kaplanis et al. 2016). *P. durvillei* is likely an additional introduction to the region, although currently restricted to a small, highly localized area. Notably, many of the non-native seaweeds in southern California are of Asian origin while introductions of seaweeds limited in distribution to Baja California or the Gulf of Mexico appear to be rare or absent.

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