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Rapid Communication

Moving forward: the Japanese kelp *Undaria pinnatifida* (Harvey) Suringar, 1873 expands in northern Patagonia, Argentina

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Abstract

Increasingly, global trade and human movement have been transporting species between regions. *Undaria pinnatifida* (Harvey) Suringar, 1873, a macroalgae native to Korea and Japan, has been transported and became established in several temperate regions of the world. Here we report its presence in a new coastal area of northern Patagonia, Argentina, with a description of the sporophytes.

Key words: biological invasion, San Matías Gulf, Atlantic coast

Introduction

The increasing global trade and human displacements worldwide are usually accompanied by unwanted movement of species (i.e. introduced species) (Mack et al. 2000) at now occurring at unprecedented rates (Ricciardi 2007). The number of introduced seaweeds in marine environments continues to increase (see review by Valentine et al. 2007), including in coastal waters of Argentina (e.g. Boltovskoy et al. 2011).

The Japanese kelp *Undaria pinnatifida* (Harvey) Suringar, 1873 (Phaeophyceae, Laminariales) (hereafter referred to as *Undaria*) is originally from Japan and Korea and has been introduced into several temperate regions worldwide (Thornber et al. 2004; Schiel and Thompson 2012; Sfriso and Facca 2013). *Undaria* has a biphasic life cycle: a macroscopic stage (sporophyte) and microscopic stages (zoospore, gametophyte), which allow it to disperse adhered to different substrates and to be transported within vessels and cargo ships (Valentine et al. 2007). In Argentina (Figure 1), *Undaria* was first reported in Puerto Madryn (Chubut Province), within Nuevo Gulf in 1992 (Piriz and Casas 1994), and 500 km southwards in Ría Deseado (Martin and Cuevas 2006) and other neighboring localities (Casas and Schwindt 2008) in 2005. In 2011, the presence of *Undaria* was also reported in Mar del Plata (Buenos Aires Province) (Meretta et al. 2012). More recently (2010), *Undaria* was found for the first time in San Matías Gulf (Carlos Zapata, pers. comm.). In January 2013, immature sporophytes were observed in Punta Colorada (PC; 41°41.689´S – 65° 01.412´W) and in April 2013 in Los Hornitos (LH; 41°52.401´S – 65°02.375´W) (MN and RG, pers. obs.). Here, we report the results of an exploratory survey conducted to assess the presence of this seaweed in the coastal area of the San Matías Gulf, with a brief description (sizes and development stages) of the sporophytes found.

Methods

San Matías Gulf (40°50´S to 42°15´S, 63°05´W to 65°10´W, Figure 1) is a semi-enclosed basin of around 20,000 km^2, with a maximum depth of 180–200 m, in the central area of Argentina. During the

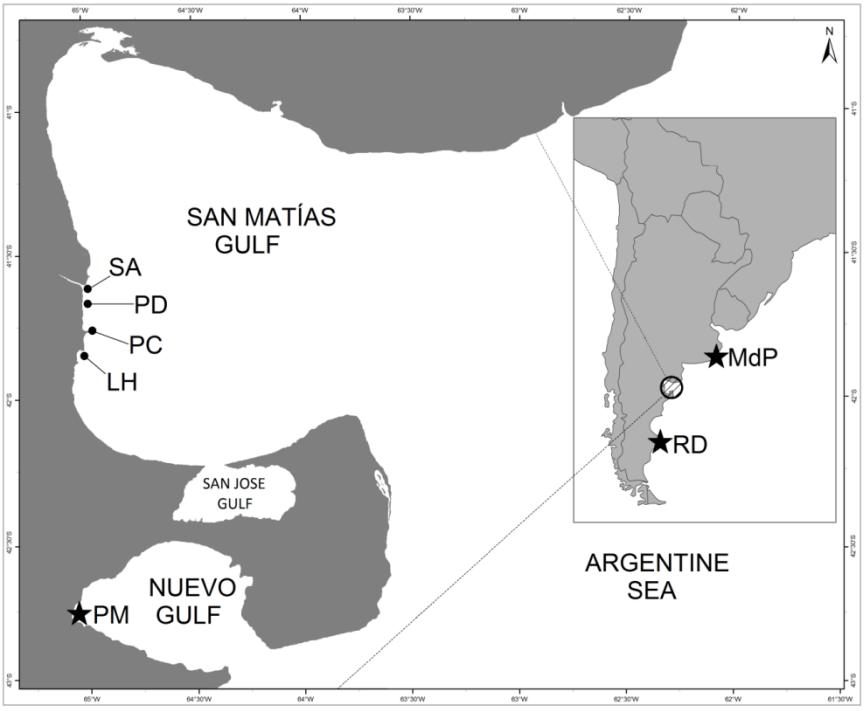

Figure 1. Map of the San Matías Gulf with details of previous records of *Undaria pinnatifida* (stars) and the localities reported in this paper (circles). References: MdP, Mar del Plata; RD, Ría Deseado; PM, Puerto Madryn; SA, mouth of Salado stream; PD, Playas Doradas; PC, Punta Colorada; LH, Los Hornitos.

warm season (October-April), a thermal front divides the Gulf into two different water masses: the northern area, with higher temperature and salinity, lower nitrate concentration and a strong thermocline, and the southern area, with lower temperature and salinity, a strong vertical mixing, and a higher nitrate concentration (Piola and Scasso 1988; Rivas and Beier 1990; Gagliardini and Rivas 2004). During winter (May-September), the frontal system vanishes and the environmental conditions become more homogeneous within the entire Gulf. The general circulation in spring-summer is dominated by a cyclonic gyre, located in the northern sector of the Gulf (Piola and Scasso 1998), which, in combination with the frontal system, determines the relative isolation of the northern water masses (Rivas and Beier 1990; Tonini 2010).

Based on early observations of *Undaria* in San Matías Gulf, and a report by a local SCUBA diver, an exploratory survey was performed on 16 November 2013 in Playas Doradas and Punta Colorada to assess the species composition of beach wrack seaweed. In this area, the beach was deeply covered with seaweeds, mostly *Undaria*, in different degrees of decomposition (Figure 2). *Undaria* was unambiguously identifiable (and impossible to be confused with other local macroalgae, see Borasso de Zaixso 2013) by the elongated stipe, pinnate divisions of the blade, and the undulate-plicated sporophyll (Okamura 1915). During the low tide, we sampled the beach at the shore-line in three different points (Figure 1): the mouth of the Salado stream (SA; 41°36.877´S; 65°01.236´W); the beach of Playas Doradas (PD; 41°37.897´S; 65°01.380´W) located 2 km to the south of SA; and Punta Colorada (PC; 48°41.8´S; 65°00.98´W) located 9 km to the south of SA) (Figure 1). The three sites were sandy, with presence of fragmented rocks in PD and PC. In Punta Colorada, there is a medium-size international harbor, which primarily exports iron.

Samples of freshly arrived sporophytes of *Undaria* were collected after recording their numbers on a single transect of 500 meters in each site. Once in the laboratory, the maximum length and width of sporophytes and sporophylls were measured using a meter stick and Vernier calipers. Sporophyte maximum length was measured from the base of the midrib to the proximal end of the stipe. Individuals with the midrib or stipe broken, or with senescent sporophylls, were not measured. The maximum width of the sporophyte was measured at the beginning of the blades (corresponding to the end of the sporophyll when it is fully developed).

Figure 2. Beach wrack consisting of *Undaria pinnatifida* in Playas Doradas (Photograph by Patricio J. Pereyra).

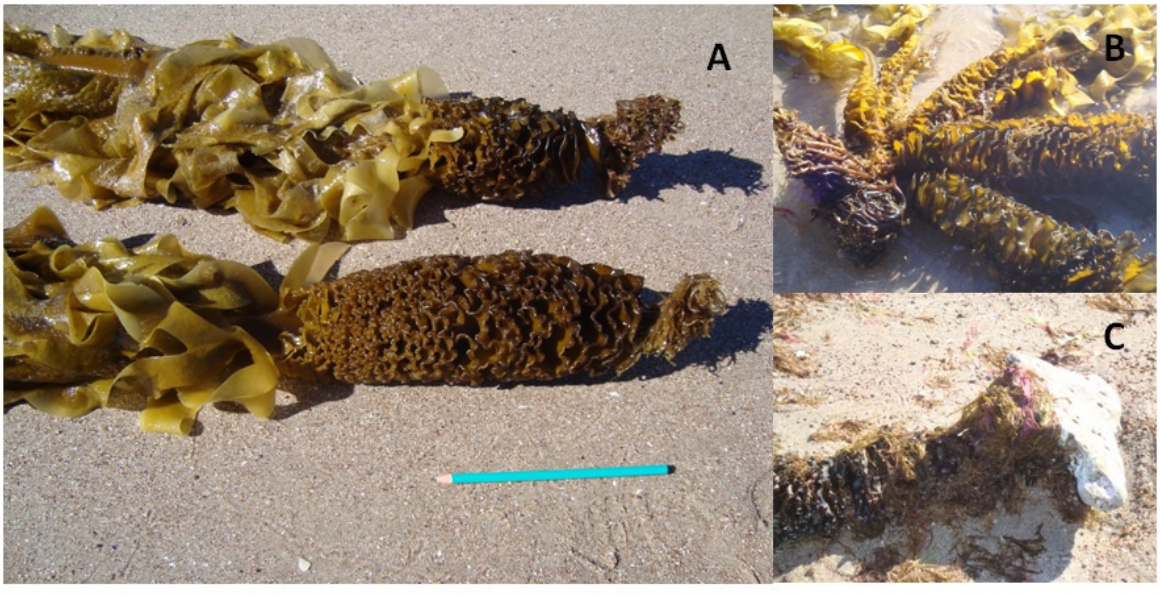

Figure 3. Sporophytes with fully developed sporophylls (A), several sporophytes with a shared midrib (B), midrib with a piece of boulder (C) (Photograph by Patricio J. Pereyra).

Results

We collected 65 *Undaria* specimens (PD = 28; SA = 21; PC = 16) and all but ten had a partially or completely developed sporophyll (corresponding to types II and III in the classification of Casas et al. 2008) (Figure 3a). Most of the specimens were single individuals but some (n = 29) were packed in groups of two to seven individuals with shared midribs (Figure 3b). The total length and width of the sporophytes varied between 400 and 1700 mm (mean = 1003.9; SD = 330.5; n = 49) and 5 and 30 mm (mean = 150.3; SD = 50.8; n = 63), respectively. Sporophyll length varied between 29 and 358 mm (mean = 129.1; SD = 87.4; n = 60) and sporophyll width between 13 and 100 mm (mean = 41.1; SD = 21.8; n = 60).

Observations made on the midribs indicated that sporophytes had attached to diverse types of natural substrates (e.g. boulders, dead and live bivalves and gastropods, green and red algae and pieces of *Corallina* sp.) (Figure 3c).

Discussion

This is the first report of *Undaria* in San Matías Gulf, an environment 150 km to the north of the most northern site colonized by the species in the Patagonia Argentina since 1992 (Piriz and Casas 1994). *Undaria* could thus be considered as an "introduced species" in the invasion continuum (Blackburn et al. 2011; Lockwood et al. 2013). The presence of fully developed sporophylls indicates the species is reproductively active (Schiel and Thompson 2012) and that it is thus colonizing the area. Until the persistence of the population is confirmed during several generations (since reproduction does not mean population persistence), *Undaria* cannot be considered as an established or even a naturalized species (*sensu* Blackburn et al. 2011). From a conservative point of view, it has been postulated that terrestrial plants need ten years to transit from an introduced to a naturalized stage (see Richardson et al. 2000). Still, such a criterion does not exist for algae, and we cannot predict whether the population of *Undaria* in San Matías Gulf will prosper or disappear (Simberloff and Gibbons 2004).

Although caution is needed in comparisons of individual sizes among the different sites invaded (owing to seasonal differences or methodological artifacts), some preliminary findings can be mentioned. Sporophytes mentioned in this report had reached a considerable size, with total lengths similar than those reported for Nuevo Gulf (Casas and Piriz 1996; Raffo et al. 2009) and larger than those from Ría Deseado (Martin and Cuevas 2006) and Mar del Plata (Meretta et al. 2012). Sporophylls were larger than those studied in Nuevo Gulf (Casas et al. 2008) and Mar del Plata (Meretta et al. 2012). No degraded sporophytes (i.e. senescent blades; according to Casas et al. 2008) were observed, which suggests that they were moved to the beaches by currents and/or wave action (Sliwa et al. 2006). Observations of some large pieces of substrates adhered to the midribs reinforce this viewpoint. The sporophytes held all types of substrates, mostly *Corallina* sp., which has been recognized as a facilitative agent in the establishment of *Undaria* (Schiel and Thompson 2012).

Although the mechanism by which *Undaria* arrived in the coastal areas within San Matías Gulf is unknown, some preliminary hypotheses can be proposed. Given the extraordinary speed (from 2 to 6 knots) of the northward currents typically occurring in the mouth of San José Gulf (Mazio and Vara 1983; SHN 2000), an environment where *Undaria* is already established (Casas and Schwindt 2008), and considering the model of the physical dynamics of San Matias Gulf (Tonini et al. 2013), the northward drift would be a reasonable hypothesis to be tested. *Undaria* was detected in San José Gulf in 2008 and 150 km to the north, in Playas Doradas, in 2010 (Carlos Zapata, pers. comm.), which indicates a rapid dispersal rate (cf. Lyons and Scheibling 2009). However, considering that as most kelp species *Undaria* has low ability of natural dispersal (Schiel and Forrest 2006; Schiel and Thompson 2012), drifting from southern populations would be a very slow process. Even when mature sporophytes with fully developed sporophylls drift away, the establishment of a new population seems to be unlikely (Reed et al. 1998; Schiel and Foster 2006). Another possible explanation is that *Undaria* has arrived with a transoceanic cargo ship to the port of Punta Colorada, or that it was introduced by recreational boats or small vessels from nearby localities, since these have been recognized as common vectors for the species (e.g. Clarke Murray et al. 2011). In this sense, it is well known that dispersal rates of *Undaria* are greatly increased when associated with human assistance (Lyons and Scheibling 2009; Russell et al. 2008). In Argentina, all the sites colonized by *Undaria* could be associated with a human vector. However, the effectiveness of the dispersal of *Undaria* through drifting sporophytes from southern areas should be investigated given the strong sea currents and circulation models (Tonini et al. 2013). To be more certain about the underlying mechanism by which *Undaria* reached the San Matías Gulf ecosystem, complementary studies such as genetic analysis (Voisin et al. 2005) and transport modeling are needed. These studies will allow us to find out whether we are facing a new introduction event or a natural or human-aided translocation of individuals from the populations located in Nuevo Gulf or San José Gulf.

The newly discovered population gives us an excellent opportunity to study which factors promote an invasion success (or failure). Wherever *Undaria* has been found, researchers found variations in its life cycle (Thornber et al. 2004, Schaffelke et al. 2005), demography (Schiel and Thompson 2012), and environmental determinants of establishment (Thornber et al. 2004). Determining which factors are more important in the invasion process is a challenge. As mentioned above, at the current state of the invasion process, it is difficult to predict

if this invasion will prosper (i.e. to transit from introduced to naturalized and further, to invasive; see Lockwood et al. 2013) or fail (e.g. Zenni and Nuñez 2013) because there are conspicuous and notorious 'invasive species' that succeed in one region but not in others (Kueffer et al. 2013; Richardson and Pysek 2013). Studying the invasion from its early stages may help to elucidate its causal basis. However, since *Undaria* is a recognized invasive species worldwide (Lowe et al. 2000), the precautionary principle should be taken (Ruesink et al. 1995) when considering this population for control and management. Ongoing monitoring research is starting in the area.

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