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The Asian red seaweed *Grateloupia turuturu* (Rhodophyta) invades the Gulf of Maine

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Abstract We report the invasion of the Gulf of Maine, in the northwest Atlantic Ocean, by the largest red seaweed in the world, the Asian *Grateloupia turuturu*. First detected in 1994 in Narragansett Bay, Rhode Island, south of Cape Cod, this alga had expanded its range in the following years only over to Long Island and into Long Island Sound. In July 2007 we found *Grateloupia* in the Cape Cod Canal and as

far north (east) as Boston, Massachusetts, establishing its presence in the Gulf of Maine. *Grateloupia* can be invasive and may be capable of disrupting low intertidal and shallow subtidal seaweeds. The plant's broad physiological tolerances suggest that it will be able to expand possibly as far north as the Bay of Fundy. We predict its continued spread in North America and around the world, noting that its arrival in the major international port of Boston may now launch *G. turuturu* on to new global shipping corridors.

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Mathieson et al. (2003) noted that introduced seaweeds are a major problem throughout the world's oceans, altering natural communities and sometimes causing significant economic losses. We here report the invasion of the Gulf of Maine, in the northwest Atlantic Ocean, by what has been described as the largest red seaweed in the world (Simon et al. 2001), the Asian *Grateloupia turuturu* Yamada (Halymeniales, Rhodophyta).

Grateloupia turuturu was first detected on the Atlantic coast of North America in 1994 in southern New England, when attached specimens were discovered south and west of Cape Cod, in Rhode Island (RI) in Narragansett Bay [Villalard Bohnsack and Harlin 1997, as *G. doryphora* (Montagne) Howe].

The plant's elongate fronds are deep red to purple, up to 15 cm in width, almost a meter in length, and attached by a small discoid base (Fig. 1). In July 2007 we discovered that this alga had taken a major leap to the north and east of Cape Cod, a long-recognized biogeographic boundary between southern warmer and northern colder waters. Between 1994 and 2006, *G. turuturu* had expanded its range only along the shores of Narragansett Bay, to Long Island, and south into Long Island Sound (Pederson et al. 2005; Mathieson et al. 2008).

On July 25 and 26, 2007, during a Rapid Assessment Survey of float-pontoon fouling communities from Woods Hole, Massachusetts (MA) to Camden and Rockland in Penobscot Bay, Maine (ME), *G. turuturu* was discovered in small boat marinas at each end of the Cape Cod Canal and in Boston MA. On July 25 it was found growing on the submerged edges of floats at a marina at the southern (western) end of the Cape Cod Canal in Buzzards Bay, Bourne MA (31 ppt, 21°C) and at the northern (eastern) end of the Cape Cod Canal at Sandwich MA in Cape Cod Bay (31 ppt, 20°C). On July 26, *G. turuturu* was found in the inner harbor of the city of Boston, at Rowes Wharf (30.6 ppt, 19°C). The plant has not been found between Boston and Camden ME. The present northward extension of *G. turuturu* is an expansion of over 132 km in less than 4 years.

The Cape Cod Canal opened in 1914. Twelve kilometers in length, it is part of the Atlantic Intracoastal Waterway, connecting Buzzards Bay to the south and west with Cape Cod Bay to the north and east. The role of canals in facilitating movement



Fig. 1 A large blade of *Grateloupia turuturu* from Waterford, Connecticut with marginal proliferations (bar = 10 cm)

of seaweeds into new habitats is well established as shown by studies on the impact of the Suez Canal on the Mediterranean flora (Lüning 1990), which opened in 1869 and allowed a Lessepsian migration of at least 20 Indo-Pacific algal species and one seagrass from the Red Sea. The Cape Cod Canal has similarly allowed migration of both native and non-native species northward into the Gulf of Maine, including fish, barnacles, and other species (J. T. Carlton, unpublished). The movement of *G. turuturu* was very likely due to transport on boat hulls into and through the canal and into Boston, as was shown for vessel-mediated transport of *Grateloupia* in the Solent region of England (Farnham 1980) and the Brittany coast of France (Simon et al. 2001).

The Asiatic green alga *Codium fragile* (Surinagar) Hariot subsp. *tomentosoides* (van Goor) P. C. Silva (now one of the most conspicuous introduced seaweeds of the Gulf of Maine) and the red alga *Porphyra katadae* Miura are two further examples of introduced seaweeds that have also been transported through the Cape Cod Canal (Carlton and Scanlon 1985; Mathieson et al. 2003; Neefus et al. 2007). *Codium* was first found on Long Island in 1957 and by the late 1960s it had migrated through the Canal to Cape Cod Bay (Carlton and Scanlon 1985). *Porphyra katadae* has been collected at three sites north of the canal in Cape Cod Bay and two locations south of the canal at Charlestown Beach RI and Buzzards Bay MA (Neefus et al. 2007).

Grateloupia turuturu is native to Japan and Korea (Gavio and Fredericq 2002; Guiry and Nic Dhonncha 2006), but now occurs in the Atlantic Ocean and the southern Pacific Ocean due to global shipping and mariculture activities. The seaweed was introduced into Narragansett Bay via ballast water or hull fouling either from Japan or Europe (Villalard-Bohnsack and Harlin 1997, 2001). Rhode Island populations of *G. turuturu* are genetically similar to European ones (Marston and Villalard-Bohnsack 2002).

Several authors (Saunders and Withall 2006; Verlaque et al. 2005; Villalard-Bohnsack and Harlin 1997, 2001) have suggested that *G. turuturu* can be invasive, and in particular may be capable of disrupting low intertidal and shallow subtidal seaweeds, including the abundant native alga *Chondrus crispus* Stackhouse (Harlin and Villalard-Bohnsack 2001) as seen in Figs. 2, 3. *Grateloupia turuturu* has the repertoire of an effective invader: it tolerates



Fig. 2 A population of *Grateloupia turuturu* at Waterford, Connecticut, growing near the native red seaweed *Chondrus crispus*

nutrient-enriched water, it grows well in 22–37 ppt, and it can survive 12–52 ppt and 4–28°C (Simon et al. 1999, 2001). The plant's broad physiological tolerances suggest that it will be able to expand into the northerly parts of the Gulf of Maine and possibly the Bay of Fundy.

Grateloupia turuturu is undergoing rapid worldwide spread, having appeared recently not only in eastern North America but also in Tasmania (Saunders and Withall 2006) and Wellington Harbor, New Zealand (D'Archino et al. 2007). The former authors noted that efforts to determine the extent and distribution of the species should be implemented with the intent of limiting its further translocation and

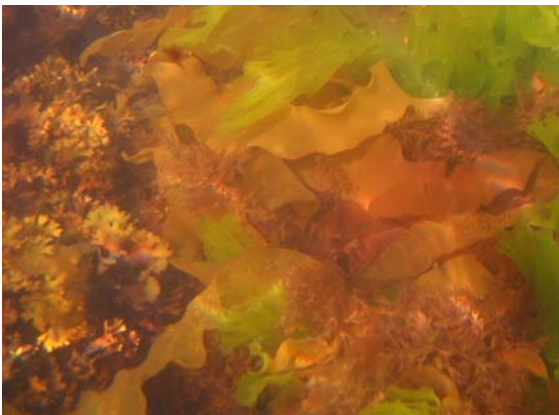


Fig. 3 A population of *Grateloupia turuturu* at Waterford, Connecticut growing among the native red alga *Chondrus crispus*

range expansion. We predict the continued spread of this seaweed both in North America and around the world, further noting that its arrival in the major international port of Boston may now launch *G. turuturu* on to new global shipping corridors.

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