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Rapid Communication

Discovery of *Undaria pinnatifida* (Harvey) Suringar, 1873 in northern New Zealand indicates increased invasion threat in subtropical regions

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Abstract

In March 2013 the Asian kelp *Undaria pinnatifida* (Harvey) Suringar, 1873 was discovered in Rangaunu Harbour, northern New Zealand (34°89′05″S, 173°29′54″E), a site where water temperatures typically range between 14 and at least 24°C. This is the first report of *Undaria* in subtropical parts of New Zealand and demonstrates that *Undaria* is capable of invading marine environments throughout the country. The presence of healthy juvenile and reproductive sporophytes during late summer (SST >21°C) is of particular concern as juvenile *Undaria* sporophytes have previously only been recorded during summer in cooler water regions. This discovery indicates a previously unreported deviation from a winter annual lifecycle at subtropical temperatures and an increased risk of invasion impacts for subtropical sites worldwide.

Key words: invasive; kelp; New Zealand; spread; temperature; climate change

Introduction

Undaria pinnatifida (Harvey) Suringar, 1873 is an invasive kelp that alters ecosystem composition and function through domination of benthic communities (Curiel et al. 2001; Sinner et al. 2000; Russell et al. 2008; Raffo et al. 2009; Irigoyen et al. 2011a,b). *Undaria pinnatifida* is native to Northern Asia where annual water temperatures range between 2–27ºC (Akiyama and Kurogi 1982). Regular seasonal temperature shifts in its native range have caused *Undaria* to develop temperature cues for growth and reproduction (Saito 1975; Akiyama and Kurogi 1982). These temperature cues align with a heteromorphic lifecycle comprising a microscopic haploid gametophyte phase and a macroscopic diploid sporophyte phase (Saito 1975). In its native range, *Undaria* is a winter annual; the sporophyte recruits in winter, becomes reproductive and sporulates in spring-early summer and subsequently dies off and disappears, only the microscopic life stages persist during the late-summer and early autumn (e.g. Akiyama and Kurogi 1982; Koh and Shin 1990).

Since the late 1980s, with increases in international maritime and aquaculture activities, *Undaria* has invaded warm- and cold-temperate marine environments around the World (Invasive Species Compendium 2013). *Undaria pinnatifida* can alter its winter annual life cycle under different temperature regimes and sporophytes can be present year-round in parts of its introduced range where seasonal variations in water temperatures are less extreme than those in its native range (Floc'h et al. 1991; Hay and Villouta 1993; Fletcher and Farrell 1999; Casas et al. 2008; Zabin et al. 2009; Scheil and Thompson 2012).

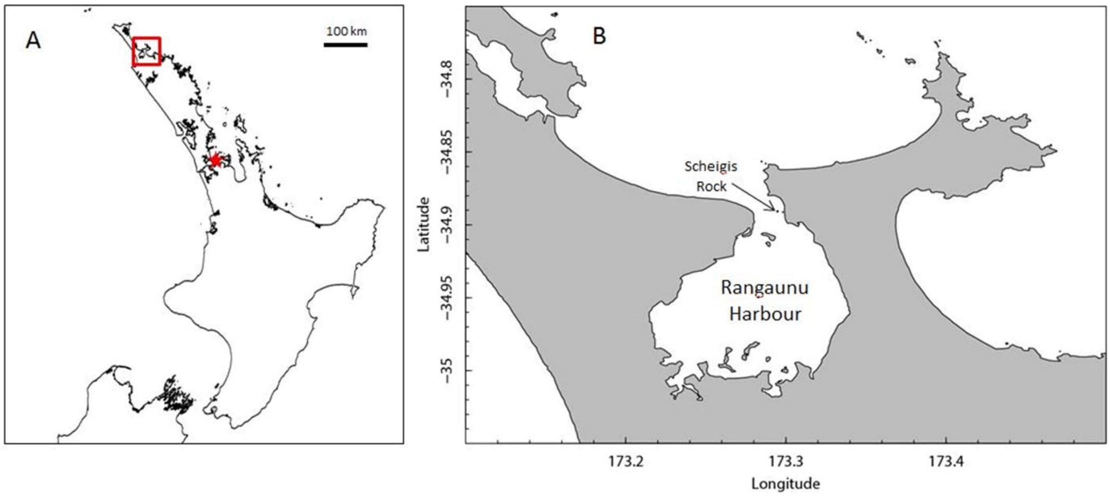

Figure 1. (A) North Island of New Zealand showing location of previously recorded northern most *Undaria* population (star) and newly discovered *Undaria* population (square) and (B) exact location of newly discovered population.

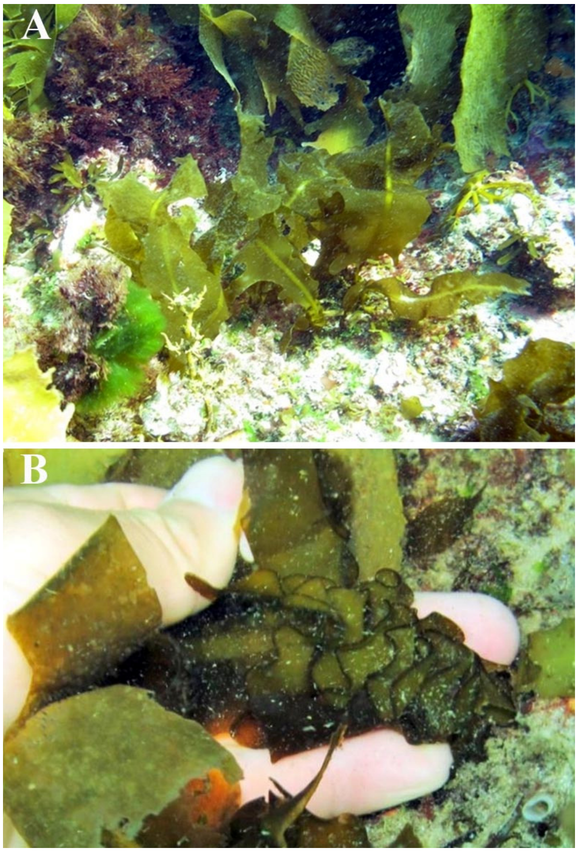

Figure 2. Juvenile *Undaria pinnatifida* sporophytes (A) and a reproductively mature sporophyte with sporophyll (B) at Scheigis rocks, Rangaunu Harbour, New Zealand, March 2013.

In northern New Zealand, *Undaria* establishment was thought to be constrained by warm sea water temperature (Hay and Villouta 1993; Sinner et al. 2000). In this note, we report on the discovery of healthy and reproductive *Undaria* sporophytes in the northern-most subtropical waters of New Zealand during late summer (Figure 1). We suggest that this observation establishes an increased risk of invasion impacts for subtropical sites worldwide.

Discovery

On 15 March 2013, *Undaria pinnatifida* was discovered growing on Scheigis Rocks, a subtidal rocky outcrop at the entrance to Rangaunu Harbour, Northland, New Zealand (34°89′05″S, 173°29′54″E) (Figure 1). Eight *Undaria* sporophytes were found growing at a depth of 3 m on a one metre square area of reef (Figure 2A). The plants ranged from 100 to 300 mm in total length. Sporophylls were present on three of the larger plants (Figure 2B). The rocky outcrop was dominated by a mixed algal assemblage consisting of the native kelp *Ecklonia radiate* (C.Agardh) J.Agardh, 1848 and large endemic fucoids *Carpophyllum maschalocarpum* (Turner) Greville, 1830 and *Sargassum sinclairii* J.D.Hooker & Harvey, 1845. *Undaria pinnatifida* was found in a clearing in the algal canopy that was otherwise dominated by crustose coralline algae, articulated coralline turfs including *Corallina officinalis* Linnaeus, 1758, a number of ephemeral species including *Colpomenia sinuosa* (Mertens ex Roth) Derbès & Solier, 1851, *Ulva sp*. and some small unidentified fleshy red algal species. The common sea urchin *Evechinus chloroticus* Valenciennes, 1846 was also present but largely restricted to crevices. Several smaller *Undaria* sporophytes (~100 mm) were also seen growing attached to shells on nearby sand flats suggesting that *Undaria* may already be widely distributed in the Rangaunu harbour.

Water temperature at the site was 21.3ºC at the time of discovery. Based on long-term remote sensing information, monthly average sea water temperatures peak at between 21 and 23°C in February, and drop to 14 to 16°C in August (http://www.niwa.co.nz). Sea surface temperatures inside the harbour are more variable, ranging between 12 and 27°C (Northland Regional Council Data, 1998). *Undaria pinnatifida* present at Scheigis Rocks during summer are likely to be exposed to water temperatures greater than 24ºC.

Discussion

The discovery of *Undaria pinnatifida* in Rangaunu Harbour, northern New Zealand, represents the northern-most known population in the Southern hemisphere. This shifts the northern range limit of *Undaria* within New Zealand approximately 250 km (Figure 1) beyond the previously reported northern limit of the Waitemata Harbour (Russell et al. 2008). This discovery of *Undaria* in the far north of New Zealand shows that the spread of *Undaria* around northern New Zealand is not limited by warm sea water temperatures, as previously thought (Hay and Villouta 1993; Sinner et al. 2000).

Within its native range *Undaria* sporophytes can tolerate temperatures up to 27°C (Morita et al. 2003), but effective recruitment of the sporophytes from the microscopic gametophyte stage generally requires temperatures between 10 and 20°C (Saito 1975; Morita et al. 2003). Consequently, in regions where summertime water temperatures rise above 20°C, such as in its native range in Asia as well as in Port la Nouvelle (France), Venice Lagoon (Italy), and Port Philip Bay (Australia), *Undaria* has a winter annual lifecycle and reproduction and recruitment do not occur over the summer months (Akiyama and Kurogi 1982; Floc'h et al. 1991; Curiel et al. 2001; Primo et al. 2010). The discovery of healthy juvenile and reproductive *Undaria* sporophytes in subtropical New Zealand waters in late summer is a significant deviation from this winter annual cycle. Previously, *Undaria* sporophytes have only been seen to recruit during summer in locations where annual water temperatures do not exceed 20ºC (e.g. Southern New Zealand, Brittany (France), Nuevo Gulf (Argentina) and Monterey Harbour (USA); Hay and Villouta 1993; Floc'h et al. 1991; Casas et al. 2008; Zabin et al. 2009).

Undaria pinnatifida is a highly adaptable and plastic species (Nyberg and Wallentinus 2005). Across regional scales, *Undaria* sporophytes and gametophytes can have different temperature tolerances. In its native range, *Undaria* populations at warmer latitudes exhibit higher temperature tolerances than those at cooler latitudes (Gao et al. 2013). These differences in high temperature tolerance have been attributed to genetic differentiation rather than phenotypic plasticity. Populations can also become locally acclimatised to different thermal stress among habitats; for example, *Undaria* can tolerate higher thermal stress in intertidal habitats where populations experience more extreme daily and seasonal heating than populations on nearby subtidal reefs (Henkel and Hofmann 2008). Further research is needed to determine whether the population at Rangaunu Harbour is a genetically thermal-tolerant strain or whether local adaptation may be behind the ability of the population to recruit during summer. Regardless of the mechanism, this population appears to be a relatively unique variant that is capable of reproducing and recruiting at higher temperatures than previously reported.

A wide range and flexibility of temperature tolerance is a significant characteristic of successful invasive species, especially with regards to persisting under future climate change scenarios. While kelps in general may be eliminated from warmer latitudes by warming ocean temperatures (Wernberg et al. 2013), it appears that *Undaria* may be capable of adapting to, and persisting at, warmer temperatures than previously thought. An ability to recruit and persist through the summer months allows *Undaria* to compete more directly with native species and increases the potential impact of *Undaria* on native ecosystems (Thornber et al. 2004; Thompson and Schiel 2012). Such impacts have already been documented at cooler-water sites (summer temperatures <20 ºC) such as Nuevo Gulf (Argentina) where persistent *Undaria* populations dominate reef sites year-round and exclude native species (Raffo et al. 2009; Irigoyen et al. 2011a,b). A greater than expected temperature tolerance for the recruitment process indicates that year-round populations could become established in subtropical regions worldwide, and that these populations will have greater ecological impacts on subtropical reef systems than previously anticipated.

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