Research article

Roberta D'Archino* and Giuseppe C. Zuccarello

Two red macroalgae newly introduced into New Zealand: *Pachymeniopsis lanceolata* (K. Okamura) Y. Yamada ex S. Kawabata and *Fushitsunagia catenata* Filloramo et G. W. Saunders

<https://doi.org/10.1515/bot-2021-0013>

Received February 10, 2021; accepted March 11, 2021;

published online March 31, 2021

Abstract: Introductions of macroalgae are becoming more common with increased surveillance and the use of molecular tools to unequivocally identify invaders. We here report two non-indigenous macroalgal species newly confirmed to be present in New Zealand. *Pachymeniopsis lanceolata* is an irregularly divided foliose blade, first detected in Lyttleton Harbour/Whakaraupō, South Island but here also reported from the North Island. It has known introductions from its native range in Pacific Asia to the Mediterranean, Atlantic and the eastern Pacific. The introduced *cox3* haplotype was also found in New Zealand, suggesting a secondary introduction from a previous introduced area, but we also found a novel haplotype in the North Island suggesting a case of multiple introductions. *Fushitsunagia catenata*, a recent segregate from *Lomentaria*, was also first detected in Whakaraupō and was initially identified as a species of *Champia*. *RbcL* data shows that it belongs to *F. catenata*. This species is also of Asian origin and has been known to have been introduced to Spain, Mexico, and Australia. We provide morphological and reproductive descriptions of the species in New Zealand. Continued surveillance, and follow up monitoring, are needed to track the expansion and effects of these macroalgae on native biotas.

Keywords: *cox3*; *Grateloupia*; haplotype; non-indigenous species; *rbcL*.

1 Introduction

Non-indigenous species are considered to be a major threat to ecosystems. If they spread and become invasive, they can displace native species, reduce biodiversity and change community composition. By monopolising substrata they can have negative consequences for fish and invertebrates, impact aquaculture, affect recreational activities, and alter food webs (e.g., Casas et al. 2004; Harries et al. 2007; Schaffelke and Hewitt 2007; South et al. 2017), although these effects are not always immediately apparent (Sanchez and Fernandez 2005). For example, the Asian brown algae *Undaria pinnatifida* and *Sargassum muticum* are considered two of the most invasive species in the world (Gallardo 2014; South et al. 2017) and their deleterious impact on native biotas has been documented (e.g., Casas et al. 2004; Monteiro et al. 2009; Salvaterra et al. 2013). Among the red algae, the genus *Grateloupia* includes several species that have been introduced from Asia to Australasia, Europe and North America, including *Grateloupia subpectinata*, *Grateloupia asiatica* and *Grateloupia imbricata* (Montes et al. 2016; Nelson et al. 2013; Verlaque et al. 2005). Some of these red algae are considered to be invasive, such as *Grateloupia turuturu* (Bolton et al. 2016; Mathieson et al. 2008; Saunders and Withall 2006) or *Pachymeniopsis lanceolata* (Kim et al. 2014).

The reports of non-indigenous macroalgae in New Zealand have doubled in the last two decades. Twenty species of seaweeds were recognised in 1999 (Nelson 1999) and 46 species in 2019 (Nelson et al. 2019). The use of molecular tools and a better understanding of the native flora have facilitated the recognition of non-native species, but the biosecurity strategy of New Zealand has similarly aided in the discovery of introductions. Since 2002, the New Zealand government has funded the Marine High-Risk Site Surveillance (MHRSS), a national programme aimed to detect non-indigenous species in the marine

*Corresponding author: Roberta D'Archino, National Institute of Water and Atmospheric Research Ltd, Private Bag 14-901, Wellington 6021, New Zealand, E-mail: roberta.darchino@niwa.co.nz
Giuseppe C. Zuccarello, School of Biological Sciences, Victoria University of Wellington, Wellington, 6140 New Zealand

environments. Surveillance operations are currently carried out every six months in 11 harbours that are visited by international vessels (Seaward et al. 2015; Woods et al. 2020). These surveillance operations target high risk species not yet present in New Zealand, e.g., *Caulerpa taxifolia* (M. Vahl) C. Agardh, while also recording the range extension of already established foreign species (e.g., *U. pinnatifida*) as well as those that are new-to-New Zealand. This surveillance programme provides the opportunity to inspect ports and marinas otherwise not accessible to scientific collectors and divers; its aim is the early detection of non-native organisms.

Several foliose red algae are known to be non-indigenous in New Zealand. The invasive *Schizymenia apoda* was first collected in Wellington Harbour in 2009 (D'Archino and Zuccarello 2014) and the widely introduced *G. turuturu*, was first confirmed in New Zealand in 2005 (D'Archino et al. 2007). Both of these are often difficult to identify in the field and can easily be confused with native species. During a survey of Lyttelton Harbour/Whakaraupō (Canterbury, South Island) in June 2019, two macroalgae were found at Te Ana Marina that appeared to be non-native species: a foliose red alga identified tentatively as *Grateloupia* sp.; the other a clump of terete branched thalli, provisionally designated as *Champia* sp. This study reports on the identity, and introduction, of these two species to New Zealand.

2 Materials and methods

Samples of both adventives were collected in Lyttelton Harbour/Whakaraupō (Canterbury, South Island) during the MHRSS programme survey in winter (June 2019) and summer (March 2020). Collections were made while carrying out shore searches, and along the floating pontoons in Te Ana Marina (43.60547°S, 172.7125348°E). Plants were growing at or just below the water mark and were easily seen from the surface. An estimation of number of plants at each site was carried out in subsequent sampling in March and May 2020. Samples were pressed as vouchers and deposited in the Museum of New Zealand Te Papa Tongarewa (WELT; Thiers 2021), with small portions of fresh thalli placed in silica gel desiccant for molecular analysis and in 5% formalin/seawater for later anatomical study. A sample was also collected from a mooring rope in September 2019 in Port Taranaki, North Island (39.05672°S, 174.04742°E) during the winter MHRSS programme survey.

Hand-cut sections were stained with 1% aniline blue acidified with 1% HCl and mounted in 40% Karo syrup (Karo, Englewood Cliffs, New Jersey, USA). Photomicrographs were taken using an Olympus BX53 microscope (Olympus, Tokyo, Japan) with an SC100 digital camera (Olympus, Münster, Germany).

DNA was extracted using a 5% Chelex solution (Zuccarello et al. 1999). The plastid-encoded large subunit of the ribulose biphosphate carboxylase/oxygenase gene (*rbcL*) was amplified using the primer

pair F57-R753 and F765-RrbcS (Freshwater and Rueness 1994). A portion of the mitochondrial cytochrome c oxidase subunit 3 (*cox3*) gene was amplified using the primers pair F290-R962 (Kim et al. 2014). The amplified products were cleaned using ExoSAP-IT (Affymetrix, Santa Clara, California, USA) and commercially sequenced (Macrogen, Seoul, Korea). The new sequences were deposited in GenBank (*rbcL*: MW689936- MW689937; *cox3*: MW689931-MW689935).

Sequences were assembled and edited in Geneious Prime (<http://www.geneious.com>). Datasets were produced using newly generated data and available sequences from GenBank. The *rbcL* and *cox3* data sets were aligned with MAFFT in Geneious, and no gaps were detected. Maximum-likelihood (ML) analyses were implemented using IQ-tree (Trifinopoulos et al. 2016). IQ-tree was used to select the molecular evolution models (ModelFinder, Kalyaanamoorthy et al. 2017). Genes were partitioned by codon, as appropriate. Models were selected using the BIC criterion. The datasets were subjected to nonparametric bootstrap analysis (500 replicates, Felsenstein 1985) in IQ-tree. A statistical haplotype network for the *cox3* *Pachymeniopsis lanceolata* dataset (Clement et al. 2000) was implemented in PopART (<http://popart.otago.ac.nz>).

3 Results

3.1 Molecular analyses

Sequence data from *cox3* and *rbcL* identified the samples as *Pachymeniopsis lanceolata* (K. Okamura) Y. Yamada ex S. Kawabata (Halymeniaceae) and *Fushitsunagia catenata* (Harvey) Filloramo et G. W. Saunders (Lomentariaceae), respectively. The *cox3* sequences of New Zealand samples tentatively identified as *Grateloupia* sp. nest within *Pachymeniopsis lanceolata* and were distinct from its congener *Pachymeniopsis garguloi* (Supplementary Figure S1). The samples from the South Island all have sequences identical to haplotype C9 from Korea that has been introduced to the USA (Kim et al. 2014), whereas the sample from the North Island has a novel haplotype 2 bp different from C9 (designated C17; MW689935) (Figure 1). *RbcL* sequence data of samples tentatively identified as *Champia* sp. in the field, nested with samples of *Fushitsunagia catenata* (Lomentariaceae) from Japan and Korea (Figure 2).

The occurrence of the previously reported *G. subpectinata* was also confirmed by sequence data, and this represents its first record from the South Island of New Zealand. *Grateloupia turuturu* was also widespread at Te Ana Marina and *cox2-3* spacer sequence data confirmed its presence in Lyttelton and Otago harbours (data not shown).

We identified these samples from Lyttelton as belong to *Pachymeniopsis lanceolata* and *Fushitsunagia catenata*, both of them new introductions to New Zealand. Below are descriptions of their habit and anatomy.

Figure 1: Statistical parsimony network of *cox3* haplotype sequences of *Pachymeniopsis lanceolata* from GenBank (Kim et al. 2014). Haplotypes marked (C1–C10, C17); samples from New Zealand had haplotype C9 and C17. Cross line indicates a 1 bp mutational step between haplotypes (circles).

Figure 2: Maximum-likelihood phylogeny ($-\log L_n = 4394.6502$) of *rbcL* sequences of *Fushitsunagia catenata* and related sequences from GenBank. Genera from the family Lomentariaceae added. *Gloiocladia laciniata* (Faucheaceae) used as an outgroup. Model used for codons (first = TN + F + I_G4; second = TN + F + I + G4; third = TPM3 + F + I). Scale bar = substitution/site.

3.2 Morphology and anatomy

3.2.1 *Pachymeniopsis lanceolata* (Figures 3–16)

Thalli (Figures 3–10) were flattened, 14–35 (60) cm high and 6–15 cm wide, and attached by a discoid holdfast, from which a short (Figures 5–6, 9–10) or nearly non-existent stipe arose (Figures 3 and 4). Thalli were solitary (Figures 4 and 5) or clustered (Figure 8), the blades were broadly lanceolate (Figures 3, 4, and 6) or irregularly divided (Figures 6–8). Old thalli became proliferous (Figures 8 and 10). Thalli were purplish-red to brownish, with a

membranous texture that became leathery in old plants. Large thalli had a strong chlorine smell. Blades were 200–600 μm thick (Figures 11 and 12), reaching up to 1 mm in thickness in old specimens. The cortex consisted of anticlinal filaments (6) 8–12 cells long, the cells becoming progressively smaller toward the surface layer of elongate cells (Figure 12). The medulla was composed of sparsely to densely compacted filaments, 2–7 μm in diameter (Figures 11 and 12). Male gametophytes were found in winter, whereas cystocarps and tetrasporophytes were seen in summer. Tetrasporangia (Figure 13) were scattered over the blade (30–53 $\times$ 15–21 μm) and were cruciately divided. The carpogonial branch ampullae were monocarpogonial (Figure 14), 45–57 $\times$ 29–40 μm . The auxiliary cell ampullae (Figure 15) were 40–46 μm in length and 30–36 μm in width. The auxiliary cell was intercalary in one of the ampullar filaments and had 12 $\times$ 7 μm dimensions. Cystocarps (Figure 16) were 100–220 μm in diameter, immersed in the blades and surrounded by a rudimentary pericarp of lax ampullar filaments. The carposporophytes consisted of three synchronously maturing lobes and contained irregularly angular carpospores (15–22 $\times$ 10–13 μm).

3.2.2 *Fushitsunagia catenata* (Figures 17–24)

Thalli grew in erect clumps, 11–14 cm in height, and were red to purple in colour. The cylindrical primary axes attached by discoid holdfasts to the substratum (Figure 17). Branching of axes was alternate or opposite at regular intervals, the branches were slightly constricted at the nodes, with straight apices (Figures 18, 20, and 23). The texture of the thalli was turgid throughout. Axes were about 1 mm wide, hollow, and composed of 6–10 layers of cells (Figure 19). The cortical cells were closely packed and consisted of periclinally elongated ovoid cells, 13–15 $\times$ 7–9 μm . The medullary cells were 23–39 $\times$ 16–19 μm . Cystocarps were globose, nearly sessile, and produced in small groups or singly along the main and secondary axes, globose and nearly sessile, 800–950 μm in diameter and surrounded by a smooth firm ostiolate pericarp (Figures 20–22). Tetrasporangia were tetrahedrally divided and formed in patches (460–912 $\times$ 180–400 μm) on the upper branches which become swollen (Figures 23 and 24). A further detailed description of this species as *Lomentaria catenata* is provided by Lee (1978).

3.3 Field observations

Thalli were growing at the mean water level (*P. lanceolata*; Figures 25 and 26) or just below it (*F. catenata*; Figure 27) on

Figures 3–16: *Pachymeniopsis lanceolata*. Habit, vegetative and reproductive morphology. (3–10) Morphological variation of samples collected in Lyttelton (WELT A034375–A034381) and Taranaki (WELT A034374) (Figure 6). Scale bar = 2 cm. (11) Cross-section through a young blade showing the thin anticlinal cortex and a lax medulla composed of sparse periclinal filaments (WELT A034376). Scale bar = 20 µm. (12) Cross-section through a mature blade showing a thick cortex and a medulla composed of densely aggregated filaments (WELT A034380). Scale bar = 20 µm. (13) Tetrasporangia (arrows) borne in and dislodged from the cortex (WELT A034377). Scale bar = 20 µm. (14) A carpogonial branch ampulla. Arrow shows trichogyne (WELT A034381). Scale bar = 20 µm. (15) An auxiliary cell ampulla. Arrow shows auxiliary cell (WELT A034381). Scale bar = 20 µm. (16) mature carposporophytes, the distal globular consolidated gonimolobes borne aloft on a columnar fusion cell into the central cystocarp chamber (WELT A034380). Scale bar = 20 µm.

Figures 17–24: *Fushitsunagia catenata*. Habit, vegetative and reproductive morphology. (17) A tetrasporic specimen collected in Lyttelton harbour (WELT A034384). Scale bar = 2 cm. (18) Alternate clavate branches of a tetrasporangial specimen (WELT A034384). Scale bar = 1 mm. (19) The abrupt transition between sub isodiametric cells of the pseudoparenchymatous inner cortex and the two or three layered outer cortex (WELT A034384). Scale bar = 20 μ m. (20) Irregular branching of a cystocarpic specimen (WELT A034383). Scale bar = 1 cm. (21) Clustered sessile and basally constricted globose cystocarps (WELT A034383). Scale bar = 1 mm. (22) Surface of an ostiolate pericarp (WELT A034383). Scale bar = 1 mm. (23) Alternate or opposite branching of a tetrasporic specimen (WELT A034382). Scale bar = 1 cm. (24) Tetrasporangia encircling the inside margins of wide sorus opening (WELT A034382). Scale bar = 1 mm.

floating pontoons and were widespread and at several sites in the Te Ana Marina. *Pachymeniopsis lanceolata* and *F. catenata* were growing together with *G. turuturu* (Figure 28), *G. subpectinata* (Figure 29) and *U. pinnatifida*. *Fushitsunagia catenata* and *G. subpectinata* hosted high numbers of the invasive caprellid, *Caprella mutica* Schurin 1935. Other invasive invertebrates introduced to Lyttelton Harbour/Whakaraupō and observed in Te Ana marina are the ascidians *Styela clava* Herdmann 1881, *Clavelina lepadiformis* Müller 1776, *Didemnum vexillum* Kott 2002 and the tunicates *Ciona intestinalis* Linnaeus 1767 and *Ciona savignyi* Herdmann 1882.

4 Discussion

While it is sometimes difficult to establish if a species is native or introduced, in this case *P. lanceolata* and *F. catenata* can be confidently identified as recent introductions to

New Zealand. If knowledge of the local flora (poorly known diversity in a region), or taxonomic expertise (ability to identify species of similar morphology), are lacking, introduced species can be overlooked or treated as native species. For example, *Polysiphonia sensu lato* (D'Archino et al. 2013) is not well characterized in New Zealand but that is not the situation here because detailed investigations of New Zealand foliose red algae have been underway for over a decade (D'Archino et al. 2011, 2012, 2016; D'Archino and Zuccarello 2020) and have included collections made throughout New Zealand. Neither of the species reported here has been seen previously, including as part of the MHRSS programme with which the first author has been involved since 2008.

4.1 *Pachymeniopsis lanceolata*

Although *Pachymeniopsis lanceolata* can be easily confused with *Grateloupia turuturu*, which was previously established

Figures 25–29: Field images. (25) *Pachymeniopsis lanceolata* on a pontoon in Te Ana Marina (Lyttelton). (26) *Pachymeniopsis lanceolata* on a mooring rope in Port Taranaki. (27) *Fushitsunagia catenata* on a pontoon in Te Ana Marina. (28) *Grateloupia turuturu* attached to the keel of a boat moored in Te Ana Marina. (29) *Grateloupia subpectinata* on a pontoon in Te Ana Marina.

in Lyttelton Harbour/Whakaraupō, as well as with the native *Grateloupia urvilleana* (Montagne) P. G. Parkinson, its thalli are thicker and firmer in texture and not silky, as are *G. turuturu* and *G. urvilleana* (although older plants of these latter species can be tougher). In addition, *P. lanceolata* thalli had a strong chlorine smell that the other two lack.

The genus *Pachymeniopsis* was originally described by Kawabata in 1954 based on *Aeodes lanceolata* Okamura (1934) from material collected in Japan. *Pachymeniopsis* was later merged with *Grateloupia* (Kawaguchi 1997) but was reinstated (Gargiulo et al. 2013) based on reproductive features and molecular data. The genus *Pachymeniopsis* currently includes four species native in northeast Asia (Guiry and Guiry 2021): *P. lanceolata*, *P. gargiuloi* S. Y. Kim, Manghisi, Morabito et S. M. Boo, *P. pseudoellittica* S. Kawabata and *Pachymeniopsis volvita* M. Y. Yang et M. S. Kim. Only *P. lanceolata* and *P. gargiuloi* have been reported outside their native range. *Pachymeniopsis lanceolata* has been introduced to Thau Lagoon, Mediterranean France,

probably with Asiatic oysters in the 1970s or later (Verlaque 2001; Verlaque et al. 2005). In 2003, it was discovered at Santa Catalina Island and in southern California in 2008 (Miller et al. 2009). It has been recorded from the Canary Islands (García-Jiménez et al. 2008) and has been found in Sydney harbour (<https://www.nationaltribune.com.au/non-native-marine-algae-detected-in-botany-bay/>). *Pachymeniopsis gargiuloi* so far has been introduced only to Italy (Kim et al. 2014) and northern Spain (Montes et al. 2016).

The genetic diversity of New Zealand samples of *P. lanceolata*, assessed by *cox3* sequence data, revealed a haplotype (C9) of *P. lanceolata* found in Korea and the USA (Kim et al. 2014). While it is more likely that this species came from Asia rather than California, this alternative route cannot be eliminated based on our data. If from Asia, it is interesting that the same haplotype has established in two non-native environments, which could be just a coincidence or an indication of some particular physiological property of haplotype C9. It is known that within species

different genetic variants can have different physiological properties (see Zuccarello et al. 2001). The North Island sample is of a novel haplotype (C17) not found before in New Zealand or in any samples from its native range (Kim et al. 2014). This could represent either a novel introduction from its native range of a haplotype not sampled, or a range expansion from a single previous introduction that went undetected. Increased sampling is needed both in New Zealand and overseas, especially within its native range, to determine if these two populations are derived from one or separate introductions.

In France's Thau Lagoon, *P. lanceolata* has successfully established and developed reproductive populations without becoming invasive (Verlaque et al. 2005). Its possible expansion in New Zealand should continue to be monitored and its phenology studied. Miller et al. (2009) warned that monitoring of this species was needed as it has been reported to act as a 'weed' having 'ample reproduction, tenacious recruitment and broad physiological tolerances' (Nyberg and Wallentinus 2005). From our observations it seems that *P. lanceolata* can form large populations that could spread easily. In winter 2019, few plants were encountered at Te Ana Marina, whereas in summer and winter of 2020 it was one of the dominant species, in conjunction with *F. catenata* and *G. turuturu*. Both gametophytic and tetrasporangial thalli were growing on artificial substrata and mussels and were reproductive (both carposporophytes and tetrasporophytes present).

4.2 *Fushitsunagia catenata*

Fushitsunagia catenata belongs to the Lomentariaceae. The Lomentariaceae in New Zealand is represented by two genera, *Ceratodictyon* and *Lomentaria*. In the field, *F. catenata* was tentatively identified as a *Champia* but clearly differed morphologically from the common native species *Champia novae-zelandiae* and *Champia chathamensis* (Nelson 2020) as well as from the introduced species *Champia affinis* (Adams 1994). *Champia affinis* is considered to have been an early introduction to New Zealand (Adams 1983) and it has a restricted distribution in southern New Zealand and is considered a 'low impact, low risk' species (Nelson 1999).

The genus *Fushitsunagia* was recently segregated from *Lomentaria* (Filloramo and Saunders 2016). Although De Toni (1924) synonymised *L. catenata* with *Lomentaria umbellata* (Hook.f. et Harv.) Yendo from New Zealand, the latter is smaller, up to 8 cm high, has a soft and flaccid texture, with curved side branches and swollen tips (Nelson 2020) while *F. catenata* is larger (10–15 cm high),

has straight apices and it is turgid. The other three native species: *Lomentaria caespitosa*, *Lomentaria saxigena*, and *Lomentaria secunda* are also smaller in size, 1–3 cm high (Adams 1994).

The native range of *Fushitsunagia catenata* is Japan and Korea with the type locality Shimodo, Japan (Masuda et al. 1995). *Fushitsunagia catenata* is also found in the Gulf of California (Norris et al. 2017), New South Wales, Australia (Millar and Kraft 1993, as *Lomentaria catenata*) and Spain (Gallardo et al. 2016). Species in the family that have been reported as non-indigenous are *Lomentaria hakodatensis* which is native in Asia and introduced to Italy (Curiel et al. 2006) and presumably California, USA and Pacific Mexico (Miller et al. 2011), *Lomentaria clavellosa* and *Lomentaria orcadensis*, native in Europe and introduced to the northwest Atlantic (Mathieson et al. 2008).

Fushitsunagia catenata is perennial, and the new fronds regenerate at the broken or eroded margins. In Japan, it is luxuriant in winter and autumn (Lee 1978).

Lee (1978) reported the presence of gland cells in Japanese samples of *F. catenata* (as *Lomentaria catenata*); however these were not noticed by Okamura (1902) and were absent from our samples. More samples should be examined.

4.2.1 Vector and spread

The most likely vector of introduction of invasive species to New Zealand is hull fouling or ballast water. Te Ana Marina in Lyttelton Harbour/Whakaraupō has only recently been built (2017–2018) but its location, and port facilities for international cruise and cargo ships, makes it obviously vulnerable to foreign introductions of both algae and invertebrates. While the old pile mooring served domestic recreational vessels, the new pontoon in Te Ana Marina has also begun receiving an increasing number of visits from international recreational vessels. Although the introduction of *Pachymeniopsis lanceolata* to Europe and California has mainly been attributed to the importation of oysters from Japan (Miller et al. 2009; Verlaque et al. 2005), and Pacific oysters were introduced to New Zealand possibly in the early 1960s (Dinamani 1971; Dromgoole and Foster 1983), *Pachymeniopsis* appears to be a recent introduction and unrelated to the presence of Pacific oysters, which are not cultivated in the Lyttelton area.

Pachymeniopsis lanceolata has an isomorphic life cycle and sexual thalli are monoecious. The carpospores develop tiny crusts that reach 100 µm in a month and initiate the erect thalli, which reach 500 µm in two weeks (Kawaguchi 1997). These early stages could tightly adhere to ship and barge hulls for considerable periods of time to become reproductively mature and capable of spreading when they

reach ports where vessels are moored or anchored. *Grateloupia turuturu*, for example, has a great tolerance to stress factors such as temperature, daylength and salinity fluctuations (Liu and Pang 2010) and cystocarpic blades and diatom-covered crusts of it have been found to be resistant to bleach treatment (Capistrant-Fossa and Brawley 2019).

In New Zealand, *G. turuturu* was discovered in 2006 (D'Archino et al. 2007) and is currently well established in both the North and South Islands (Auckland, Tauranga, Wellington, Picton, Nelson, Lyttelton), and was recently discovered in Otago Harbour (Dunedin, South Island) during the last summer surveillance programme (2020). *Grateloupia subpectinata* was introduced to New Zealand attached to a tugboat that was travelling from Australia. Despite the hull being treated twice with heated seawater (Nelson et al. 2013), *G. subpectinata* is now well established in Tauranga, Auckland, Wellington and Lyttelton harbours. *Pachymeniopsis lanceolata* has the potential to spread to other New Zealand harbours through both international and local commercial and recreational shipping. The main macroalgal species occurring in Te Ana Marina are introduced species (*P. lanceolata*, *G. turuturu*, *G. subpectinata*, *F. catenata*, *U. pinnatifida*) that seem to have replaced the common native inhabitants e.g., *Hargdiophyllum crispatum* (J. D. Hooker et Harvey) Showe M. Lin, Hommersand et W. A. Nelson, *Schizoseris* spp., and *Plocamium* spp. found in marinas. The systematic monitoring of the marine entry points for introduced, and potentially invasive species, has led to the discovery of two new introductions. Further monitoring will establish if these species spread from this location and studies are warranted to evaluate the impact of these, and other, introduced species on the native flora.

Acknowledgements: We thank Gerry Kraft for a careful reading of a previous version of this manuscript. Chris Woods and Louis Olsen (NIWA) are thanked for field images, and Ant Kusabs (Museum of New Zealand – Te Papa Tongarewa) for assistance with sample registration.

Author contributions: All the authors have accepted responsibility for the entire content of this submitted manuscript and approved submission.

Research funding: This work was supported by NIWA with the Strategic Science Investment Fund (SSIF) Coast and Oceans Biodiversity Research and the Marine Invasives Taxonomic Service (MITS), and via strategic research funds from the School of Biological Sciences at Victoria University of Wellington. We acknowledge Biosecurity New Zealand for funding the Marine High-Risk Site Surveillance programme (SOW18048) through which *P. lanceolata* and *F. catenata* were first detected.

Conflict of interest statement: The authors declare no conflicts of interest regarding this article.

References

- Adams, N.M. (1983). Checklist of marine algae possibly naturalised in New Zealand. N. Z. J. Bot. 21: 1–2.
- Adams, N.M. (1994). *Seaweeds of New Zealand*. Canterbury University Press, Christchurch, p. 360.
- Bolton, J.J., De Clerck, O., Francis, C.M., Siyanga-Tembo, F., and Anderson, R.J. (2016). Two newly discovered *Grateloupia* (Halymeniaceae, Rhodophyta) species on aquaculture rafts on the west coast of South Africa, including the widely introduced *Grateloupia turuturu*. Phycologia 55: 659–664.
- Capistrant-Fossa, K. and Brawley, S.H. (2019). Unexpected reproductive traits of *Grateloupia turuturu* revealed by its resistance to bleach-based biosecurity protocols. Bot. Mar. 62: 83–96.
- Casas, G., Scrosati, R., and Piriz, M.L. (2004). The invasive kelp *Undaria pinnatifida* (Phaeophyceae, Laminariales) reduces native seaweed diversity in Nuevo Gulf (Patagonia, Argentina). Biol. Invasions 6: 411–416.
- Clement, M., Posada, D., and Crandall, K.A. (2000). TCS: a computer program to estimate gene genealogies. Mol. Ecol. 9: 1657–1659.
- Curiel, D., Bellemo, G., Scattolin, M., and Marzocchi, M. (2006). First report of *Lomentaria hakodatensis* (Lomentariaceae, Rhodophyta) from the lagoon of Venice (Adriatic Sea, Mediterranean). Acta Adriat. 47: 65–72.
- D'Archino, R., Nelson, W.A., and Zuccarello, G.C. (2007). Invasive marine red alga introduced to New Zealand waters: first record of *Grateloupia turuturu* (Halymeniaceae, Rhodophyta). N. Z. J. Mar. Freshw. Res. 41: 35–42.
- D'Archino, R., Nelson, W.A., and Zuccarello, G.C. (2011). Diversity and complexity in New Zealand Kallymeniaceae (Rhodophyta): resurrection of the genus *Ectophora* and description of *E. marginata* sp. nov. Phycologia 50: 241–255.
- D'Archino, R., Nelson, W.A., and Zuccarello, G.C. (2012). *Stauromenia australis*, a new genus and species in the family Kallymeniaceae (Rhodophyta) from Southern New Zealand. Phycologia 51: 451–460.
- D'Archino, R., Neill, K., and Nelson, W.A. (2013). Recognition and distribution of *Polysiphonia morrowii* (Rhodomelaceae, Rhodophyta) in New Zealand. Bot. Mar. 56: 41–47.
- D'Archino, R., Lin, S.-M., Gabrielson, P.W., and Zuccarello, G.C. (2016). Why one species in New Zealand, *Pugetia delicatissima* (Kallymeniaceae, Rhodophyta), should become two new genera, *Judithia* gen. nov. and *Wendya* gen. nov. Eur. J. Phycol. 51: 83–98.
- D'Archino, R., and Zuccarello, G.C. (2014). First record of *Schizymenia apoda* in New Zealand. N. Z. J. Mar. Freshw. Res. 48: 155–162.
- D'Archino, R. and Zuccarello, G.C. (2020). Foliose species of red algae: diversity of *Tsengia* species in New Zealand, and the description of *T. northlandica* sp. nov. (Tsengiaceae, Halymeniales). Phycologia 59: 437–448.
- De Toni, G.B. (1924). *Sylloge algarum omnium hucusque cognitarum*. Vol. VI. Florideae. Sectio V. Additamenta. Sumptibus auctoris, Patavii [Padua], pp. [i]–xi, [1]–767, frontispiece.

- Dinamani, P. (1971). Occurrence of the Japanese oyster, *Crassostrea gigas* (Thunberg), in Northland, New Zealand. N. Z. J. Mar. Freshw. Res. 5: 352–357.
- Dromgoole, F.I. and Foster, B.A. (1983). Changes to the marine biota of the Auckland harbour. Tane 29: 79–96.
- Felsenstein, J. (1985). Confidence limits on phylogenies: an approach using the bootstrap. Evolution 39: 783–791.
- Filloramo, G.V. and Saunders, G.W. (2016). Application of multigene phylogenetics and site-stripping to resolve intraordinal relationships in the Rhodymeniales (Rhodophyta). J. Phycol. 52: 339–355.
- Freshwater, D.W. and Rueness, J. (1994). Phylogenetic relationships of some European *Gelidium* (Gelidiales, Rhodophyta) species, based on *rbcL* nucleotide sequence analysis. Phycologia 33: 187–194.
- Gallardo, B. (2014). Europe's top 10 invasive species: relative importance of climatic, habitat and socio-economic factors. Ethol. Ecol. Evol. 26: 130–151.
- Gallardo, T., Bárbara, I., Afonso-Carrillo, J., Bermejo, R., Altamirano, M., Gómez Garreta, A., Barceló Martí, M.C., Rull Lluç, J., Ballesteros, E., and De la Rosa, J. (2016). Nueva lista crítica de las algas bentónicas marinas de España. A new checklist of benthic marine algae of Spain. Algas. Boletín Informativo de la Sociedad Española de Ficología 51: 7–52.
- García-Jiménez, P., Gerladino, P.J.L., Boo, S.M., and Robaina, R.R. (2008). Red alga *Grateloupia imbricata* (Halymeniaceae), a species introduced into the Canary Islands. Phycol. Res. 56: 166–171.
- Gargiulo, G.M., Morabito, M., and Manghisi, A. (2013). A re-assessment of reproductive anatomy and postfertilization development in the systematics of *Grateloupia* (Halymeniales, Rhodophyta). Cryptogam. Algol. 34: 3–25.
- Guiry, M.D. and Guiry, G.M. (2021). *AlgaeBase*. World-wide electronic publication. National University of Ireland, Galway, Available at: <<https://www.algaebase.org>> (Searched 09 February 2021).
- Harries, D.B., Harrow, S., Wilson Mair, J.R., and Donnan, D.W. (2007). The establishment of the invasive alga *Sargassum muticum* on the west coast of Scotland: a preliminary assessment of community effects. J. Mar. Biol. Assoc. U. K. 87: 1057–1067.
- Kalyanamorthy, S., Minh, B.Q., Wong, T.K.F., von Haeseler, A., and Jermini, L.S. (2017). ModelFinder: fast model selection for accurate phylogenetic estimates. Nat. Methods 14: 587–589.
- Kawaguchi, S. (1997). Taxonomic notes on the Halymeniaceae (Gigartinales, Rhodophyta) from Japan, III. Synonymization of *Pachymeniopsis* Yamada in Kawabata with *Grateloupia* C. Agardh. Phycol. Res. 45: 9–21.
- Kim, S.Y., Manghisi, A., Morabito, M., Yang, E.C., Yoon, H.S., Miller, K.A., and Boo, S.M. (2014). Genetic diversity and haplotype distribution of *Pachymeniopsis gargiuloi* sp. nov. and *P. lanceolata* (Halymeniales, Rhodophyta) in Korea, with notes on their non-native distributions. J. Phycol. 50: 885–896.
- Lee, I.K. (1978). Studies on Rhodymeniales from Hokkaido. J. Fac. Sci. Hokkaido Univ. Ser. V Bot. 11: 1–203.
- Liu, F. and Pang, S.J. (2010). Stress tolerance and antioxidant enzymatic activities in the metabolisms of the reactive oxygen species in two intertidal red algae *Grateloupia turuturu* and *Palmaria palmata*. J. Exp. Mar. Biol. Ecol. 382: 82–87.
- Masuda, M., Kudo, T., Kawaguchi, S., and Guiry, M.D. (1995). Lectotypification of some marine red algae described by W. H. Harvey from Japan. Phycol. Res. 43: 191–202.
- Mathieson, A.C., Pederson, J.R., Neefus, C.D., Dawes, C.D., and Bray, T.L. (2008). Multiple assessments of introduced seaweeds in the Northwest Atlantic. ICES J. Mar. Sci. 65: 730–741.
- Millar, A.J.K. and Kraft, G.T. (1993). Catalogue of marine and freshwater red algae (Rhodophyta) of New South Wales, including Lord Howe Island, South-Western Pacific. Aust. Syst. Bot. 6: 1–90.
- Miller, K.A., Aguilar-Rosas, L.E., and Pedroche, F.F. (2011). A review of non-native seaweeds from California, USA and Baja California, México. Reseña de algas marinas no nativas de California, USA y Baja California, México. Hidrobiológica 21: 240–254.
- Miller, K.A., Hughey, J.R., and Gabrielson, P.W. (2009). First report of the Japanese species *Grateloupia lanceolata* (Halymeniaceae, Rhodophyta) from California, USA. Phycol. Res. 57: 238–241.
- Monteiro, C.A., Engelen, A.H., and Santos, R.O.P. (2009). Macro- and mesoherbivores prefer native seaweeds over the invasive brown seaweed *Sargassum muticum*: a potential regulating role on invasions. Mar. Biol. 156: 2505–2515.
- Montes, M., Rico, J.M., García-Vázquez, E., and Borrell, Y.J. (2016). Morphological and molecular methods reveal the Asian alga *Grateloupia imbricata* (Halymeniaceae) occurs on Cantabrian Sea shores (Bay of Biscay). Phycologia 55: 365–370.
- Nelson, W.A. (1999). A revised checklist of marine algae naturalised in New Zealand. N. Z. J. Bot. 37: 355–359.
- Nelson, W.A. (2020). *New Zealand seaweeds an illustrated guide*. Te Papa Press, Wellington, New Zealand, p. 351.
- Nelson, W.A., Kim, S.Y., D'Archino, R., and Boo, S.M. (2013). The first record of *Grateloupia subpectinata* from the New Zealand region and comparison with *G. prolifera*, a species endemic to the Chatham Islands. Bot. Mar. 56: 507–513.
- Nelson, W.A., Neill, K., D'Archino, R., and Rolfe, J.R. (2019). *Conservation status of New Zealand macroalgae, 2019. New Zealand threat classification series*. Publishing Team, Department of Conservation, The Terrace, Wellington, New Zealand.
- Norris, J.N., Aguilar-Rosas, L.E., and Pedroche, F.F. (2017). Conspectus of the benthic marine algae of the Gulf of California: Rhodophyta, Phaeophyceae, and Chlorophyta. Smithsonian Contrib. Bot. 106: 1–125.
- Nyberg, C.D. and Wallentinus, I. (2005). Can species traits be used to predict marine macroalgal introductions? Biol. Invasions 7: 265–279.
- Okamura, K. (1902). *Illustrations of the marine algae of Japan*, Vol. 1. Keigyosha & Co., Tokyo, pp. 75–93, plates XXVI–XXX.
- Okamura, K. (1934). *Icones of Japanese algae*, Vol. 7. Kazamashobo, Tokyo, pp. 19–48 (English), 17–44 (Japanese), plates CCCXI–CCCXXV.
- Salvaterra, T., Green, D.S., Crowe, T.P., and O'Gorman, E.J. (2013). Impacts of the invasive alga *Sargassum muticum* on ecosystem functioning and food web structure. Biol. Invasions 15: 2563–2576.
- Sanchez, I. and Fernandez, C. (2005). Impact of the invasive seaweed *Sargassum muticum* (Phaeophyta) on an intertidal macroalgal assemblage. J. Phycol. 41: 923–930.
- Saunders, G.W. and Withall, R.D. (2006). Collections of the invasive species *Grateloupia turuturu* (Halymeniales, Rhodophyta) from Tasmania, Australia. Phycologia 45: 711–714.
- Schaffelke, B. and Hewitt, C.L. (2007). Impacts of introduced seaweeds. Bot. Mar. 50: 397–417.

- Seaward, K., Acosta, H., Inglis, G.J., Wood, B., Riding, T.A.C., Wilkens, S., and Gould, B. (2015). The Marine Biosecurity Porthole – a web-based information system on non-indigenous marine species in New Zealand. *Manag. Biol. Invasions* 6: 177–184.
- South, P.M., Floerl, O., Forrest, B.M., and Thomsen, M.S. (2017). A review of three decades of research on the invasive kelp *Undaria pinnatifida* in Australasia: an assessment of its success, impacts and status as one of the world's worst invaders. *Mar. Environ. Res.* 131: 243–257.
- Thiers, B. (2021). [continuously updated]. Index herbariorum: a global directory of public herbaria and associated staff. New York Botanical Garden's Virtual Herbarium, Available at: <<http://sweetgum.nybg.org/science/ih/>> (Accessed 16 January 2021).
- Trifinopoulos, J., Nguyen, L.-T., von Haesele, A., and Minh, B.Q. (2016). W-IQ-TREE: a fast-online phylogenetic tool for maximum likelihood analysis. *Nucleic Acids Res.* 44: W232–W235.
- Verlaque, M. (2001). Checklist of the macroalgae of Thau Lagoon (Hérault, France), a hot spot of marine species introduction in Europe. *Oceanol. Acta* 24: 29–49.
- Verlaque, M., Brannock, P.M., Komatsu, T., Villalard-Bohnsack, M., and Marston, M. (2005). The genus *Grateloupia* C. Agardh (Halymeniaceae, Rhodophyta) in the Thau Lagoon (France, Mediterranean): a case study of marine plurispecific introductions. *Phycologia* 44: 477–496.
- Woods, C., Seaward, K., Pryor Rodgers, L., Buckthought, D., Carter, M., Lyon, W., Olsen, L., and Smith, M. (2020). Marine High Risk Site Surveillance Programme: annual synopsis report for all high risk sites 2019–20 (SOW18048). MPI Technical Paper no. 2020/05. 50 pp. + appendices.
- Zuccarello, G.C., West, J.A., Kamiya, M., and King, R.J. (1999). A rapid method to score plastid haplotypes in red seaweeds and its use in determining parental inheritance of plastids in the red alga *Bostrychia* (Ceramiales). *Hydrobiologia* 401: 207–214.
- Zuccarello, G.C., Yeates, P., Wright, J., and Bartlett, J. (2001). Population structure and physiological differentiation of haplotypes of *Caloglossa leprieurii* (Rhodophyta) in a mangrove intertidal zone. *J. Phycol.* 37: 235–244.

Supplementary Material: The online version of this article offers supplementary material (<https://doi.org/10.1515/bot-2021-0013>).

Bionotes

Roberta D'Archino

National Institute of Water and Atmospheric Research Ltd, Private Bag 14-901, Wellington, 6021, New Zealand
roberta.darchino@niwa.co.nz

Roberta D'Archino is a marine biologist working at National Institute Water and Atmospheric Research (NIWA) in Wellington. Originally, she came from Italy where she completed her studies including her PhD in phycology. In New Zealand she has been working on the taxonomy of foliose red algae, e.g., Kallymeniaceae, Halymeniaceae and described several new taxa. She has also been involved in the Biosecurity Marine Survey since 2008 to detect introduced species. Her research involves scientific diving and collection, anatomical and morphological investigations, algal cultures and molecular biology.

Giuseppe C. Zuccarello

School of Biological Sciences, Victoria University of Wellington, Wellington, 6140 New Zealand

Giuseppe C. Zuccarello is interested in the taxonomy, evolution and speciation of algae. He received a PhD degree from the University of California Berkeley. He has been president of the International Phycological Society and is currently a professor at Victoria University of Wellington. He has published over 165 peer-reviewed papers.