



HAL
open science

Revisiting Australian *Ectocarpus subulatus* (Phaeophyceae) from the Hopkins River: distribution, abiotic environment, and associated microbiota

Simon M. Dittami, Akira F Peters, Bezhin Rosko, John West, Thierry Cariou,
Hetty Kleinjan, Bertille Burgunter-Delamare, Aurelie Prechoux, Suhelen
Egan, Catherine Boyen

► To cite this version:

Simon M. Dittami, Akira F Peters, Bezhin Rosko, John West, Thierry Cariou, et al.. Revisiting Australian *Ectocarpus subulatus* (Phaeophyceae) from the Hopkins River: distribution, abiotic environment, and associated microbiota. *Journal of Phycology*, 2020, 56 (3), pp.719-729. hal-02340942v2

HAL Id: hal-02340942

<https://hal.sorbonne-universite.fr/hal-02340942v2>

Submitted on 9 Dec 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

1 REVISITING AUSTRALIAN *ECTOCARPUS SUBULATUS*
2 (PHAEOPHYCEAE) FROM THE HOPKINS RIVER: DISTRIBUTION,
3 ABIOTIC ENVIRONMENT, AND ASSOCIATED MICROBIOTA¹

4 Simon M. Dittami², Sorbonne Université, CNRS, Integrative Biology of Marine Models
5 (LBI2M), Station Biologique de Roscoff, 29680 Roscoff, France

6 Akira F. Peters, Bezhin Rosko, 40 Rue des Pêcheurs, 29250 Santec, France

7 John West, Biosciences 2, University of Melbourne, Parkville VIC 3010, Australia

8 Thierry Cariou, Sorbonne Université, CNRS, FR2424, Station Biologique de Roscoff, 29680,
9 Roscoff, France

10 Hetty KleinJan, Sorbonne Université, CNRS, Integrative Biology of Marine Models (LBI2M),
11 Station Biologique de Roscoff, 29680 Roscoff, France; present address: CEBEDEAU,
12 Research and Expertise Center for Water, Allée de la découverte, 11 (B53), Quartier
13 Polytech 1, B-4000, Liège, Belgium.

14 Bertille Burgunter-Delamare, Sorbonne Université, CNRS, Integrative Biology of Marine Models
15 (LBI2M), Station Biologique de Roscoff, 29680 Roscoff, France

16 Aurelie Prechoux, Sorbonne Université, CNRS, Integrative Biology of Marine Models (LBI2M),
17 Station Biologique de Roscoff, 29680 Roscoff, France; present address: ALGAIA,
18 Research & Development Center, 91 rue Edouard Branly, 50000 Saint-Lô, France

19 Suhelen Egan, Centre for Marine Science and Innovation, School of Biological, Earth and
20 Environmental Sciences University of New South Wales, Sydney, Australia

21 Catherine Boyen, Sorbonne Université, CNRS, Integrative Biology of Marine Models (LBI2M),
22 FR2424, Station Biologique de Roscoff, 29680 Roscoff, France

¹ Submission information to be added

² Correspondence: simon.dittami@sb-roscoff.fr, phone: +33 29 82 92 362, fax: +33 29 82 92 324

23 **Abstract**

24 In 1995 a strain of *Ectocarpus* was isolated from Hopkins River Falls, Victoria, Australia,
25 constituting one of few available freshwater or nearly freshwater brown algae, and the only one
26 belonging to the genus *Ectocarpus*. It has since been used as a model to study acclimation and
27 adaptation to low salinities and the role of its microbiota in these processes. To provide more
28 background information on this model, we assessed if *Ectocarpus* was still present in the
29 Hopkins river twenty-two years after the original finding, estimated its present distribution,
30 described its abiotic environment, and determined its *in situ* microbial composition.

31 We sampled for *Ectocarpus* at 15 sites along the Hopkins River as well as 10 neighboring sites
32 and found individuals with ITS and *cox1* sequences identical to the original isolate at three sites
33 upstream of Hopkins River Falls. The salinity of the water at these sites ranged from 3.1-6.9 psu,
34 and it was rich in sulfate (1-5 mM). The diversity of bacteria associated with the algae *in situ*
35 (1312 operational taxonomic units) was one order of magnitude higher than in previous studies of
36 the original laboratory culture, and 95 alga-associated bacterial strains were isolated from algal
37 filaments on site. In particular, species of *Planctomycetes* were abundant *in situ* but rare in
38 laboratory-cultures.

39 Our results confirmed that *Ectocarpus* was still present in the Hopkins River, and the newly
40 isolated algal and bacterial strains offer new possibilities to study the adaptation of *Ectocarpus* to
41 low salinity and its interactions with its microbiome.

42 **Keywords:** *Ectocarpus subulatus*; distribution; low salinity adaptation; freshwater colonization;
43 microbiota.

44 **Introduction**

45 Brown algae (Phaeophyceae) are widespread in the tidal and sub-tidal zone of rocky shores in
46 temperate marine environments, but they are rarely found in fresh water (Dittami *et al.* 2017).
47 While there are ca. 2,000 known species of marine brown algae, covering a large range of
48 morphologies from small filamentous algae to large and morphologically complex kelp species,
49 there is only a handful of known freshwater brown algae, all of them small and with simple
50 morphology (crust-forming or filamentous). Among these freshwater brown algae the genus
51 *Ectocarpus* has a unique position because it corresponds to a predominantly marine genus,
52 which, on two occasions, has been recorded also in rivers: One occurrence of *Ectocarpus*
53 *crouaniorum* Thuret in a highly salt-contaminated section of the Werra river in Germany
54 (Geissler 1983), and one occurrence of *Ectocarpus subulatus* Kützing in a nearly freshwater
55 habitat (salinity 1ppt) in the Hopkins River, Victoria, Australia (West and Kraft 1996; Peters *et*
56 *al.* 2015).

57 The isolate from the latter site (Culture Collection of Algae and Protozoa accession 1310/196),
58 constitutes a potential model system to study marine-freshwater transitions in brown algae. The
59 species *E. subulatus* (Peters *et al.* 2015) is related to the genomic model species *Ectocarpus*
60 *siliculosus* (Dillwyn) Lyngbye (Cock *et al.* 2010) and has previously been found in highly
61 variable environments, including environments with high levels of abiotic stressors. Its
62 occurrence was reported, for instance, at Port Aransas, Texas, USA, where monthly average
63 water temperatures reach 30°C in July (Bolton 1983). More recently, the nuclear genome of *E.*
64 *subulatus* has been sequenced, revealing that *E. subulatus*, in comparison to *Ectocarpus*
65 *siliculosus*, has lost members of gene families down-regulated in low salinities, and conserved
66 those that were up-regulated (Dittami *et al.* 2018, preprint). The *E. subulatus* strain from Hopkins

67 River Falls has further been used for physiological experiments: it can grow in both seawater and
68 fresh water and its transcriptomic and metabolic acclimation to these conditions has been
69 examined (Dittami *et al.* 2012) along with the composition of its cell wall with regard to sulfated
70 polysaccharides (Torode *et al.* 2015). Moreover, the capacity of the freshwater strain to grow in
71 low salinities has been shown to depend on its associated microbial community, although the
72 nature of this dependence is still unknown (Dittami *et al.* 2016). Extensive efforts have been
73 made to develop a collection of cultivable bacteria to study this phenomenon (KleinJan *et al.*
74 2017).

75 Despite this increasing quantity of data on the physiology of the Hopkins River Falls strain of *E.*
76 *subulatus*, we currently know little about its abiotic environment *in situ*. The original paper
77 describing its isolation (West and Kraft 1996) states that it was isolated on March 24th, 1995 from
78 cracks between the basalt rock of the Hopkins River, just above the Hopkins River Falls. Water
79 temperature was 16°C, salinity was approximately 1 ppt, and conductivity approximately 3 mS·s⁻¹.
80 However, it is unknown if *E. subulatus* is still present at Hopkins River Falls, and if so what its
81 current distribution is. Furthermore, the culture has undergone > 20 years of cultivation in
82 different laboratories, potentially having a strong impact on its associated microbiota.

83 In this study, we address both of these knowledge gaps by returning to the Hopkins River and
84 searching for this alga for the first time since its discovery 20 years ago. We found *E. subulatus*
85 individuals at three locations along the Hopkins River, examined its associated microbiome *in*
86 *situ*, and isolated several novel alga-associated bacterial strains from these samples. These data
87 provide important background information for the use of *E. subulatus* as a model to study low
88 salinity acclimation/adaptation and the role of microbes in these processes.

89 **Materials and methods**

90 *Biological samples*

91 The sampling campaign was carried out from March 21st to March 27th, 2017 and covered several
92 locations along the Hopkins River between Warrnambool and Ararat (sites 1-15; selected due to
93 their accessibility and to cover the entire length of the river), as well as ten sites selected
94 arbitrarily along the Southern Australian Coastline between Port Fairy and Avalon (Figure 1,
95 Table 1). At each sampling site, we manually searched for filamentous algae resembling a
96 member of the Ectocarpales within a range of ca. 50m and for at least 30 min. If filaments were
97 found, small amounts of live samples were taken and rinsed three times in sterile 50 mL Falcon
98 tubes with 0.2µm-filtered local water (3 replicates). A small piece of each sample was stored at
99 max. 20°C in sterile 2mL Eppendorf tubes filled with the surrounding water for live algal
100 cultures. The second part of the samples was ground on-site according to Tapia *et al.* (2016), with
101 50 µL of 0.2 µm-filtered local water in a sterile mortar and the proximity of a Bunsen burner.
102 One, seven, and 35 µL of the ground alga were diluted with 0.2µm-filtered local water to a final
103 volume of 50 µL and spread immediately onto pre-prepared R2A agar plates (Sigma-Aldrich, St.
104 Louis, MO, USA) for isolation of culturable bacteria. These plates were kept at ambient
105 temperature (max. 25°C) and were monitored for two weeks. Newly emerging colonies were
106 purified once more on fresh R2A plates and then put into culture in liquid Zobell medium (Zobell
107 1941) with 8-fold reduced salt concentration, identified by 16S rRNA gene sequencing (see
108 below), and put into stock at -80°C in 40% Glycerol. The remaining sample was dried using
109 silica gel for downstream analysis of the microbial community composition, and frozen at -20°C
110 after the sampling campaign.

111 For all sites, we also collected samples for germling emergence experiments to detect the
112 presence of *Ectocarpus* spores. Three to seven sediment samples including small pieces of solid
113 substrate (shells, pebbles, branches) if present. Approximately 0.1 mL of sediment were kept as
114 live samples in sterile 2 mL Eppendorf tubes. After two weeks these samples were transferred to
115 fresh Provasoli-enriched (Starr and Zeikus 1993) medium based on 5%, 25%, or 100% seawater,
116 depending on the salinity of the water at the sampling site. Seawater for culture media was
117 collected in Roscoff (48°46'40" N, 3°56'15" W), 0.45 µm filtered, and autoclaved at 120°C for 20
118 min) prior to use. The sediment samples were then kept at 13°C in a 14/10 light-dark cycle at an
119 irradiance level of 25 µmol PAR·m⁻²·s⁻¹, and the emergence of *Ectocarpus*-like germlings was
120 monitored over four months.

121 Both live algae collected *in situ* and those recovered from germling emergence experiments were
122 cleaned by rigorous pipetting with a Pasteur pipette and several transfers to fresh, sterile,
123 medium. Any diatoms that remained attached to the algal filaments were removed via treatment
124 with 3mg·L⁻¹ GeO₂ for 3 weeks.

125 *Water samples*

126 Approximately 100 mL of water were taken from each site, immediately filtered with 0.45
127 µM syringe filters to remove particulate matter, and then pasteurized for 1h at 95-100°C to
128 remove any remaining bacterial activity. Filtered samples were stored at ambient temperature
129 until the end of the sampling campaign (max. 2 weeks) and then frozen at -20° C until analysis.
130 The conductivity of water samples was determined using a Type CD78 conductivity meter
131 (Tacussel Electronique, Villeurbanne, France) and converted to practical salinity units (psu)
132 according to Fofonoff and Millard (1983). Phosphate, nitrite, and nitrate concentrations were
133 determined using an AA3 auto-analyser (SEAL Analytical, Southampton, UK) following the

134 method of Aminot and K  rouel (2007) with an accuracy of $0.02 \mu\text{mol}\cdot\text{L}^{-1}$, $0.01 \mu\text{mol}\cdot\text{L}^{-1}$, and
135 $0.01 \mu\text{mol L}^{-1}$ for NO_3^- , NO_2^- , PO_4^{3-} , respectively. Sulfate concentrations were determined by
136 high-performance anion-exchange chromatography (HPAEC), according to a protocol adapted
137 from Pr  choux *et al.* (2016). After suitable dilution, water samples were injected onto an
138 IonPacTM AS11-HC column (4 x 250 mm) equipped with an AG11-HC guard column (4 x 50
139 mm), using an ICS-5000 Dionex system (SP-5 & Analytical CD Detector, Thermo Fisher
140 Scientific, Waltham, MA, USA). Elution was performed with isocratic 12mM NaOH at a flow
141 rate of $1 \text{ mL}\cdot\text{min}^{-1}$, and sulfate ions were detected in conductimetry mode (ASRS 500, 4 mm) and
142 quantified using a standard calibration curve. To test if variations in sulfate concentration merely
143 mirrored variations in the overall salinity, a Pearson correlation coefficient was calculated
144 between both variables.

145 *Barcoding of algal and bacterial isolates*

146 Algal isolates were identified to a species level using the mitochondrial *cox1* and the nuclear
147 ITS1+2 markers. Algal DNA was extracted from the cleaned cultures using the Macherey Nagel
148 (D  ren, Germany) NucleoSpin Plant II kit according to the manufacturer's instructions (PL1
149 protocol with two 25 μL elutions), and $1 \mu\text{L}$ of DNA (10-30 ng) was used in subsequent PCRs.
150 For the ITS region, we used the AFP4LF (3'-CAATTATTGATCTTGAACGAGG-5') and
151 LSU38R (5'-CGCTTATTGATATGCTTA-3') primers (Lundholm *et al.* 2003; Peters *et al.*
152 2004), and for the 5' *cox1* gene the GAZF2 (3'-CCAACCAYAAAGATATWGGTAC-5') and
153 GAZR2 (3'-GGATGACCAAARAACCAAAA-5') primers (Lane *et al.* 2007), each at a final
154 concentration of $0.5 \mu\text{M}$. PCRs were carried out using a GoTaq polymerase and the following
155 program: 2 min. $95 \text{ }^\circ\text{C}$ followed by 30 cycles [1 min $95 \text{ }^\circ\text{C}$; 30 sec. 50°C for ITS or 55°C for
156 *cox1*; 3 min $72 \text{ }^\circ\text{C}$] and a final extension of 5 min $72 \text{ }^\circ\text{C}$.

157 Bacterial cultures were identified by partial sequencing of their 16S rRNA gene. Fifty μ L of
158 dense bacterial culture were heated to 95°C for 15 min, spun down for 1 min, and 1 μ L of
159 supernatant was used as a template in a PCR reaction with the 8F (5'-
160 AGAGTTTGATCCTGGCTCAG-3') and 1492R 5'-GGTTACCTTGTTACGACTT-3')
161 (Weisburg *et al.* 1991) at a final concentration of 0.5 μ M. Except for the annealing temperature
162 (53°C here), the same PCR protocol as above was employed.

163 All PCR products were purified using ExoStar (Thermo Fisher Scientific) and the purified 16S
164 rRNA gene amplicons were sequenced with Sanger technology at the GENOMER platform
165 (FR2424, Roscoff Biological Station), using the BigDye Xterminator v3.1 cycle sequencing kit
166 (Applied Biosystems, Waltham, MA, USA). For bacterial strains, sequencing was carried out
167 only in one direction using the 8F primer, and for algal sequences both the forward and the
168 reverse strand were sequenced and manually assembled. Sequence identification was carried out
169 using RDP classifier (Wang *et al.* 2007) for bacterial 16S rRNA gene sequences, and BLAST
170 searches against the NCBI nt database (July 2017) for algal sequences. They were further aligned
171 together with reference sequences from the NCBI nt database using the MAFFT server (Kato *et al.*
172 *al.* 2002) and the G-INS-i algorithm. All positions with less than 95% site coverage were
173 eliminated. Phylogenetic analyses were carried out with MEGA 7 (Kumar *et al.* 2016) using the
174 Maximum Likelihood method based on the GTR+G+I model and 1,000 bootstrap replicates.

175 ***Amplicon sequencing of in situ bacterial communities***

176 Amplicon sequencing of bacterial communities was carried out to assess the *in situ* composition
177 of the *E. subulatus* microbiome. Sufficient material for these analyses was obtained at two of the
178 three sites with *Ectocarpus* individuals: sites 8 and 9 (Figure 1). Approximately 20mg dry weight
179 for each of the three replicate samples for each site were ground twice for 45 sec. at 30 Hz in a

180 TissueLyser II (Qiagen, Hilden, Germany). DNA was then extracted using the Qiagen DNeasy
181 Plant mini kit according to the manufacturer's instructions. Approximately 50 ng of DNA (as
182 estimated using a NanodropONE, Thermo Fisher Scientific), were then used to amplify the V3-
183 V4 region of the 16S rRNA gene. Furthermore, a mock community comprising a mix of DNA
184 from 26 bacterial genera cultivated in our laboratory (see Thomas *et al.* 2019 for details) as well
185 as a negative control, were added alongside the samples. PCR amplification, indexing, and
186 library construction were carried out following the standard "16S Metagenomic Sequencing
187 Library Preparation" protocol (Part # 15044223 Rev. B). Final library concentrations were
188 measured using a BioAnalyzer (Agilent, Santa Clara, CA, USA) before pooling. Libraries for
189 each sample were then pooled in an equimolar way, diluted to 5nM final concentration and
190 supplemented with 20%PhiX to add sufficient diversity for sequencing on an Illumina MiSeq
191 using a 2x300bp cartridge. Raw data were deposited at the European Nucleotide Archive (ENA)
192 under project accession number PRJEB34906
193 (<https://www.ebi.ac.uk/ena/data/search?query=PRJEB34906>).

194 Raw reads were first trimmed and filtered using the fastx_quality_trimmer script
195 (http://hannonlab.cshl.edu/fastx_toolkit/), assembled using Pandaseq 2.11 (Masella *et al.* 2012)
196 and further processed with mothur according to the Miseq SOP (version April 4th, 2018; Kozich
197 *et al.* 2013). Sequences were aligned to the non-redundant SSU ref database version 132,
198 chimeric sequences removed using Vsearch (Rognes *et al.* 2016), and operational taxonomic
199 units (OTUs) defined based on a 97% identity threshold (Stackebrandt and Goebel 1994). Rare
200 sequences (<5 reads across all samples) were removed from the final analyses. Taxonomic
201 assignments were generated for both the raw reads and the final OTUs using the RDP classifier
202 method (Wang *et al.* 2007). Non-metric multidimensional scaling (NMDS) of the OTU matrix

203 was carried out in R 3.5.1 using the isoMDS function of the Vegan package and Bray-Curtis
204 dissimilarity as a distance measure. An Analysis of Similarity (ANOSIM) was used to test for
205 differences in the overall community composition between the two sites (3 replicates each, 719
206 permutations). Statistical differences between the two sites at the level of individual OTUs were
207 assessed by multiple two-sided t-tests (one test per OTU) on log-transformed abundance data
208 with subsequent correction for multiple testing according to Benjamini and Hochberg (1995).
209 Alpha diversity was estimated using the Shannon index with e as a base and the diversity()
210 function of the VEGAN package. A two-sided t-test was used to compare these indexes obtained
211 for the replicate samples of both sites. Differences between sites were considered significant if
212 the Type I error rate was below 0.05.

213 **Results**

214 *Distribution of Ectocarpus subulatus along the Hopkins River*

215 We found live *E. subulatus* at three of the 15 sampled sites along the Hopkins River, and
216 germlings of other Ectocarpales emerged from four additional marine sites along the Victorian
217 coastline, including at the mouth of Hopkins River (Table 1). Despite extensive searches, no
218 traces of *Ectocarpus* were found at the original isolation site of *E. subulatus* at Hopkins River
219 Falls (site 7, Figure 1). *Ectocarpus* was, however, abundant at two sites (Framlingham Forest
220 reserve and Kent's Ford, sites 8 and 9, Figure 1), which were approximately 12km and 37 km
221 upstream of Hopkins River Falls. The third finding of *Ectocarpus* was registered 83 km upstream
222 (site 10), although only a few filaments were found at this site. The *cox1* and ITS sequences
223 obtained from *Ectocarpus* cultures from all three sites were identical to those of the strain

224 isolated from Hopkins River Falls in 1995 (Figure 2). We found no *E. subulatus* individuals in
225 other sampled rivers, along the coastline, or in germling emergence experiments.

226 *Water chemistry*

227 The salinity of the Hopkins River was highest close to the source (8.4 psu; approximately $\frac{1}{4}$ that
228 of seawater), and then gradually decreased towards the mouth of the river, where it dropped to ca.
229 1 psu, before re-spiking due to the influence of seawater (Figure 3). This decrease corresponded
230 to an increase in the flow of water masses towards the mouth river. Sulfate concentrations
231 followed the same pattern as salinity (Pearson correlation $r=0.995$, $p<0.001$) and decreased from
232 nearly 7 mM to approximately 0.4 mM close to the river mouth. Finally, phosphate and
233 nitrite/nitrate concentrations were variable along the river. They were highest at the Chatsworth
234 site (site 11), reaching 3.3 and 22.8 μM , respectively, and then strongly decreased at sites where
235 *Ectocarpus* was found (PO_4^{3-} 0.5-0.8 μM , $\text{NO}_2^-/\text{NO}_3^-$ 0.8-1.7 μM ; Figure 3).

236 *Bacterial communities associated with algae*

237 *In situ* bacterial community composition was determined by 16S rRNA gene amplicon
238 sequencing for field samples taken at Framlingham Forest reserve (site 8) and Kent's Ford (site 9)
239 (Figure 4A). We detected 1312 OTUs across the three sampled individuals from both sites
240 (Supporting Information File S1). The bacterial communities of both sites were dominated by
241 *Alphaproteobacteria* (25% of reads), *Bacteroidetes* (20%), *Gammaproteobacteria* (8%),
242 *Planctomycetes* (8%), and *Actinobacteria* (8%) (Figure 4a,b), and there was a significant
243 difference in the community structure between the two sites (ANOSIM $p=0.001$, Figure 4B).
244 Examining the OTUs individually, we identified 86 OTUs that were specific to Framlingham
245 Forest reserve (including 31 *Proteobacteria* and 22 *Planctomycetes*), and 60 more had a higher
246 relative abundance there. At Kent's Ford, 27 OTUs were site-specific (including 13

247 *Proteobacteria* and 6 *Bacteroidetes*), and 13 more exhibited higher relative abundance. In three
248 cases, site-specific OTUs from both sites were found to belong to the same genera: *Rickettsiales*
249 of the SM2D12 group, *Flavobacterium*, and *Luteolibacter*. A detailed list of these OTUs is
250 provided in Supporting Information File S1. Alpha-diversity (Shannon index) was also slightly
251 higher at the Framlingham Forest reserve (t-test $p=0.03$; Figure 4C). Amplicon sequencing
252 analyses of bacterial communities were complemented by *in situ* isolation of bacterial strains
253 from the algae after thorough rinsing with sterile river water (Figure 5). They comprise
254 *Gammaproteobacteria* (48 isolates, including 28 *Pseudomonas*), *Firmicutes* (27 isolates),
255 *Actinobacteria* (8 isolates), *Alphaproteobacteria* (7 isolates), and *Bacteroidetes* (5 isolates). No
256 members of the *Planctomycetes* were isolated.

257 **Discussion**

258 The data presented in this paper confirm that the original finding of *E. subulatus* by West and
259 Kraft was not the result of a transient “contamination”, but that algae with identical ITS
260 sequences are present in the river at three sites upstream of the original location. At the time of
261 sampling, the water at these sites was saline and contained high levels of sulfate for a river, but
262 low levels of nitrite/nitrate and phosphate compared to other upstream and downstream sites.
263 Furthermore, the bacterial community associated with the algae *in situ* comprised over 1300
264 OTUs, which is highly diverse compared to laboratory cultures. It also, it included a high
265 diversity of *Planctomycetes*. Each of these findings, discussed in more detail below, provides
266 valuable background information when using *E. subulatus* cultures as a model system to study
267 acclimation, adaptation, or interactions with their associated microbiome.

268 Based on these observations, it seems likely that *E. subulatus* has persisted in the Hopkins River
269 for over 20 years, maintaining a population despite the water currents. *Ectocarpus* spores and
270 gametes are motile, but swimming speeds reported are only in the range of 150-270 $\mu\text{m}\cdot\text{s}^{-1}$
271 (Müller 1978). This implies that *E. subulatus* in Hopkins River either (1) does not rely on gamete
272 releases for reproduction, (2) that its gametes are able to remain close to the substratum as has
273 been suggested for male gametes (Müller 1978) and direct their movement upstream, or (3) that
274 gametes rely on zoochory, as has been proposed in the case of red algae (Žuljević *et al.* 2016).
275 Our findings thus open interesting perspectives for population genetics studies as well as more
276 detailed studies of the reproductive biology of *Ectocarpus* in this area. Furthermore, the fact that
277 no traces of *E. subulatus* were found in nearby rivers or along the coastline suggests that it may
278 be restricted to the Hopkins River, although the range of colonization within the river may have
279 been subject to variation, notably because individuals of *E. subulatus* were no longer found at the
280 original isolation site.

281 Although limited to a single point in time, our sampling campaign also provides novel
282 information on the chemical parameters in the Hopkins River at the time of sampling. Notably,
283 the observed salinity at sites with *E. subulatus* between 3.1 and 6.9 psu leads us to classify the
284 water in the Hopkins River at the sites with *E. subulatus* at the time of sampling as low salinity
285 brackish water rather than fresh water (usually defined by a salinity <0.5 psu, International
286 Symposium for the Classification of Brackish Waters 1958). This may be one of the factors
287 enabling *E. subulatus* to be competitive in this environment, a hypothesis which is supported by
288 the fact that no individuals were found in the lower portions of the river with lower salinity. High
289 salinity in our samples also positively correlated with high sulfate concentrations between 1 and 5
290 mM - average sulfate concentrations in fresh water are 0.12 mM (vs. 28 on average in the ocean;

291 Wetzel 2001). Sulfated polysaccharides are typical components of the cell walls of marine plants
292 and algae (Popper *et al.* 2011) and require sulfate for their synthesis, but their importance for
293 *Ectocarpus* remains to be explored. In the same vein the question remains open to what extent the
294 low nitrate concentrations at sites with *E. subulatus* compared to upstream and downstream sites,
295 are related to the presence of the algae, either as a cause or as an effect. It should be noted,
296 though, that a direct metabolomic comparison of *E. subulatus* and the marine *E. siliculosus*
297 revealed markers for high nitrogen status (total amino acids, ratio of glutamine to glutamate) in *E.*
298 *subulatus* (Dittami *et al.* 2012). Regardless of the physiological implications of the composition
299 of the Hopkins River water, we argue that it may be more appropriate to refer to the *E. subulatus*
300 strains isolated from the Hopkins River as “fluvatile”, *i.e.* “river” strains rather than freshwater
301 strains, despite their capacity to grow in fresh water in laboratory conditions (Dittami *et al.*
302 2012).

303 In addition to these facts about the distribution and environment of *E. subulatus*, the present
304 study provides insights into its associated microbiome – a component likely connected to the
305 capacity of this species to grow in low salinity (Dittami *et al.* 2016). The number of OTUs
306 associated with *E. subulatus* in our *in vivo* study was one order of magnitude higher than in a
307 previous study of the laboratory strain after 20 years of cultivation (1312 OTUs for six samples
308 from two sites vs 84 OTUs for six samples in two conditions) (Dittami *et al.* 2016). Moreover, a
309 direct taxonomic comparison of these two studies at the genus level revealed only 5 genera
310 (*Acinetobacter*, *Phycisphaera*, *Maribacter*, *Marinoscillum*, and *Gaiella*) that were found in both
311 studies. All of them were rare *i.e.* supported by < 0.01% of reads in our study; Supporting
312 Information File S1). Both studies were based on sequencing runs with similar depth and
313 employed similar analysis pipelines, yet many technical factors could contribute to such

314 differences: the sampling protocol, the primers used, library preparation, the sequencing platform
315 and chemistry (Illumina Miseq V2 vs V3), etc.. Nevertheless, the profoundness of the observed
316 differences suggests that either the microbiome of *E. subulatus* in the Hopkins River has evolved
317 and diversified over time or that the cultivation of algae in the laboratory has impacted its
318 microbiome, leading to a reduction of diversity and a change in composition. In a context of the
319 development of new laboratory models for the study of marine holobionts (Dittami *et al.* 2019,
320 preprint), a targeted examination of these potential changes, *e.g.* by following the evolution of
321 alga-associated microbiomes in the field as well as over several cultivation cycles may yield
322 important insights on possible limitations of laboratory model systems. If confirmed, such biases
323 would underline the necessity of devising targeted experiments to test the validity of laboratory
324 findings in the field.

325 The availability of parallel amplicon sequencing data of bacterial communities and untargeted
326 cultivation efforts further allows us to identify under-sampled lineages in cultivation experiments.
327 In this study particularly *Planctomycetes* stand out, as they constituted 176 OTUs and 8% relative
328 abundance of all algae-associated reads but did not have a single associated culture.

329 *Planctomycetes* are notoriously difficult to cultivate, partially due to their long doubling time of
330 up to one month. They require low organic content in media, physical separation from fast-
331 growing competitors *e.g.* via dilution to extinction experiments, and they may benefit from the
332 use of fungicides (Lage and Bondoso 2012). In contrast to the present study, previous barcoding
333 data (Dittami *et al.* 2016) on cultivated *E. subulatus* revealed the presence of very few
334 *Planctomycetes* (0.1% of reads), implying that these culturing techniques would need to be put
335 into place using freshly collected material. In contrast, the high abundance of *Firmicutes* in the

336 isolation experiments although they account for only 1% of the reads in the amplicon sequencing
337 data may be because these bacteria were particularly amenable to the culture condition.

338 The present study enhances our knowledge on *E. subulatus* from the Hopkins River and its
339 associated microbiome. It furthermore provides a new set of microbes for coculture experiments
340 and thus strengthens the use of *E. subulatus* both as a model for the study of acclimation and
341 adaptation to low salinity and of algal-bacterial interactions.

342 **Acknowledgments**

343 This work was funded partially by ANR project IDEALG (ANR-10-BTBR-04) “Investissements
344 d’Avenir, Biotechnologies-Bioressources”, the European Union’s Horizon 2020 research and
345 innovation Programme under the Marie Skłodowska-Curie grant agreement number 624575
346 (ALFF), and an internal call for proposals from the UMR8227 (CNRS, Sorbonne University). We
347 thank Cécile Hervé, Amandine Simeon, and Agnieszka P. Lipinska for helpful discussions;
348 Gwenn Tanguy and Erwan Legeay from the GENOMER platform, Roscoff for support during the
349 library construction and sequencing; and the ABIMS platform for providing the computational
350 facilities for the amplicon sequencing analyses.

351 **Conflict of interest statement**

352 The authors declare no conflict of interest.

353 **Author’s contributions**

354 SD, AFP, HK, SE, JW, CB planned the study; TC performed nutrient analyses; AP measured
355 sulfate concentrations; BBD performed amplicon sequencing analyses of bacterial communities ;

356 SD performed sampling, culturing, *in silico* analyses, and wrote the manuscript; All authors
357 corrected the manuscript and approved the final draft.

358 **References**

359 **Aminot A, K erouel R. 2007.** Dosage automatique des nutriments dans les eaux marines :
360 m ethodes en flux continu. In: *M ethodes d'analyse en milieu marin*. Ifremer, 1–188.

361 **Benjamini Y, Hochberg Y. 1995.** Controlling the false discovery rate - a practical and powerful
362 approach to multiple testing. *Journal of the Royal Statistical Society Series B - Methodology* **57**:
363 289–300.

364 **Bolton JJ. 1983.** Ecoclinal variation in *Ectocarpus siliculosus* (Phaeophyceae) with respect to
365 temperature growth optima and survival limits. *Marine Biology* **73**: 131–138.

366 **Cock JM, Sterck L, Rouz  P, et al. 2010.** The *Ectocarpus* genome and the independent
367 evolution of multicellularity in brown algae. *Nature* **465**: 617–21.

368 **Dittami SM, Arboleda E, Auguet J-C, et al. 2019.** A community perspective on the concept of
369 marine holobionts: current status, challenges, and future directions. *PeerJ Preprints*: 27519.

370 **Dittami SM, Corre E, Brillet-Gueguen L, et al. 2018.** The genome of *Ectocarpus subulatus*
371 highlights unique mechanisms for stress tolerance in brown algae. *bioRxiv*: 307165.

372 **Dittami SM, Duboscq-Bidot LL, Perennou M, et al. 2016.** Host–microbe interactions as a
373 driver of acclimation to salinity gradients in brown algal cultures. *ISME Journal* **10**: 51–63.

374 **Dittami SM, Gravot A, Goulitquer S, et al. 2012.** Towards deciphering dynamic changes and
375 evolutionary mechanisms involved in the adaptation to low salinities in *Ectocarpus* (brown

376 algae). *Plant Journal* **71**: 366–377.

377 **Dittami SM, Heesch S, Olsen JL, Collén J. 2017.** Transitions between marine and freshwater
378 environments provide new clues about the origins of multicellular plants and algae. *Journal of*
379 *Phycology* **53**: 731–745.

380 **Fofonoff NP, Millard RCJ. 1983.** Algorithms for computation of fundamental properties of
381 seawater. *UNESCO Technical Papers in Marine Science*: 44–53.

382 **Geissler U. 1983.** Die salzbelastete Flusstrecke der Werra - ein Binnenlandstandort für
383 *Ectocarpus confervoides* (Roth) Kjellmann. *Nova Hedwigia* **37**: 193–217.

384 **International Symposium for the Classification of Brackish Waters. 1958.** The Venice
385 system for the classification of marine waters according to salinity. *Limnology and*
386 *Oceanography* **3**: 346–347.

387 **Katoh K, Misawa K, Kuma K, Miyata T. 2002.** MAFFT: a novel method for rapid multiple
388 sequence alignment based on fast Fourier transform. *Nucleic Acids Research* **30**: 3059–66.

389 **KleinJan H, Jeanthon C, Boyen C, Dittami SM. 2017.** Exploring the cultivable *Ectocarpus*
390 microbiome. *Frontiers in Microbiology* **8**: 2456.

391 **Kozich JJ, Westcott SL, Baxter NT, Highlander SK, Schloss PD. 2013.** Development of a
392 dual-index sequencing strategy and curation pipeline for analyzing amplicon sequence data on
393 the miseq illumina sequencing platform. *Appl. Environ. Microbiol.* **79**: 5112–5120.

394 **Kumar S, Stecher G, Tamura K. 2016.** MEGA7: Molecular Evolutionary Genetics Analysis
395 Version 7.0 for Bigger Datasets. *Molecular Biology and Evolution* **33**: 1870–1874.

396 **Lage OM, Bondoso J. 2012.** Bringing *Planctomyces* into pure culture. *Frontiers in*
397 *Microbiology* **3**: 405.

398 **Lane CE, Lindstrom SC, Saunders GW. 2007.** A molecular assessment of northeast Pacific
399 *Alaria* species (Laminariales, Phaeophyceae) with reference to the utility of DNA barcoding.
400 *Molecular Phylogenetics and Evolution* **44**: 634–648.

401 **Lundholm N, Moestrup Ø, Hasle GR, Hoef-Emden K. 2003.** A study of the *Pseudo-nitzschia*
402 *pseudodelicatissima/cuspidata* complex (Bacillariophyceae): what is *P. pseudodelicatissima*?
403 *Journal of Phycology* **39**: 797–813.

404 **Masella AP, Bartram AK, Truszkowski JM, Brown DG, Neufeld JD. 2012.** PANDAseq:
405 paired-end assembler for illumina sequences. *BMC Bioinformatics* **13**: 31.

406 **Müller DG. 1978.** Locomotive Responses of male gametes to the species specific sex attractant
407 in *Ectocarpus siliculosus* (Phaeophyta). *Archiv fur Protistenkunde* **120**: 371–377.

408 **Peters AF, Coucerio L, Tsiamis K, Küpper FC, Valero M. 2015.** Barcoding of cryptic stages
409 of marine brown algae isolated from incubated substratum reveals high diversity. *Cryptogamie,*
410 *Algologie* **36**: 3–29.

411 **Peters AF, Scornet D, Müller DG, Kloareg B, Cock JM. 2004.** Inheritance of organelles in
412 artificial hybrids of the isogamous multicellular chromist alga *Ectocarpus siliculosus*
413 (Phaeophyceae). *European Journal of Phycology* **39**: 235–242.

414 **Popper ZA, Michel G, Hervé C, et al. 2011.** Evolution and diversity of plant cell walls: from
415 algae to flowering plants. *Annual Review of Plant Biology* **62**: 567–90.

416 **Préchoux A, Genicot S, Rogniaux H, Helbert W. 2016.** Enzyme-assisted preparation of

417 furcellaran-like κ -/ β -carrageenan. *Marine Biotechnology* **18**: 133–143.

418 **Rognes T, Flouri T, Nichols B, Quince C, Mahé F. 2016.** VSEARCH: a versatile open source
419 tool for metagenomics. *PeerJ* **4**: e2584.

420 **Stackebrandt E, Goebel BM. 1994.** Taxonomic note: A place for DNA-DNA reassociation and
421 16S rRNA sequence analysis in the present species definition in bacteriology. *International*
422 *Journal of Systematic and Evolutionary Microbiology* **44**: 846–849.

423 **Starr RC, Zeikus JA. 1993.** UTEX - the culture collection of algae at the University of Texas at
424 Austin: 1993 list of cultures. *Journal of Phycology* **29**: 1–106.

425 **Tapia JE, González B, Goulitquer S, Potin P, Correa JA. 2016.** Microbiota influences
426 morphology and reproduction of the brown alga *Ectocarpus* sp. *Frontiers in Microbiology* **7**:
427 197.

428 **Thomas F, Dittami SM, Brunet M, et al. 2019.** Evaluation of a new primer combination to
429 minimize plastid contamination in 16S rDNA metabarcoding analyses of alga-associated
430 bacterial communities. *Environmental Microbiology Reports* **in press**: 1758-2229.12806.

431 **Torode TA, Marcus SE, Jam M, et al. 2015.** Monoclonal antibodies directed to fucoidan
432 preparations from brown algae. *PloS One* **10**: e0118366.

433 **Wang Q, Garrity GM, Tiedje JM, Cole JR. 2007.** Naive Bayesian classifier for rapid
434 assignment of rRNA sequences into the new bacterial taxonomy. *Applied and Environmental*
435 *Microbiology* **73**: 5261–7.

436 **Weisburg WG, Barns SM, Pelletier DA, Lane DJ. 1991.** 16S ribosomal DNA amplification for
437 phylogenetic study. *Journal of Bacteriology* **173**: 697–703.

- 438 **West J, Kraft G. 1996.** *Ectocarpus siliculosus* (Dillwyn) Lyngb. from Hopkins River Falls,
439 Victoria - the first record of a freshwater brown alga in Australia. *Muelleria* **9**: 29–33.
- 440 **Wetzel RG. 2001.** *Limnology: lake and river ecosystems, third edition*. San Diego, CA:
441 Academic Press.
- 442 **Zobell CE. 1941.** Studies on marine bacteria. I. Cultural requirements of marine heterotrophic
443 aerobes. *Journal of Marine Research* **4**: 42–75.
- 444 **Žuljević A, Kaleb S, Peña V, et al. 2016.** First freshwater coralline alga and the role of local
445 features in a major biome transition. *Scientific Reports* **6**: 19642.

446

447

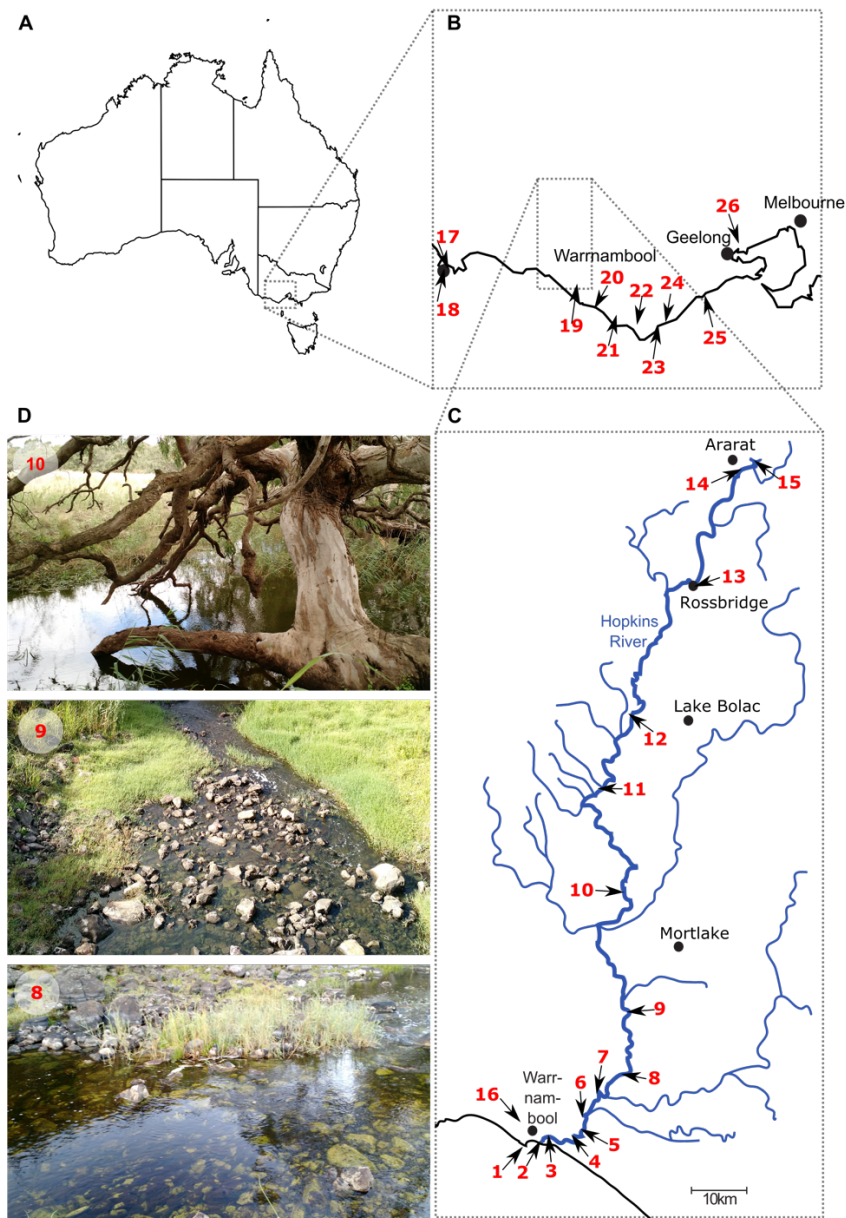
448

449 **Tables**

450 **Table 1:** Overview of samples taken and species identified. The numbers in the location column
 451 correspond to site numbers in Figure 1.

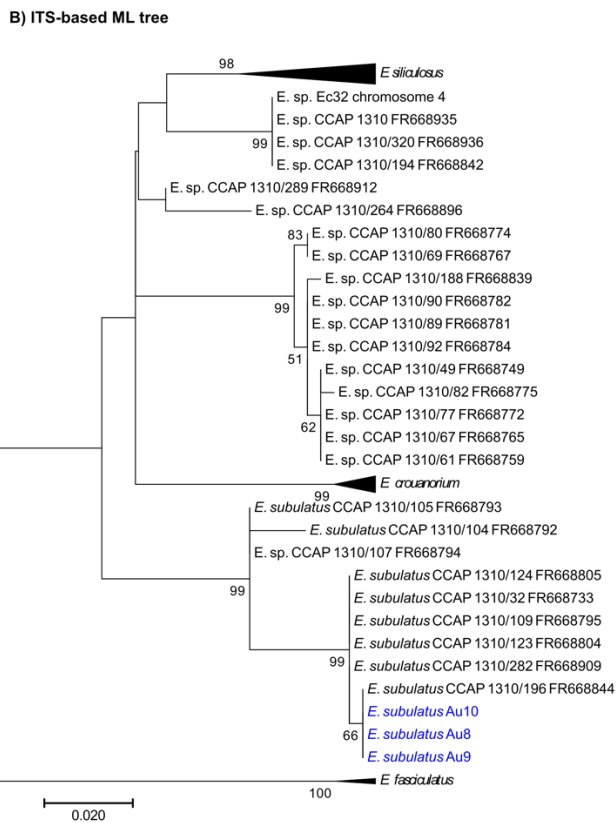
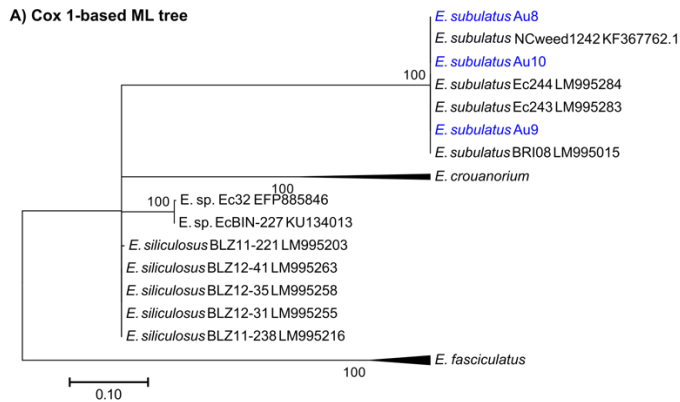
Date	Location	Material sampled	<i>Ectocarpus</i> tissue found	GPS coordinates	Germling emergence	Sequence accession(s)
2017-03-22	1. Merri Island	pebbles/mussels in tide pool	no	-38.402116, 142.471548	-	-
2017-03-22	2. Point Ritchie	sand/ sandstone	no	-38.401275, 142.509318	<i>Ectocarpus siliculosus</i>	LR735221 (<i>cox1</i>) LR735414 (ITS)
2017-03-22	3. Mahoney Road	sand, wood/plastic	no	-38.392103, 142.531644	-	-
2017-03-22	4. Smith Lane	mud, wood	no	-38.397984, 142.578286	-	-
2017-03-22	5. Allan's Ford	rock (granite)	no	-38.385325, 142.587398	-	-
2017-03-22	6. Donovans Lodge	granit, clay	no	-38.355110, 142.599250	-	-
2017-03-22	7. Hopkins River Falls	volcanic rock	no	-38.333509, 142.621352	-	-
2017-03-23	8. Framlingham Forest Reserve	rock, pebbles	<i>E. subulatus</i> Au8 (abundant)	-38.297064, 142.668291	-	LR735222 (<i>cox1</i>) LR735415 (ITS)
2017-03-23	9. Kent's Ford	rock, pebbles	<i>E. subulatus</i> Au9 (abundant)	-38.191574, 142.698058	-	LR735223 (<i>cox1</i>) LR735416 (ITS)
2017-03-23	10. Hexham	mud, wood	<i>E. subulatus</i> Au10 (rare)	-37.995732, 142.689141	-	LR735224 (<i>cox1</i>) LR735417 (ITS)
2017-03-23	11. Chatsworth	mud, sand, detritus	no	-37.856357, 142.650644	-	-
2017-03-23	12. Wickliffe	sand, detritus	no	-37.694348, 142.726074	-	-
2017-03-24	13. Rossbridge	rock, pebbles	no	-37.480217, 142.849465	-	-
2017-03-23	14. Ararat	sand	no	-37.300211, 142.973979	-	-
2017-03-24	15. Green Hill Lake	pebbles	no	-37.295320, 142.979170	-	-
2017-03-24	16. Merri River, Warnambool	concrete	no	-38.362077, 142.484414	-	-
2017-03-24	17. Killarney beach	sand, lava pebbles, shells	no	-38.357966, 142.306880	<i>Kuckuckia</i> sp.	LR735225 (<i>cox1</i>) LR735418 (ITS)
2017-03-25	18. Belfast Lough airport	sand, wood pollar	no	-38.361889, 142.262045	-	-
2017-03-25	19. Curdies River	rock	no	-38.519965, 142.833558	-	-
2017-03-25	20. Port Campbell	tide pool. sand	no	-38.620681, 142.992981	<i>Feldmannia</i> sp.	LR735226 (<i>cox1</i>)
2017-03-25	21. Gellibrand River	mud, detritus	no	-38.727482, 143.250932	-	-
2017-03-25	22. Aire River	mud, pebbles	no	-38.763797, 143.474727	-	-
2017-03-25	23. Wild Dog Creek	sand	no	-38.735911, 143.683545	-	-
2017-03-25	24. Smythe's Creek	pebbles, biofilm	no	-38.704648, 143.762856	-	-
2017-03-26	25. Lorne	tide pool, sand shells	no	-38.531281, 143.980994	<i>Acinetospora</i> sp.	LR735227 (<i>cox1</i>)
2017-03-26	26. Hovell's Creek	clay	no	-38.018825, 144.402156	-	-

452 **Figure legends**



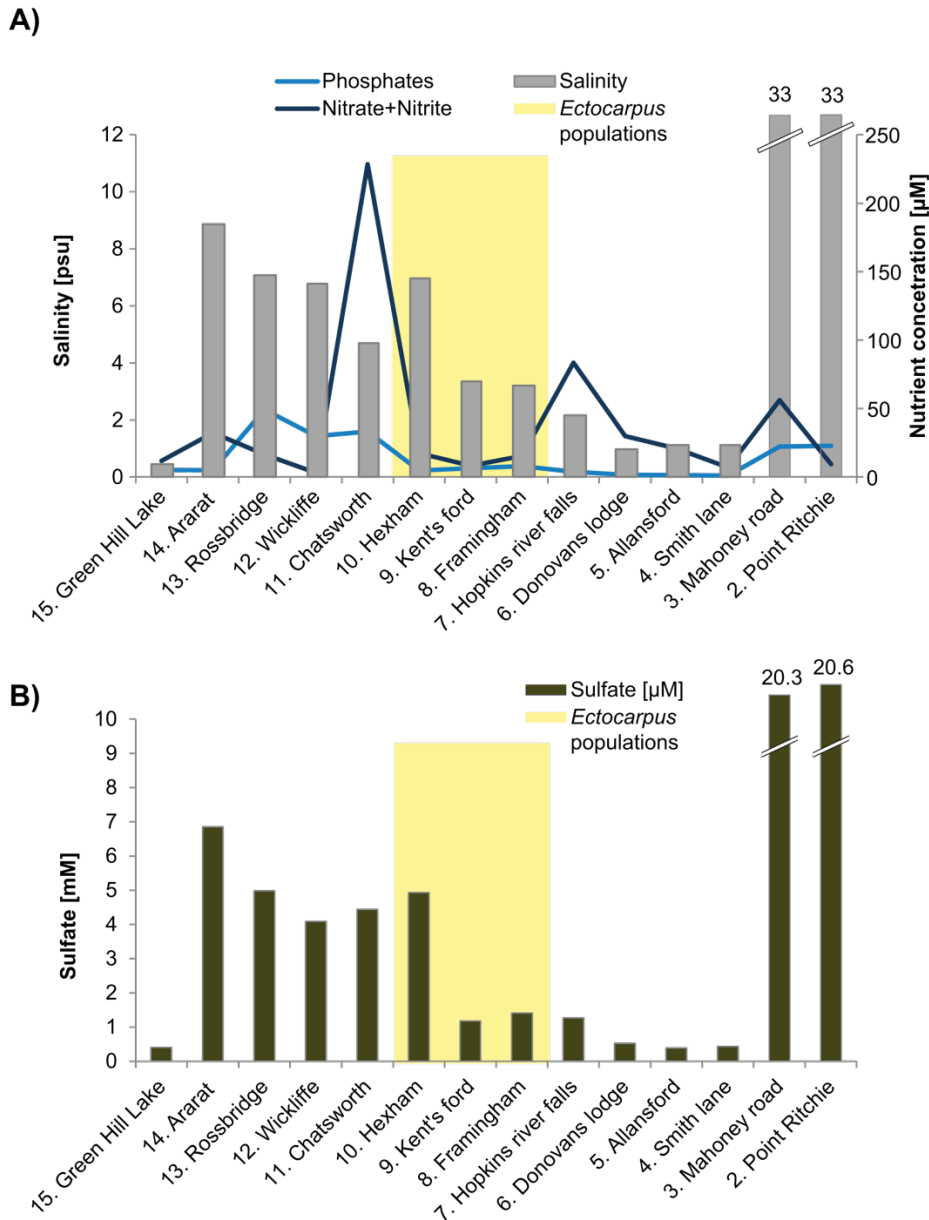
453

454 **Figure 1: Sites sampled.** Panels A-C: Map of sampling sites at an increasing scale. Each
455 sampling site is numbered (1-26, see Table 1). *Ectocarpus* individuals were found at (sites 8, 9,
456 10), and Panel D contains photos taken at these sites. Hopkins River Falls, the original site of
457 isolation, corresponds to site 7.



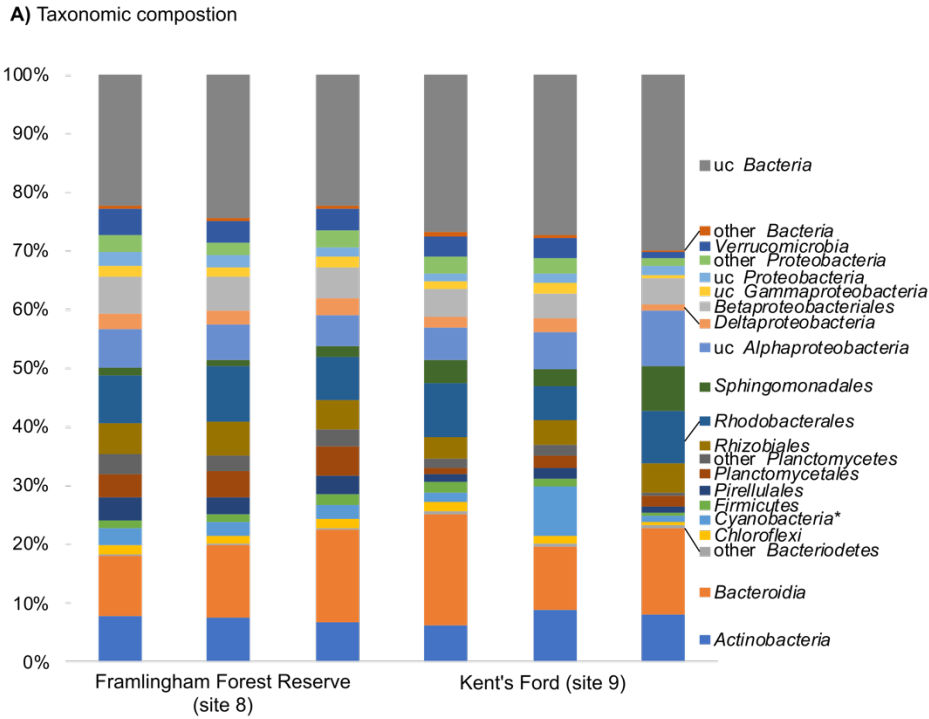
458

459 **Figure 2: Maximum-likelihood tree of *Ectocarpus* isolates from Hopkins River and related**
 460 **strains.** Panel A displays a tree based on the *COX1* gene (alignment of 677 bp after curation),
 461 and Panel B on the ITS region (860bp after curation). Blue color indicates isolates from this
 462 study. Support values correspond to the percentage of support using 1000 bootstrap replicates.

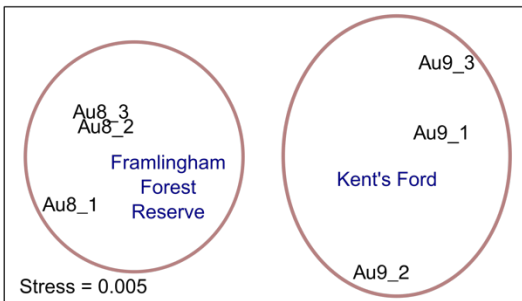


463

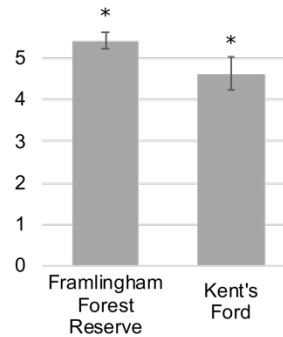
464 **Figure 3: Water chemistry at the different sampling sites along the Hopkins River** (see
 465 Figure 1). Panel A displays salinity (gray bars) and nutrient concentrations (blue lines), and Panel
 466 B shows sulfate concentrations. Yellow background indicates sites with the occurrence of
 467 *Ectocarpus*. Each measurement corresponds to a single sample collected between 2017-03-22
 468 and 2017-03-24.



C) NMDS plot

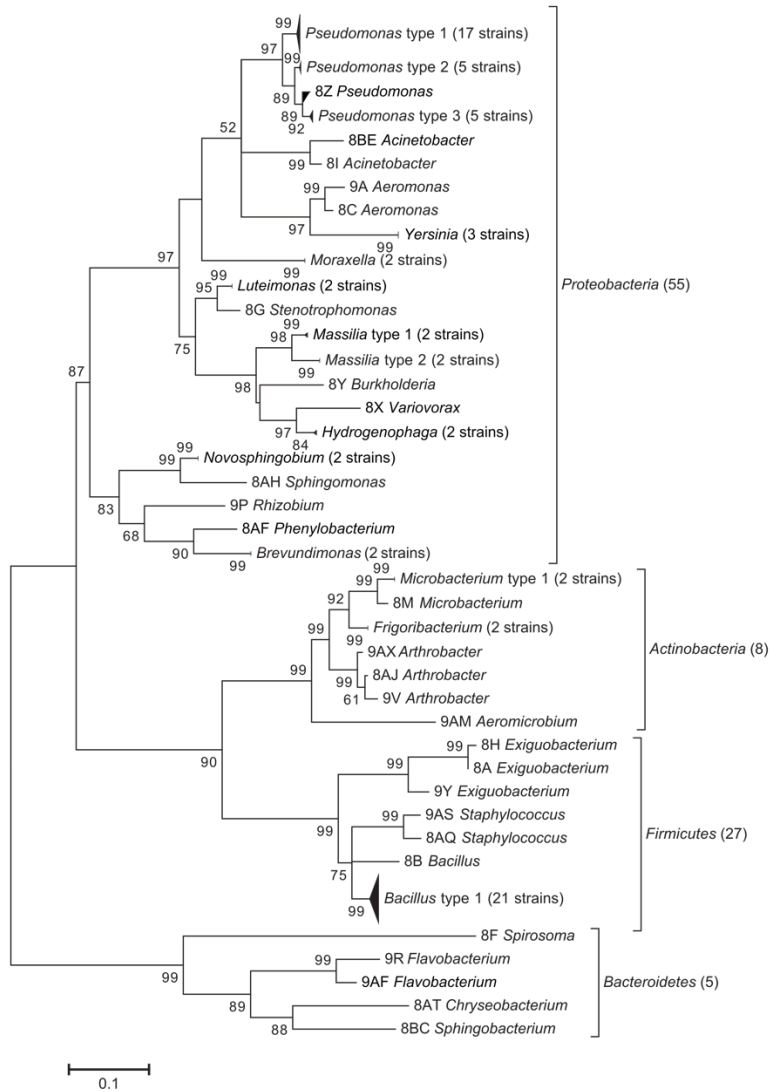


D) Alpha diversity (Shannon index)



469

470 **Figure 4: Bacterial community at isolation sites determined by 16S rDNA amplicon**
 471 **sequencing of bacterial communities.** Panel A shows the taxonomic distribution of the bacterial
 472 communities associated with each replicate at the two sampling sites with sufficient material, uc
 473 = unclassified. Panel B shows the distances between the communities (NMDS plot based on
 474 Bray-Curtis dissimilarity matrix); communities at both sites differed significantly (ANOSIM
 475 $p=0.001$). Panel C shows the alpha-diversity of bacterial communities in the two sites (mean of
 476 three replicates \pm SD; * indicates a significant difference, two-sided t-test, $p=0.03$).



477

478 **Figure 5: Maximum-likelihood tree of bacterial isolates obtained from *E. subulatus* in situ.**

479 The tree is based on an alignment of 16 rRNA gene sequences of all isolated strains and

480 comprised 598 bases after cleaning. Support values correspond to the percentage of support using

481 1000 bootstrap replicates. Sequence accession numbers are ENA:LR735444-LR735537.

482

483 **Supporting Information**

484 **Supporting Information File S1 – Amplicon sequencing results of bacterial communities.**

485

486