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The Diversity of Eucheumatoid Seaweed Cultivars in the Philippines

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3 **1 Eucheumatoid seaweed cultivar diversity in the Philippines**
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Word count: 3597

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2
3 54 **Abstract**
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5 55 Collectively known as eucheumatoids, *Eucheuma denticulatum*, *Kappaphycus*
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8 56 *alvarezii*, *K. malesianus* and *K. striatus* are the main farmed seaweed species in the
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10 57 Philippines. The success of seaweed farming for over five decades in the country is
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13 58 due, in part, to the high diversity of cultivars maintained by the Filipino farmers.
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15 59 Notwithstanding the fact that many eucheumatoid cultivars are presently (and
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18 60 consistently) recognised by the Filipino farmers, there has been no attempt to
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20 61 summarise the current state of the farmer's knowledge about their diversity.
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23 62 Hence, a review is presented of the taxonomy, diversity, distribution and
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25 63 conservation strategies of eucheumatoid cultivars based on farmers' knowledge
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27 64 and genetic identification in the Philippines. The diverse cultivars identified in this
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29
30 65 study suggest that the Filipino farmers possess important traditional knowledge
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32 66 that can be useful for future crop selection and breeding.
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39 69 **Keywords:** carrageenophytes, distribution, ethnobotany, seaweed farming,
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42 70 taxonomy, traditional knowledge
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78 **Introduction**

79 Whilst seaweed use dates to the Neolithic (Dillehay et al. 2008), it is only in the
80 last five decades that its domestication has been commercially exploited,
81 particularly in the tropics (Doty 1973; Doty and Alvarez 1973; Parker 1974).
82 Seaweeds currently comprise a significant portion of the world's aquaculture
83 production, with over 32 million tonnes of fresh weight harvested in 2018 (FAO
84 2020; Chopin and Tacon 2021). Evolving pressures brought by diseases and pests
85 and growing environmental challenges (changing climate, pollution, coastal use
86 conflicts, etc.) bring into question the foundation of today's farming systems (Naylor
87 et al. 2021; Ward et al. 2020, 2021). Sustainable and high yield production has,
88 however, become a critical factor in the successful development of this global
89 industry.

90
91 The term 'phyconomy' was coined by Hurtado et al. (2019) to describe a unified
92 concept of extensive and sustainable seaweed farming for livelihood purposes.
93 Coupled with economic benefits are the legacies that phyconomy has rendered to
94 human histories, especially on redefining demographics of coastal settlements
95 (Nimmo 1986; Nor et al. 2017; Hussin and Khoso 2021) and promoting women's
96 roles in the industry (Periyasamy et al. 2014; Valderrama et al. 2013; Msuya and
97 Hurtado 2017; Larson et al. 2021). Today, seaweed farming is not only seen as a
98 food crop enterprise, but also as a multi-use system with significant potential for
99 carbon sequestration to mitigate ocean acidification, (Duarte et al. 2017; Froehlich et
100 al. 2019; Xiao et al. 2021), aid in eutrophic environment restoration (Zhang et al.

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3 101 2019; Roleda and Hurd 2019) and provide an eco-engineering solution for problems
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5 102 on urban shorelines (Heery et al. 2020).
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10 104 Species belonging to the rhodophyte genera *Kappaphycus* and *Eucheuma*,
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12 105 collectively known as eucheumatoids, were initially cultivated in the Philippines to
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14 106 support an industry suffering from the commercial decline in the amount and quality
15
16 107 of carrageenan-producing crops (viz. *Chondrus crispus*) from the wild (Blanchetti-
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18 108 Revelli 1995; Kraft 1997). Carrageenan is a food ingredient composed of sulfated
19
20 109 hydrocolloid molecules that are added to other foods as gelling, thickening and
21
22 110 stabilising agents, and are proven safe for human use (McKim et al. 2019).
23
24 111 Carrageenan is also recently seen as an effective encapsulating agent (helps
25
26 112 improve drug release) used for viral infection treatments (Derby et al. 2018; Jang et
27
28 113 al. 2021). Selection of fast-growing clones from wild stocks by pioneering Filipino
29
30 114 farmers (Doty and Alvarez 1975) and the successful establishment of farms in the
31
32 115 1970s led to the rapid expansion of seaweed farming in the Philippines (Trono and
33
34 116 Largo 2019, see also Figure 1). There are currently 58 coastal provinces engaged in
35
36 117 seaweed farming in the country (Figure 1). Local and seasonal changes in
37
38 118 environmental conditions and farming problems can influence crop production and
39
40 119 as a result, a number of local farming customs have been developed including
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42 120 selection of cultivars (i.e. after exchange of cultivars between the Filipino farmers),
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44 121 cropping calendars (i.e. selecting growing season and harvesting time to maximise
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46 122 production), type of planting and drying methods (Quiaoit et al. 2016; Hurtado et al.
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48 123 2019).
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3 125 The selected eucaumatoid cultivars typically exhibit traits that favour high biomass
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5 126 production and qualities, such as carrageenan yield and gel strength (Trono et al.
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8 127 2000; Phang et al. 2010; Parenrengi et al. 2020). These traits are either pre-existing
9
10 128 (from their evolutionary history) or have arisen during the domestication process
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13 129 through breeding and artificial selection (Valero et al. 2017). It has been suggested
14
15 130 that a classification system based on the farmers' knowledge can serve as a
16
17 131 starting point for assessing the diversity of crop cultivars, such as observed in
18
19 132 maize (Hopkins 2006), potato (De Haan et al. 2007), rice (Wang et al. 2016; Loko
20
21 et al. 2021) and yam (Asfaw et al. 2021). For eucaumatoid cultivars, improving
22
23 133 knowledge on genetic and phenotypic diversity could help identify suitable
24
25 134 candidates for strain amelioration and increase their resilience to disease and pest
26
27 135 outbreaks (Valero et al. 2017; Ward et al. 2020, 2021; Hinaloc and Roleda 2021).
28
29 136 This diversity, in combination with knowledge on farming practices can also be
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31 137 used as a valuable reference in national planning initiatives in providing effective
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33 138 policy frameworks to sustainably develop the industry (Cottier-Cook et al. 2016;
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35 139 Brakel et al. 2021).
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44 142 The seaweed cultivars initially identified for commercial exploitation in the Philippines
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46 143 (Doty 1973; Doty and Alvarez 1973; Parker 1974) have now been distributed
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48 144 worldwide (Zuccarello et al. 2006; Neish et al. 2017; Kelly et al. 2020). Over five
49
50 145 decades of seaweed farming, Filipino farmers have accumulated extensive
51
52 146 knowledge on farming practices and cultivar selection (Mateo et al. 2021; Suyo et
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54 147 al. 2021). Despite this long history of seaweed farming, the diversity and
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56 148 distribution of seaweed cultivars in the country have not been thoroughly
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3 149 reviewed. We aim to present the first detailed assessment of the taxonomy,
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5 150 diversity, distribution of eucheumatoid cultivars based on farmers' knowledge, as
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8 151 well as their genetic differentiation and conservation strategies in the Philippines.
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11 153 ***Literature review***

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15 154 A systematic review was conducted of peer-reviewed journal articles, local books
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17 155 and unpublished lists that mention local names of eucheumatoid cultivars identified
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20 156 by the Filipino farmers. We determined which species these cultivars belonged to
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22 157 by either consulting the farmers directly or, if previously reported, by assessing the
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25 158 original reporting sources. We determined which species were recognized by each
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27 159 of the sourced authors, local names that were used by other authors to refer to a
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30 160 similar cultivar name, cultivar name etymologies and their distribution in the
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32 161 Philippines. Translation and interpretation of the meanings of the local names were
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34 162 provided by the farmers and expert native speakers. The reported *cox2-3*
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37 163 intergenic spacer barcodes of eucheumatoids from the Philippines were also
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39 164 gathered from existing literature.
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42 166 ***Nomenclatural note***

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46 167 The terms *cultivar*, *strain* and *variety* are commonly used interchangeably in
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48 168 differentiating morphological diversities among algae, particularly in seaweed
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51 169 crops. The term *strain* may either refer to a wild or cultivated eucheumatoid. The
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54 170 name of a strain can be derived from a name based on farmer's knowledge or a
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56 171 name based on investigator's desired assignment (of a replicate) generally used for
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58 172 experimental studies (see Hayashi et al. 2007; Mendoza et al. 2002; Ali et al.
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3 173 2017). In this review, only the term *cultivar* will refer to the seaweed crops grown
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6 174 and named by the farmers in accord with the definition of the International Code
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8 175 of Nomenclature for Cultivated Plants (Brickell et al. 2016). Likewise, as specified
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10 176 in the International Code of Nomenclature for Algae, Fungi, and Plants (Turland et
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13 177 al. 2018), the use of the term *variety* in this study will pertain to a variation below
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15 178 species level effected by a valid taxonomic description.
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180 ***Taxonomy of seaweed cultivars in the Philippines***

181 Eucheumatoid seaweeds (tribe Eucheumatoideae, family Solieriaceae, order
182 Gigartinales, division Rhodophyta) represent the majority of farmed species in the
183 Philippines (Doty 1988). The tribe Eucheumatoideae originally contain three genera:
184 *Eucheuma*, *Kappaphycus* and *Betaphycus* (Doty 1988, 1995). Recent phylogenomic
185 reconstruction based on 21 mitochondrial genomes suggests that the three genera
186 form a clade (Li et al. 2018). Recent molecular phylogenetic analyses inferred within
187 the Eucheumatoideae has now led to the addition of three genera, *Tacanoosca*
188 (Norris 2014), *Eucheumatopsis* (Nuñez-Resendiz et al. 2019) and *Mimica* (Santiañez
189 and Wynne 2020), each segregated from *Eucheuma sensu lato*.

190

191 Although radiation within the tribe has been hypothesised to have occurred in the
192 ancient Tethys Ocean prior to continental shifts some 100 MYA (Fredericq et al.
193 1999), the highest eucheumatoid diversity is currently reported in the Indo-Pacific
194 (Doty 1988; Hurtado et al. 2016). Members of the eucheumatoids are found growing
195 in a variety of habitats from shallow reefs to depths of over 45 m (Doty 1973). As a
196 consequence of intentional transplantations that have taken place for farming uses,

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3 197 eucheumatoids are also now established in many non-indigenous regions
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6 198 characterised by warm waters (Kelly et al. 2020; Brakel et al. 2021).
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8 199
9
10 200 *Eucheuma denticulatum*, *Kappaphycus alvarezii*, *K. malesianus* and *K. striatus*
11
12 201 (Figure 2-3) are among the most farmed eucheumatoids in the Philippines.
13
14 202 Morphologically they are characterised by a set of several overlapping characters
15
16 203 (Doty 1988; Tan et al. 2014; Hurtado et al. 2016) that make definitive identification
17
18 204 difficult at times. Progress on their phylogeny and taxonomy has been enhanced by
19
20 205 the use of molecular data (Zuccarello et al. 2006; Dumilag et al. 2016a; Lim et al.
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22 206 2017). Despite the considerable morphological diversity that domesticated
23
24 207 eucheumatoids display, there are only four taxonomic varieties recognised. These
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26 208 include *Eucheuma denticulatum* var. *endong* (Ganzon-Fortes et al. 2012),
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28 209 *Kappaphycus alvarezii* var. *alvarezii*, *Kappaphycus alvarezii* var. *tambalangii* and
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30 210 *Kappaphycus alvarezii* var. *ajakii-assii* (Liao 1996). Except for *K. alvarezii* var.
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32 211 *alvarezii* (type locality is in Malaysia) the Philippines is the type locality of all these
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34 212 varieties (Doty 1985).
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214 ***Commercial nomenclature in eucheumatoids***

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46 215 Far predating the advent of their domestication, the use of seaweeds as food in the
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48 216 Philippines has a history dating back to pre-colonial occupation of the islands
49
50 217 (Velasquez 1977). The earliest Philippine record of seaweed as a trade commodity
51
52 218 began in the seventeenth century when *Agal-agal*, a local name for
53
54 219 eucheumatoids, was recorded as a major food product in the early Sulu enterprises
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56 220 and as an exchange commodity for imports from China (Saleeby 1908; Fry 1970).
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3 221 *Agal-agal* has since remained a highly sought after product, with deep cultural
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6 222 value among communities in the southern Philippine Sulu Archipelago (Dumilag
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8 223 2019).
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13 225 Stable nomenclature for products is necessary for communication and record
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15 226 keeping regarding biological resources and their acceptance for trading purposes.
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17 227 The standard use of names is also fundamental to various scientific applications.
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20 228 Seen as such is the possible mixing of carrageenan extracts from two (or more)
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22 229 eucheumatoid species belonging to different genera, which may lead to ineffective
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24 230 process of extraction, hence, lowering quality of the final product (see Ganzon-
25
26 231 Fortes et al. 2012). Since the 1980s, taxonomists have been aware of the significant
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28 232 confusion that exists in relation to the correct scientific epithets for commercially
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30 233 important seaweeds (Bolton 2020), including of eucheumatoids (Table 1). The
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32 234 situation is compounded, as some investigators continue to publish their work using
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34 235 outdated nomenclature, e.g. the use of "*Eucheuma cottonii*" (see Surya et al. 2021,
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36 236 Teo et al. 2021), "*Eucheuma spinosum*" (see Bouanati et al. 2020, Gurav et al.
37
38 237 2021) and even a non-existent taxonomic combination, "*Kappaphycus spinosum*"
39
40 238 (see Adharini et al. 2019). This highlights the importance of proactive assessment
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42 239 and intervention by journal editors and expert reviewers, particularly in applied
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44 240 sciences where reports of invalid species names are prevalent (c.f. Roleda et al.
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46 241 2021b; Roleda and Heesch 2021) and are most often left uncorrected, except in
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48 242 rare occasion (e.g. Roleda et al. 2021c).
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245 **Diversity of eucheumatoid cultivars based on farmer's knowledge**

246 Sixty-five eucheumatoid cultivars are identified and named in the Philippines,
247 largely based on morphology as seen by Filipino farmers (Table 2). Based on our
248 analysis, 27 cultivars are identified as *K. alvarezii*, 15 as *K. striatus*, six as *E.*
249 *denticulatum* and three as *K. malesianus*. However, an additional 14 cultivar names
250 require further investigation to determine what species they belong to. The
251 majority (83%) of cultivar names are identified as a single scientific species whilst
252 others are attributed to more than one species. For example, the cultivar *Aring-*
253 *Aring* is represented by all three farmed *Kappaphycus* species while the cultivars
254 *Cottonii* (or *Katunay*) and *Sacol* may be attributed to *K. alvarezii* or *K. striatus*.
255 Even the *Spinsum*, the most common cultivar name for *E. denticulatum*, can be
256 referred to as a cultivar of *K. alvarezii* (Table 2).

257
258 Local cultivars are structurally named, using either a unitary (single word) or binary
259 (two words) format. Unitary names predominate, constituting 61 of the 65 cultivars
260 identified by farmers. Of these, 82.54% are derived from local dialects, whilst the
261 others are adapted from English. Some unitary names are formed through full
262 lexical reduplication (i.e. repeating names such as *Milyon-Milyon*, *Kab-Kab*, *Butay-*
263 *Butay*), a familiar word formation process among Philippine dialects (Blake 1917;
264 Rubino 2005; Mattes 2014). With the exception of the cultivars *Ara Mina* and *Kuku*
265 *Belleh*, the others have binary names adapted from English (e.g. *Nile Green*,
266 *Sweet Loving* and *Seven Colours*).

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3 268 The translation of names reveals that most cultivar names match certain aspects of
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5 269 the seaweed. The name derivation is based on several attributes or objects, such
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8 270 as the description of the branching pattern (e.g. *Endong*, *Kab-Kab*, and *Repolyo*),
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10 271 colour (e.g. *Nile Green*, *Pula-Pula* [red], and *Seven Colours*), source locality (e.g.
11
12 272 *Digos*, *Sacol*, and *Zamboanga*) and the person who discovered them (e.g. *Aring-*
13
14 273 *Aring* and *Tambalang*). Only a few names indicate no clear reference as to the
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16 274 characteristic or history of the origin of the cultivar. For example, some cultivars
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18 275 are named from popular personalities (e.g. *Ara Mina* and *Marimar*), or random
19
20 276 brand names (e.g. *Duralex*, *Bitsi-Bitsi* from Mitsubishi, and *Vanguard*). Two
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22 277 cultivars have unknown etymologies (i.e. *Sweet Loving* and *Way-Way*).
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30 279 Eighteen cultivars have variant names (Table 2). The cultivar *Tambalang* (Figure
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32 280 3C) has the greatest number of variants with 14 name combinations. Colour is the
33
34 281 most common trait attributed to a variant name. Brown, green, red are the
35
36 282 dominant colours of seaweed cultivars in the Philippines (Figure 4). *Kappaphycus*
37
38 283 *striatus* exhibit the most variability in this respect. The *K. striatus* cultivar named
39
40 284 *Seven Colours* (only recorded in Tawi-Tawi, southern Philippines to date, see
41
42 285 Figure 3B) however, cannot be categorised as one discrete colour, since the thallus
43
44 286 is multi-coloured ranging from yellow, to green to brown. Several individuals of the
45
46 287 *E. denticulatum* cultivar *Spinosum* (Figure 2A) exhibit a bi-coloured (brown and
47
48 288 red) thalli. This colour pattern is observed in specimens sampled from varying
49
50 289 environments, indicating that it may have a genetic basis, as previously shown in
51
52 290 *Gracilaria* species (e.g. van der Meer 1979; Plastino et al. 1999; Marchi and
53
54 291 *Plastino* 2020). Accordingly, the green and brown colour variants of *K. alvarezii*
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3 292 cultivar *Burikat* and *K. striatus* cultivar *Kab-Kab* (Figure 3C) are each represented
4
5 293 by differing *cox2-3* haplotypes (Dumilag et al. 2016, see Table 2). Other variant
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8 294 identification features are based on a combination of other cultivar names (e.g.
9
10 295 *Tambalang Giant*, *Tambalang Sacol*, *Sacol Vanguard*) or size differences (e.g.
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12 296 *Tambalang diki* means small and *Tambalang heya* means big).

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16 17 18 298 ***Seaweed cultivar distribution in the Philippines***

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20 299 The eucaematoid species and the corresponding distribution of cultivars in the
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22 300 Philippines are appeared to be random (Figure 5, Table 2). Twenty-six of the
23
24 301 named cultivars are recorded in multiple areas throughout the country. Thirty-nine
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26 302 cultivars are exclusive to a single area, particularly in Regions IX and XIII, and
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28 303 BARMM. A highest number of cultivars are recognised within the larger farming
29
30 304 areas, including Tawi-Tawi (BARMM, n=30), Zamboanga City and Zamboanga del
31
32 305 Sur (Region IX, n=17 and n=12 respectively), and Palawan (Region IV-B, n=11).
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34 306 *Spinsum* (Figure 2A) is the most widely distributed cultivar of *E. denticulatum*,
35
36 307 whereas, the *Cottonii*, *Tambalang* (Figure 2C) and *Giant* (Figure 2F) is accounted
37
38 308 for the three most common *K. alvarezii* cultivars whilst *Sacol* (Figure 3A) and
39
40 309 *Vanguard* are the most common for *K. striatus*. *Kappaphycus malesianus* has the
41
42 310 most restricted distribution, only being reported in Tawi-Tawi with three locally
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44 311 recognized cultivars, *Aring-Aring* (Figure 3D), *Halaw* (Figure 3E), *Kuku Belleh'*
45
46 312 (Figure 3F). Nearly all cultivars that have yet to be identified by scientific names
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48 313 are only known from their respective areas, mostly from southern Mindanao.
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3 315 The wide distribution of farmed *K. alvarezii* and *K. striatus* in the Philippines is due
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5 316 to the higher demand for their extracts (i.e. kappa-carrageenan as compared with
6
7 317 the iota type) and its reputation for greater environmental adaptability (Glenn and
8
9 318 Doty 1992; Bindu and Levine 2011). The widespread use of cultivar names, e.g.
10
11 319 *Spinsum*, *Tambalang* and *Cottonii*, is most likely related to the free exchange of
12
13 320 seedstocks across the country (see Quiaoit et al. 2016). Reciprocal transfers of
14
15 321 cultivars follow traditional practice of solidarity, as they occur between relatives,
16
17 322 friends, or neighbours usually within similar ethnic groups (R. Dumilag, personal
18
19 323 observation). Seedstocks are also exchanged after loss of crops (e.g. by typhoons
20
21 324 or diseases and pests), during farm expansion, or when testing other cultivars for
22
23 325 better yields. Government interventions also play an important role in the supply of
24
25 326 seedstocks among farmers in the Philippines (Suyo et al. 2020). Farmers receive
26
27 327 seaweed cultivars from the government agencies such the Department of Science
28
29 328 and Technology (DOST), Bureau of Fisheries and Aquatic Resources (BFAR),
30
31 329 Department of Trade and Industry (DTI) and the respective local government units
32
33 330 (Quiaoit et al. 2016). It is also possible that the same cultivar names have been
34
35 331 given to distinct farmed genotypes in different areas and that information based on
36
37 332 farmer knowledge underestimate morphological and genetic diversity at the
38
39 333 national or regional level (as in case study in yam by Asfaw et al. 2021).
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335 ***Genetic diversity of Philippine seaweed cultivars***

336 Information on genetic diversity among Philippine seaweed cultivars is still
337 incomplete, with only 25 cultivars sequenced for mitochondrial markers. The most
338 recent analysis based on the *cox2-3* spacer revealed that Philippine cultivars include

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3 339 seven haplotypes (Roleda et al. 2021a). A survey of mitochondrial *cox2-3* spacer
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5 340 sequences revealed between one to three farmed haplotypes per species: *E.*
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8 341 *denticulatum* (haplotype 13), *K. alvarezii* (haplotypes 3, KALV-1 and KALV-2), *K.*
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10 342 *malesianus* (haplotype MY216), and *K. striatus* (haplotypes 89 and 117). There is no
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13 343 clear correspondence between mitochondrial haplotypes, morphology and cultivar
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15 344 names. Notwithstanding this apparently high genetic similarity and lack of
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18 345 concordance between haplotypes and phenotypes, the morphological features of the
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20 346 different cultivars still allow their differentiation. The differences also appear to be
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23 347 fairly stable in different environmental conditions, which explains how farmers are
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25 348 able to recognise each cultivars in the field. This observable phenotypic diversity
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27 349 raises the possibility that more informative genetic markers would be able to
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30 350 genetically differentiate between these cultivars (see Thien et al. 2020; Risjani and
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32 351 Abidin 2020). As can also be applied for eucaumatoid cultivars, high throughput
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34 352 sequencing and single nucleotide polymorphisms (SNPs) have been helpful in
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37 353 exploring the neutral and functional genetic diversity among crops: allowing
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40 354 detection of misclassified cultivars, examining reduction of genetic diversity and
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42 355 accumulation of deleterious alleles during selection steps (O'Connor et al. 2019;
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44 356 Diaz-Garcia et al. 2020).

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49 358 One of the most common impacts of intensive cultivation is the severe reduction of
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51 359 genetic diversity in crops due to recurrent bottlenecks. The narrowing of the
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54 360 genetic basis begins with selection of a few strains of interest from wild
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56 361 environments and is intensified during the development of elite cultivars through
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59 362 intensive breeding programs. The propagation based on asexual reproduction can
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3 363 dramatically affect crop genetic diversity (McKey et al. 2010; Meyer et al. 2012;
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5 364 Smýkal et al. 2018). In potatoes and yam for example, farming based on asexual
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8 365 reproduction has led to a severe reduction of genetic diversity and an accumulation
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10 366 of deleterious alleles (Ramu et al. 2017; Pandey et al. 2021). Albeit the history of
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12 367 domestication is more recent in seaweeds, typical hallmarks of impact of extensive
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14 368 use of vegetative propagation in farms, are very low levels of clonal variation, life
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16 369 cycle disruption and reduction of fertility as has been detected in the red alga
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18 370 *Agarophyton chilense* (Guillemin et al. 2008; Usandizaga et al. 2021). The problem
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20 371 could be especially acute in eucheumatoid farms where cultivation from vegetative
21
22 372 thalli has led to the wide use of mitochondrially similar haplotypes around the
23
24 373 world (Zuccarello et al. 2006). These farmed haplotypes have spread to adjacent
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26 374 areas both in the Philippines and in regions where these cultivars have been
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28 375 introduced (Halling et al. 2013; Tano et al. 2015; Dumilag et al. 2016b).
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32 377 High genetic and phenotypic diversity is expected in areas of crop origin (e.g.
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34 378 Hardigan et al. 2017). In the Philippines, a number of natural populations of
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36 379 eucheumatoids are located near the farms and gene flows probably occurs
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38 380 between domesticated and their wild populations (R. V. Dumilag, personal
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40 381 observation). Such condition can help delay the genetic diversity loss during
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42 382 domestication allowing introduction of new alleles at each generation even in
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44 383 highly asexually cultivated crops (Elias et al. 2001). Exchange of cultivars among
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46 384 Filipino farmers could also help to maintain potentially high population sizes, or
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48 385 genetic variants in multiple populations, but only through vegetative propagation.
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50 386 Introgression of new alleles in eucheumatoid crops due to natural crosses with
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3 387 individuals from nearby natural populations or distinct cultivars introduced from
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5 388 other regions may generate new genotypic combinations and potentially superior
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8 389 cultivars without the burden of performing costly breeding effort (Pautasso et al.
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10 390 2012; Labeyrie et al. 2016). The continuous discovery of new eucheumatoid
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12 391 haplotypes demonstrates that high genetic diversity available in both farms and
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14 392 natural populations is still uncovered in the Philippines (Dumilag et al. 2016a,
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16 393 2016b, 2018; Roleda et al. 2021). It is therefore imperative to further explore this
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18 394 untapped diversity and to create seedbanks from sites without cultivation activity.
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20 395 These strategies could mitigate the decline of genetic diversity and can provide
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22 396 access to extensive genes variants better adapted to unprecedented challenges of
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24 397 today's seaweed farming system. The high number of cultivars in the Philippines
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26 398 makes the region one of the best sites for the discovery of new cultivars that can
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28 399 be preserved and their economic potential explored in future crop selection and
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30 400 breeding programmes.
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402 **The way forward**

403 The extent to which the role of cultivar diversity can potentially contribute to
404 advancing seaweed aquaculture is still largely under researched. Given the need to
405 maintain cultivar diversity as a means of promoting resilience of seaweed crops to
406 disease and pests and the increasing use of carrageenan, particularly in emerging
407 products such as the medical (Pereira and Critchley 2020; Morokutti-Kurz et al.
408 2021) and bioplastics industry (Schmidtchen et al. 2021). New cultivars will likely
409 play a more important role in the future. Future studies on cultivar diversity would
410 benefit from greater integration of ethnophycology (the study of the relationship

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3 411 between seaweeds and people; see Brodie, 2010) on farming, as explicit
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6 412 consideration of how farmers perceive cultivar-level variability and integration of
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8 413 farmer knowledge and their acceptance are essential to produce and utilize new
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10 414 cultivars.

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32 423 characterization, selection and production of high quality eucaumatoid cultivars in
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34 424 the Bangsamoro Autonomous Region in Muslim Mindanao, Field Testing of
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3 997 **List of Table and Figures:**
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6 998

7
8 999 **Table 1.** Commercial names of farmed seaweed species in the Philippines.
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13 1001 **Table 2.** A list of seaweed cultivars identified and named by Filipino farmers,
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15 1002 including their etymology, *cox2-3* haplotype assignment and distribution.
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20 1004 **Figure 1.** Distribution of seaweed farms in the Philippines. The number of provinces
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22 1005 in the Philippines engaging in seaweed farming has increased since its inception in
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24 1006 the late 1960s (inset).
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30 1008 **Figure 2.** Philippine *E. denticulatum* and *K. alvarezii* cultivars. *E. denticulatum*
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32 1009 cultivars *Spinosum* (A) from Cebu and *Milyon-Milyon* (B) from Batangas. *K. alvarezii*
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34 1010 cultivars *Tambalang* (C) and *Marimar* (D) from Tawi-Tawi, *Digos* (E) and *Giant* (F)
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36 1011 from Surigao del Sur. Scale bars: A: 5 cm, B: 3 cm, C: 5 cm, D: 3 cm, E: 3 cm, F: 12
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38 1012 cm.
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44 1014 **Figure 3.** Philippine *K. striatus* and *K. malesianus* cultivars. *K. striatus* cultivars
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46 1015 *Sacol* (A) from Batangas, *Seven Colours* (B) from Tawi-Tawi, *Kab-Kab* (C) from
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48 1016 Zamboanga City. *K. malesianus* cultivars *Aring-Aring* (D), *Halaw* (E) and *Kuku Belleh'*
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50 1017 (F) from Tawi-Tawi. Scale bars: A: 3 cm, B: 3 cm, C: 5 cm, D: 3 cm, E: 3 cm, F: 6
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52 1018 cm.
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3 1020 **Figure 4.** Percent frequency of seaweed cultivars corresponding to their thallus
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5 1021 colour.
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10 1023 **Figure 5.** Distribution of seaweed cultivars in the Philippines. Pie chart represents
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13 1024 eucaumatoid species grown by farmers per province grouped by political region in
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15 1025 the Philippines. Numbers indicate provinces shown in Figure 1.
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Table 1

Extracted carrageenan	Commercial name	Taxonomic name		Commonly confused species name
		Currently accepted species	Common Synonym	
beta-carrageenan	serra	<i>Betaphycus gelatinus</i>	<i>Eucheuma gelatinae</i>	<i>Eucheuma serra</i> ¹
			<i>Betaphycus gelatinum</i>	<i>Eucheuma perplexum</i> ¹
			<i>Betaphycus philippinensis</i>	
iota-carrageenan	spinosum	<i>Eucheuma denticulatum</i>	<i>Eucheuma spinosum</i>	<i>Eucheuma serra</i>
kappa-carrageenan	cottonii	<i>Kappaphycus alvarezii</i>	<i>Eucheuma alvarezii</i>	<i>Kappaphycus cottonii</i> ²
		<i>Kappaphycus malesianus</i>		(as <i>Eucheuma cottonii</i>)
		<i>Kappaphycus striatus</i>	<i>Eucheuma striatum</i>	

Non-domesticated eucheumatoid species producing ¹iota- or ²kappa-carrageenan.

Table 2.

Local Name (variant)	Etymology (dialect)	cox23 haplotype	Philippine distribution
<i>E. denticulatum</i>			
Endong, Spaghetti (br, gr)	worm-like (Sama)		17 ^a , 27 ^b , 58 ^b
Korea	as the country		37 ^c
Spinosum (br, gr)	spinous morphology	13 ^d	5 ^b , 6 ^b , 10 ^b , 12 ^b , 17 ^b , 18 ^b , 19 ^b , 21 ^b , 22 ^b , 24 ^b , 25 ^b , 27^d , 28 ^b , 32 ^b , 33 ^b , 36 ^b , 37 ^b , 42 ^b , 45 ^b , 46 ^b , 51 ^b , 54 ^b , 57 ^b , 58 ^b
Milyon-Milyon	presence of numerous branches (Tagalog, derived from the English word million)		6 ^b , 11 ^b , 12 ^b , 19 ^b , 22 ^b , 27 ^b , 37 ^b
Nile green	refers to its colour		45 ^b , 48 ^b , 47 ^b
Zamboanga	the province of its origin, Zamboanga		54 ^b
<i>K. alvarezii</i>			
Adik-Adik /Adis-Adis (br, gr, rd)	refers to a junkie, a drug addict (Bisayan pop culture)		35 ^b , 37 ^{b,e,f} , 45 ^b , 46 ^b
Aring-Aring (br, gr)	after Mr. Joe Aring, the owner of large seaweed farms in Umapoy Is., Sibutu, Tawi-Tawi	3 ^g	17 ^g , 58 ^c
Barako	boar, related to a local coffee from Batangas, origin may be from this area (Tagalog)	3 ^h	22 ^{b,h}
Bermuda	refers to its colour, Bermuda green	3 ^h	42 ^b , 53 ^b , 54 ^{b,h}
Burikat (br, gr)	to open one's legs wide (Bisaya)	KALV-1 (br) ^h KALV-2 (gr) ^h	35 ^b , 54 ^h
Cottonii, Katunay (br, gr)	named after Arthur Disbrowe Cotton, an English botanist who supplied Anna Antoinette Weber van Bosse the specimens used to describe <i>Kappaphycus cottonii</i> – katunay is an onomatopoeic form of Cottonii	3 ^d	4 ^b , 5 ^b , 7 ^b , 13 ^b , 18 ^b , 17 ^b , 19 ^b , 22 ^b , 25 ^b , 27^{b,d} , 28 ^b , 31 ^b , 34 ^b , 35 ^b , 36 ^b , 37 ^b , 42 ^b , 44 ^b , 45 ^b , 53 ^b , 54 ^b , 57 ^b , 58 ^c
Digos (br, gr)	its area of origin, Digos City, Davao del Sur	3 ^h	54 ^h
Giant (kapilaran, original)	pertains to its large size	3 ^h KALV-1 ^h	12 ^b , 25^f , 28 ^b , 31 ^b , 32 ^b , 33 ^b , 34 ^b , 35 ^b , 36 ^b , 37 ^{b,f} , 53 ^b , 54^{b,h} , 58 ^{b,h}
Gulaman	anything jelly (Tagalog)		18 ^b , 30 ^b , 31 ^b

1	Jackpot, Swerte	Lucky (English, Spanish)		58 ^b
2	Kab-Kab, Pay-Pay	fan-like (Tausug)	3 ^d	35 ^b , 37 ^d , 58 ^b
3	Kinangkong, Natural, Plastic	water spinach-like, vegetable-like (Tagalog)		13 ^b , 14 ^b
4	Kinse-Kinse	refers to fifteen days before harvest (Spanish 'quince')		11 ^b , 12 ^b , 58 ^c
5	Kulot	curly (Tagalog)		37 ^b , 58 ^c
6	Lakway	from 'lakaw' means to walk (Bisaya)		43 ^b , 44 ^b , 54 ^b
7	Marimar	a famous 1990s Mexican soap opera released in the Philippines under the same title	3 ^h	58 ^h
8	Milo-Milo, Milo	a popular brand of cocoa drink, referring to its branch colour	3 ⁱ	35 ^b , 37 ⁱ , 58 ^b
9	Patig	from 'fatigue', a khaki-olive green military suit		58 ^c
10	Pula-Pula	red (Tagalog, Bisaya)		58 ^c
11	Putan	from the same name of a Sama local sticky rice cake. Its brown colour matches that of the cultivar's branches (Tausug)		58 ^c
12	Tambalang (abu [gy], adik, batu [rock], br, diki [small], giant, heya [big], milo, monten [mountain], pu, lapsi, rd, sacol, tunay [shortened from Katunay])	derived from the owner of the farm, Mr. Tambalang Bin Panggian from Sitangkai	3 ^d	6 ^b , 7 ^b , 12 ^b , 14 ^b , 16 ^b , 18 ^b , 22 ^b , 25 ^h , 35 ^b , 37 ^h , 40 ^b , 42 ^b , 43 ^b , 44 ^b , 45 ^b , 46 ^b , 47 ^b , 48 ^b , 57 ^b , 58 ^{b,c,d}
13	Tungawan	a municipality in Zamboanga Sibugay		22 ^j
14	Spinusum (br, gr)	spinous morphology	3 ^h	54 ^h
15	Sweet Loving	unknown etymology		58 ^b
16	Sacol (rd, vanguard)	an island in Zamboanga City	3 ^d	12 ^c , 37 ^d
17	Vanguard	from the brand name of the machine, Vanguard, bought by a seaweed farmer after his good harvest.	3 ^d	37 ^d
18	Way-Way	unknown entity		39 ^b , 41 ^b , 36 ^b ,
19	<i>K. malesianus</i>			
20	Aring-Aring	from Mr. Joe Aring, the owner of large seaweed farms in Umapoy Is., Sibutu, Tawi-Tawi		58 ^b
21	Halaw	illegal Filipino deportees to borders of Malaysia (Tausug/Sama)	MY216 ^h	58 ^h
22	Kuku Belleh'	eagle's talon (Sama)	MY216 ^h	58 ^h

<i>K. striatus</i>			
Aring-Aring (br, gr)	from Mr. Joe Aring, the owner of large seaweed farms in Umapoy Is., Sibutu, Tawi-Tawi	89 ^g	17 ^g
Bitsi-Bitsi, Bitsi (gr)	from the corrupted name of a boat engine brand, Mitsubishi	89 ^h	58 ^h
Bola-Bola	ball-like (Tagalog)		25 ^b , 28 ^b
Bukoy-Bukoy	a name of a child, presumably from Palawan		12 ^{b,c}
Cottonii, Katunay (bl, br, gr, rd, sacol)	named after Arthur Disbrowe Cotton, an English botanist who supplied Anna Antoinette Weber van Bosse the specimens used to describe <i>Kappaphycus cottonii</i>	89 ^d	17 ^b , 22 ^b , 27 ^{b,d} , 57 ^b , 58 ^{b,d}
Duyan-Duyan (br, gr, rd)	hammock-like (Tagalog)		48 ^b , 57 ^b , 58 ^b
Emo (br, gr)	presumably a name of a farmer who first used it from Zamboanga, Mr. Emo	89 ^h	37 ^h
Jackpot, Swerte	lucky (English, Spanish)	89 ^h	58 ^h
Jayan-Jayan	giant-like, an onomatopoeic form of 'giant' from English		58 ^c
Kab-Kab, Paypay (br, gr)	fan-like (Tausug/Sama, Tagalog, Bisaya)	89 (gr) ^h , 117 (br) ^h	35 ^b , 58 ^{b,d,h}
Payaka, Yaka	squatting posture or form (Bisaya)		25 ^b , 32 ^b , 53 ^b
Sacol, Cauliflower, Flower, Repolyo (br, gr, or)	the area of its origin, Sacol Is., Zamboanga, cabbage-like (Tagalog)	89 ^{d,h}	6 ^{b,h} , 12 ^b , 17 ^b , 19 ^b , 21 ^b , 22 ^{b,h} , 25 ^b , 28 ^b , 35 ^b , 37 ^{b,d,h,f} , 53 ^b , 57 ^b
Seven Colours	pertains to the seven colours of its branches		58 ^{b,c}
Subul/Subol-Subol (br, gr, rd)	a young male (Tausug)		58 ^c
Vanguard, Banggard	derived from the name of a boat engine brand; Banggard is a spelling variant of Vanguard	89 ^h	5 ^b , 11 ^b , 12 ^b , 18 ^b , 25 ^b , 27 ^b , 28 ^b , 34 ^b , 35 ^b , 39 ^b , 41 ^b , 53 ^b , 58 ^{b,h}
Unknown species			
Ara Mina	screen name of Hazel Pascual Reyes, a popular Philippine actress		36 ^b , 37 ^b
Bulawan	golden (Tausug, Bisaya)		12 ^b
Butay-Butay	like a coconut leaf midrib (Cebuano)		27 ^b
Dayang-Dayang	a princess (Tausug/Sama)		25 ^b
Dugong	<i>Dugong dugon</i> , the sirenian		43 ^b , 44 ^b

1	Duralex	a popular brand name of dishware	35 ^b
2	Durian	from <i>Durio zibethinus</i> , the strongly aromatic fruit in SE Asia	58 ^{b,c}
3			
4	Marlin	a fish belonging to family Istiophoridae	37 ^k
5	Original	originally sourced from Antique province only	19 ^b
6	Polotan	any food eaten without rice (Tagalog)	35 ^b
7	Sakot	ingredient (Bisaya)	19 ^b
8	Sparkle	pertaining to its green colour	58 ^c
9	Sprite	a popular soft drink brand, inspired by the similar green colour of its bottle	12 ^b
10	Tangtang-utang	literally dropping of debt (Bisaya)	37 ^c
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bold numbers indicate site of collection of DNA barcoded specimen/s

bl: black, br: brown, gr: green, gy: grey, or: orange, pu: purple, rd: red

^aGanzon-Fortes et al. 2012

^bQuiaoit et al. 2016

^cThis study

^dLim et al. 2014

^eHurtado and Biter 2007

^fHurtado et al. 2009

^gDumilag and Lluisma 2016

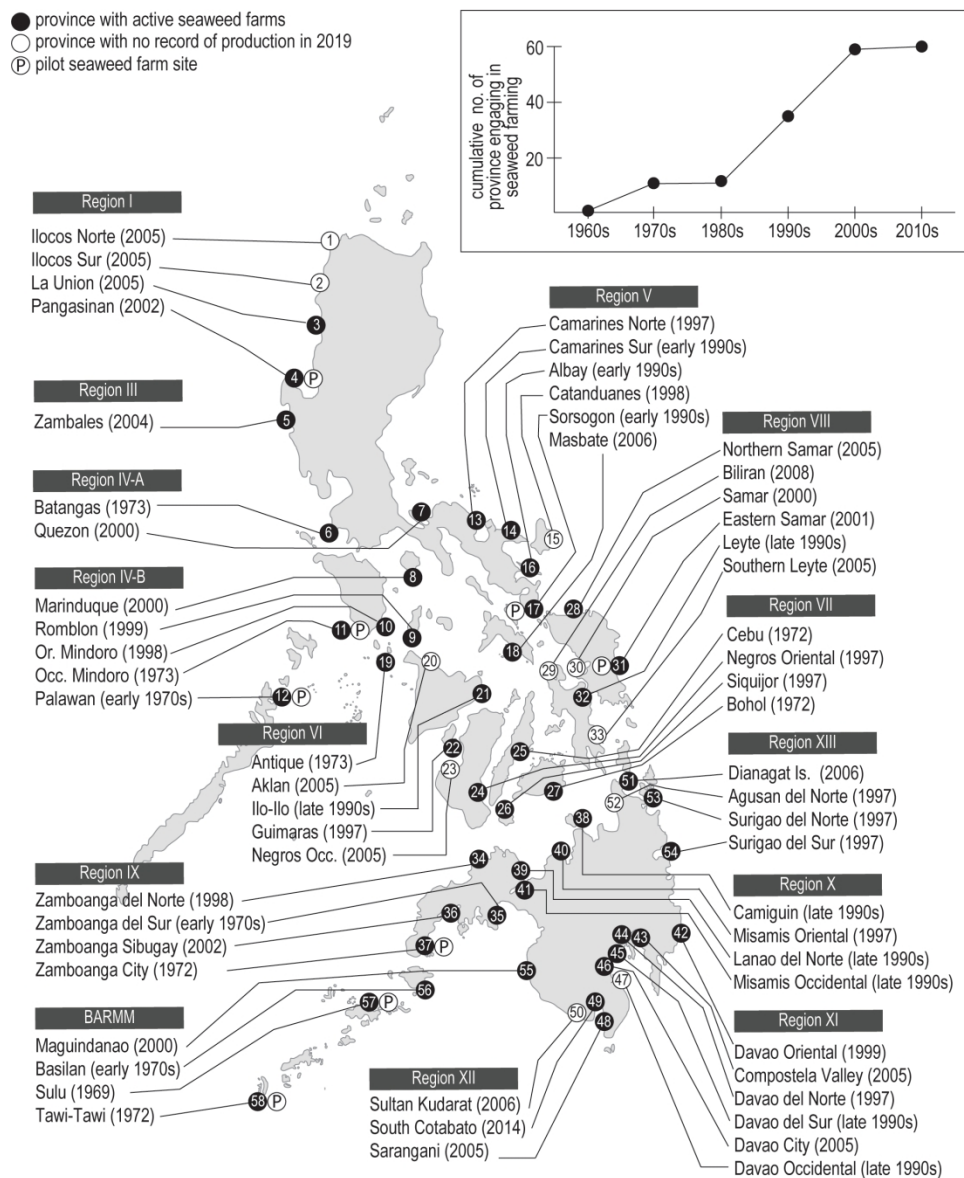
^hDumilag et al. 2016

ⁱTan et al. 2012

^kBorlongan et al. 2011

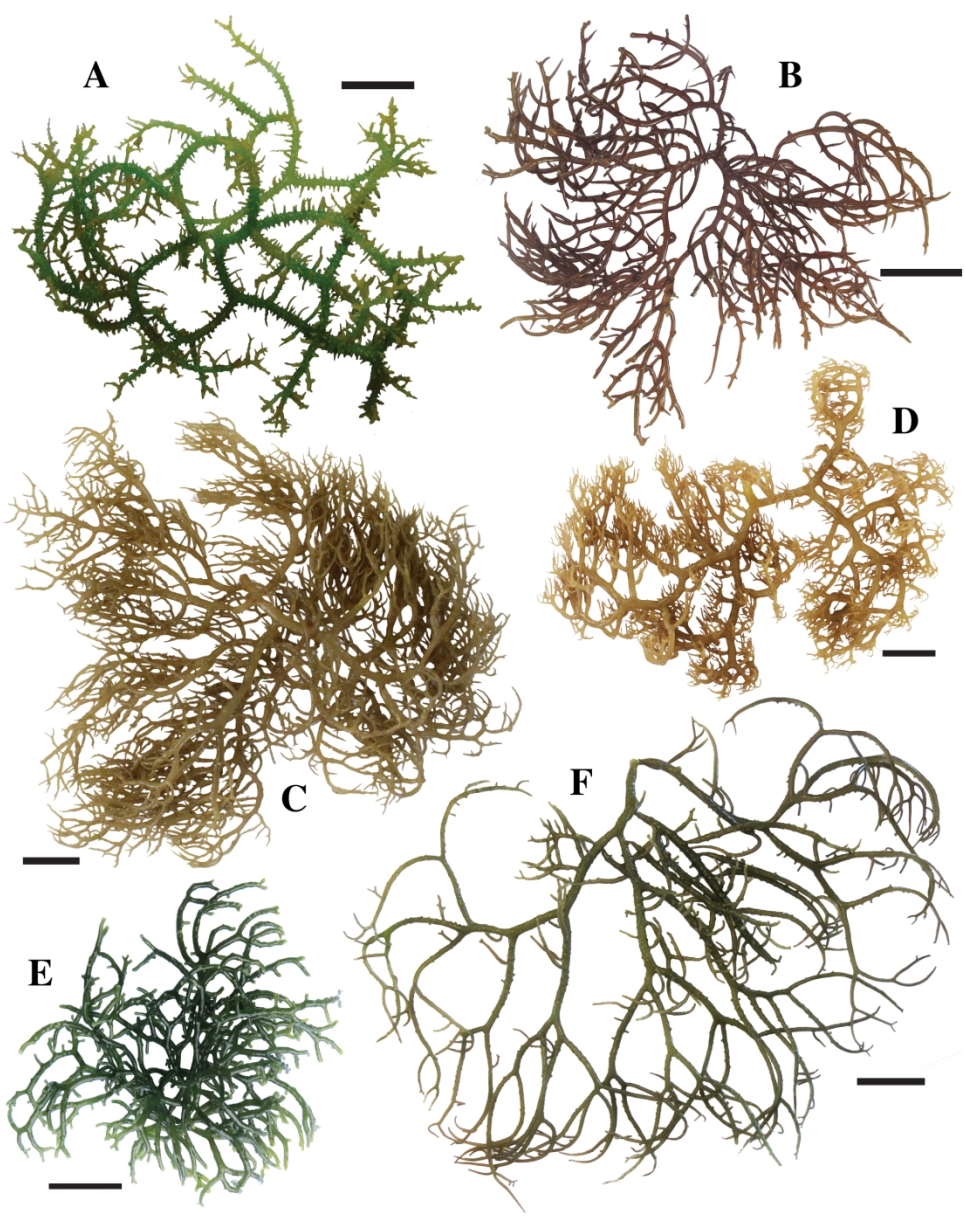
^kSuyo et al. 2020

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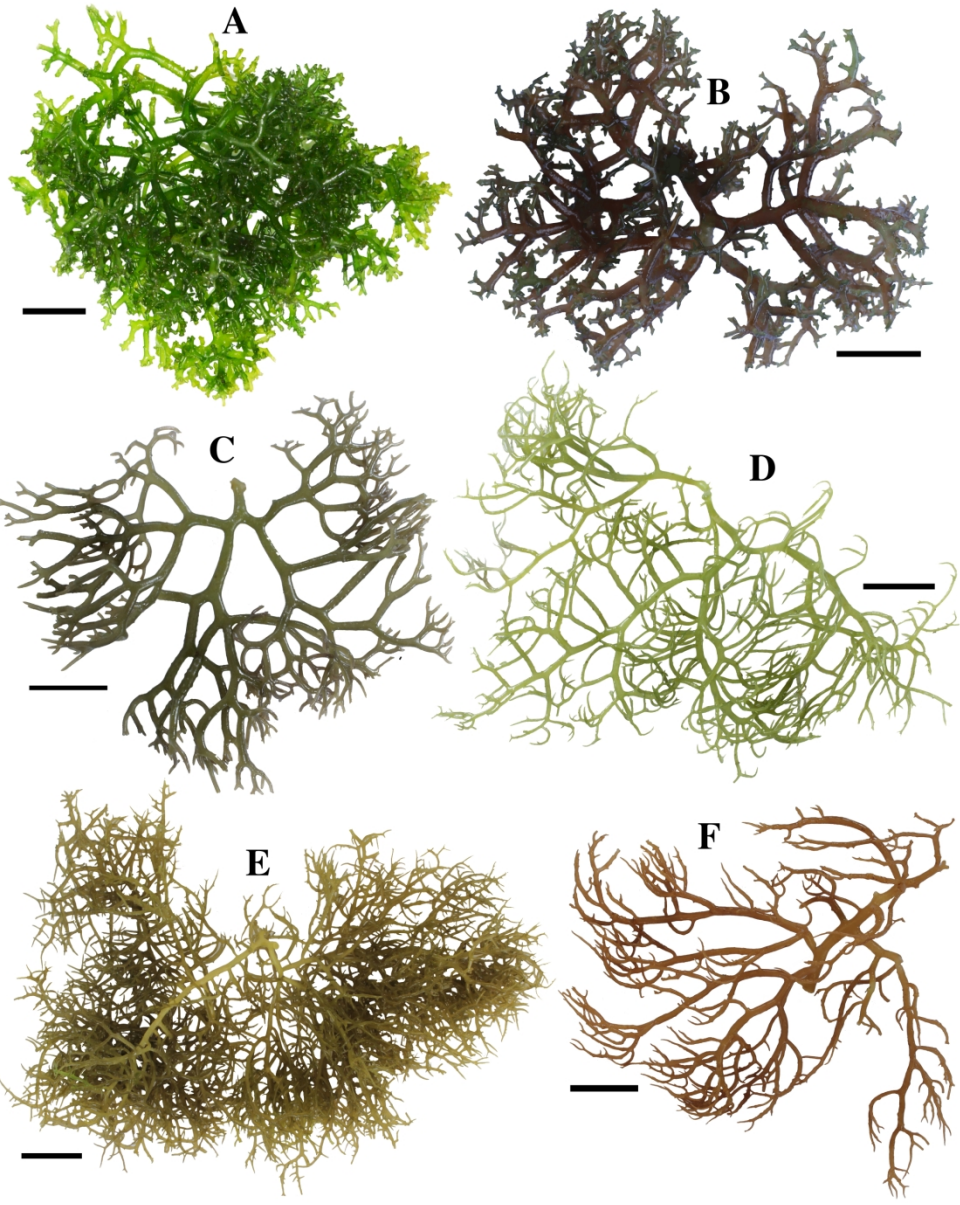


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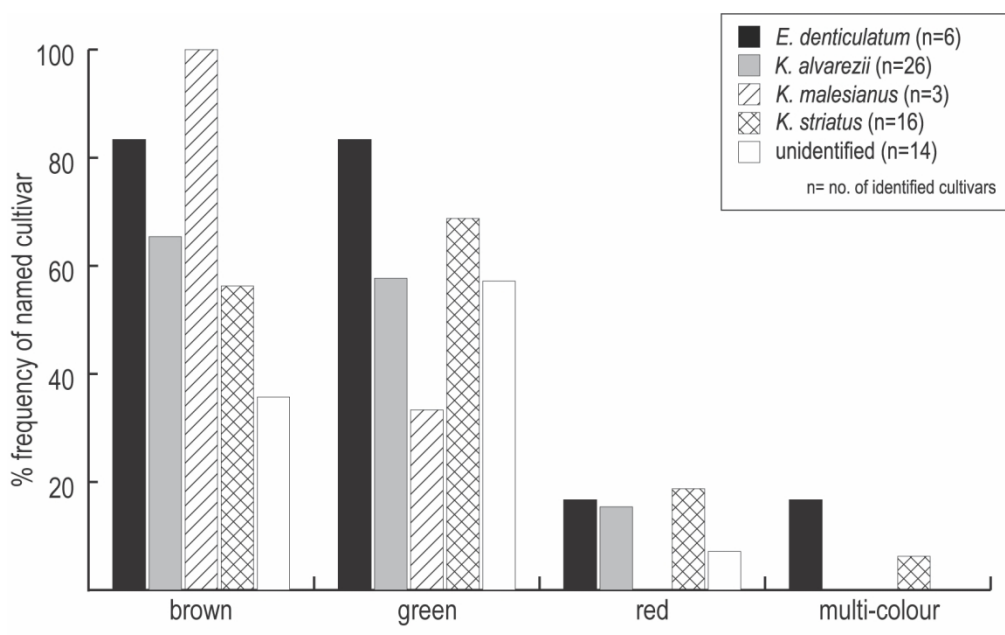
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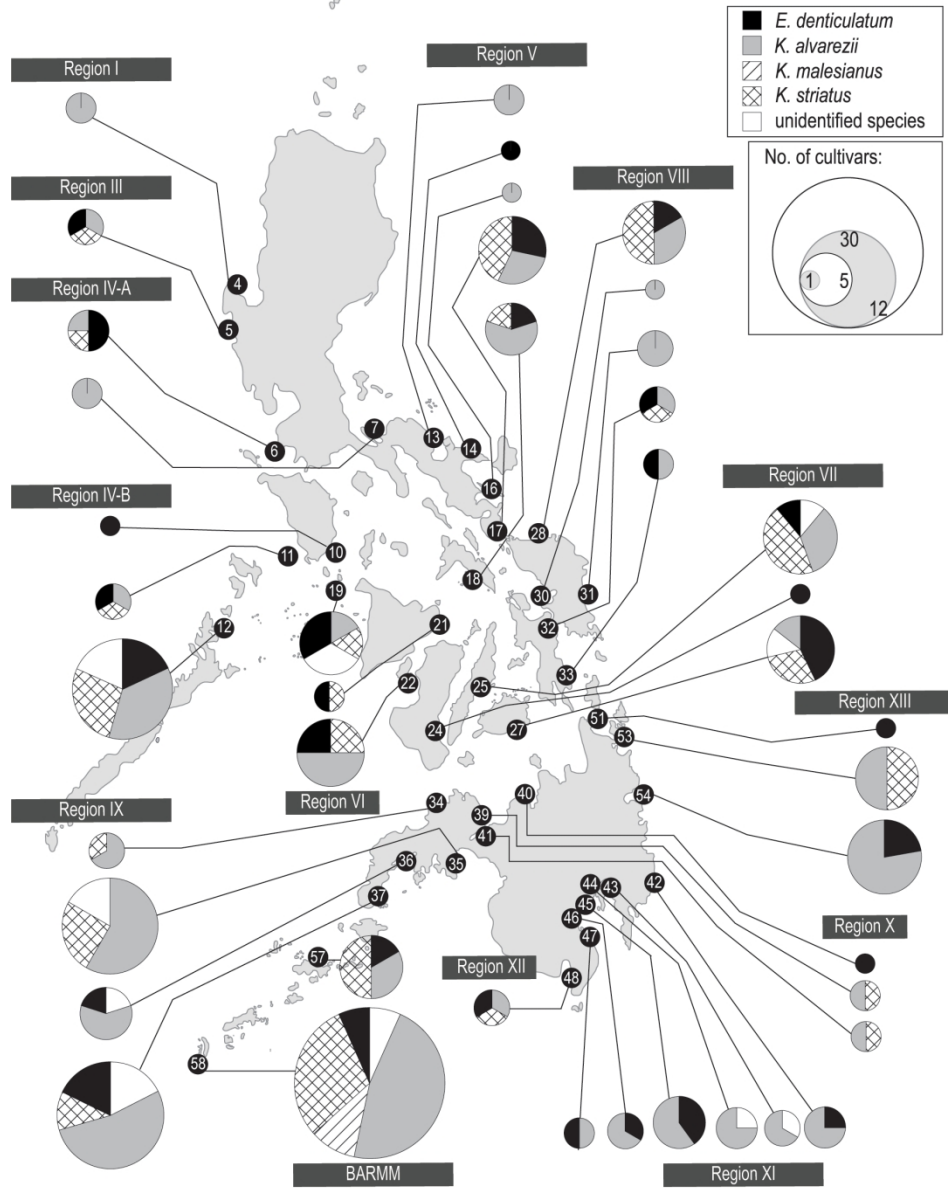


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