Chapter 15

Grasses (Poaceae) of Easter Island — Native and Introduced Species Diversity

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Additional information is available at the end of the chapter

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1. Introduction

Rapa Nui (Easter Island, Isla de Pascua), also known as Te Pito O Te Henua, is a small oceanic island of volcanic origin discovered by the Dutch explorer Jakob Roggeveen in April 1722. It has belonged to Chile since 1888 and is administratively part of the Region of Valparaíso, Province Isla de Pascua. At around 163.6 km^2, it is the largest island of the Chilean insular territory, situated in Polynesia, *ca*. 3,700 km from continental Chile in the Pacific Ocean (27°7'S, 109°22'W). Rapa Nui is considered the most remote inhabited island in the world, with a population of nearly 5,800 inhabitants. Approximately 43.5 % of the island territory is under the protection of the National System of Wild Protected Areas of the State of Chile (SNASPE). The Rapa Nui National Park, administered by the National Forest Corporation of Chile (CONAF) was created on 16th January, 1935 and declared a World Heritage Site by UNESCO in 1995 to protect the Rapa Nui culture, and especially the 887 statues known as *moai* [1].

The climate is warm and sub-tropical. The flora of Rapa Nui is extremely poor compared to other oceanic tropical islands [2]. Approximately 40 % of the flora is indigenous. Nearly 23 % of the vascular flora is represented by endemic species, and some 20 species of the native flora, 10 of which are endemic, have disappeared or are endangered, principally due to invasive plants, fire, overgrazing and agriculture, among other factors [3]. Nearly 90 % of the territory corresponds to herbaceous vegetation, with species of Poaceae (grasses) as the principal component, most of them alien [4]. There are, however, very dense little forests composed of species that have come with human beings since the island was colonized. Wetlands are located chiefly in the craters of volcanoes, the largest in Rano Kau (Fig. 1) and others in Ranu Raraku and Ranu Aroi. The flora of these wetlands consists of *Schoenoplectus californicus*, *Persicaria acuminata*, *Cyperus eragrostis*, *Cyperus polystachyos* and *Sorghum halepense*. It has been suggested

that the original vegetation of the island was represented by palm-dominated forests that have since disappeared and been replaced by a large number of introduced species that became naturalized. Pollen analyses of lake sediment cores showed a replacement of forests dominated by the palm species *Paschalococcus disperta* by grass-dominated vegetation communities [5]. Deforestation would have occurred either in AD 1000-1200 or 600 years later. It has been suggested that the deforestation of the island occurred due to intense human activity, including clearing, introduction of the Polynesian rat, fire and agriculture, among other factors [7, 8]. However, the existence of vegetation dominated by trees, as well as the proposed ecological disaster, still needs to be proven conclusively [5].

Grasslands present on the island can be divided into two types: 1. Very low grasslands, with high species diversity, overgrazed by livestock, especially horses. 2. Higher grasslands composed almost exclusively of *Melinis minutiflora*.

Figure 1. Crater of the volcano Rano Kau. Photo: G. Rojas.

The number of species reported for the island is not consistent in the scientific literature. Most of the differences in number of species occur, probably, because the authors include or exclude cultivated plants, and due to synonyms and nomenclatural changes.

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Castro *et al*. [6] report only 40 species of monocots for Rapa Nui from a total of 121 vascular plants; these authors did not specify how many species of Poaceae there are; on the basis of 121 vascular species, Poaceae represent *ca*. 44 % of the entire vascular flora of the island. Previously, Skottsberg [9] indicated 44 species from 18 families of vascular plants, including eight genera and 12 species of Pteridophyta, and 28 genera and 32 species of Spermatophyta; Poaceae comprises 10 species. Two decades before, Fuentes reported *ca.* 124 species from 104 genera and 48 families [10]; five species reported by Fuentes are non-vascular plants and Poaceae numbers 19 species. Zizka [12] reported 100 wild angiosperms. Zizka [13, 14] reported 46 species of Poaceae. Dubois *et al*. [3] found 21 species of grasses. It has been suggested that more than 370 species of vascular plants have been introduced by humans to Rapa Nui, of which some 180 became naturalized [3].

The aim of this chapter is to provide a synopsis of the diversity of the family Poaceae (Gramineae) in Rapa Nui, to provide a catalogue of all species of Poaceae and to analyse the completeness of the inventory, to analyse the taxonomic distribution, life cycle, photosynthetic pathway, and phytogeographical origin of Poaceae in Rapa Nui and to compare the diversity of Poaceae in Rapa Nui with those of other oceanic islands. To date, the most complete list of grass species published on the flora of Rapa Nui comprises 46 species [14]. Our data indicate that in Rapa Nui, the family Poaceae comprises 50 species and one infraspecific taxon, from 37 genera and seven subfamilies. Recent taxonomic treatments have followed to update the nomenclature and the classification of the species.

2. History of the botanical expeditions to Rapa Nui

The first botanical collections made in Rapa Nui were those of Johann Reinhold Forster and his son Georg, during Cook's second voyage aboard the "Resolution", who sighted Rapa Nui on 13th March, 1774, and the next day landed at Hanga Roa [15]. Both Cook and Forster made similar and interesting comments, mainly on crop species such as sugarcane, potatoes and bananas. They also mentioned *Sophora toromiro* (Fabaceae) as the only native shrub species growing on the island, which was scarce, and with hard and heavy wood [16]. Georg Forster [15] cited 9 species on the island in the *Florulae insularum Australium Prodomus* which three belong to the grass family Poaceae: *Saccharum officinarum*, *Panicum filiforme* and *Avena filiformis* (=*Lachnagrostis filiformis*).

During a voyage of the Russian ship "Rurik", commanded by Captain Kotzebue, and with Adelbert von Chamisso, a naturalist, on board, it passed by Rapa Nui on a short visit; apparently, a small botanical collection was made [18]. Between 1825 and 1828, Captain Beechey's journey of exploration in the "Blossom" visited several locations in Chile, of which an important record is retained in the publications of Hooker and Arnott (1830 and 1832). The ship arrived at Rapa Nui on 16th November, 1825, but there are no records of plants [19].

Endlicher [20] in *Bermerkungen über die Flora der Südseeinseln*, lists numerous species on the islands they visited. For Rapa Nui, he mentions 11 species previously studied by Chamisso

and Forster, but no specimens were deposited in herbarium. In this work, five species of Poaceae were recorded: *Paspalum filiforme*, *Agrostis conspicua*, *Deyeuxia chamissonis* (=*Lachnagrostis filiformis*), *Deyeuxia forsteri* (=*Lachnagrostis filiformis*) and *Lepturus repens*.

Savatier, during the campaign of the "Magicienne", reached Rapa Nui in August, 1877. Plants collected on the island are kept in the herbarium of the Museum of Paris, but no list was published. In 1885, Hemsley, in his *Report of the present stage of knowledge of various insular floras* [21], listed species of the island that were present in the work of Endlicher (except *Centaurea apula*), and also mentioned that there were other widely distributed plants that had been collected, such as the already known *Sophora tetraptera* and *Sesuvium portulacastrum*. The zoologist Alexander Agassiz, as a member of the Albatross expedition to the Tropical Eastern Pacific, visited Rapa Nui in 1904, making an important collection of plant specimens that he sent to Cambridge, Gothenburg and Washington.

In 1911, Francisco Fuentes was commissioned by the Chilean government to conduct a study on Rapa Nui. As a result of this work, Fuentes published his *Reseña botánica sobre la isla de Pascua* [10], where he mentions 135 species, of which 40 % are native or naturalized, and of these 25 are typically tropical. Grasses are represented by 19 species and 14 genera. He mentions that grasses cover the entire surface of the island, forming a steppe-like vegetation consisting mainly of *Paspalum orbiculare* (=*P. scrobiculatum* var. *orbiculare*), *Sporobolus indicus*, *Eragrostis diandra* (probably *E. tenuifolia* or *E.atrovirens*), *Andropogon halepensis* (=*Sorghum halepense*) and *Panicum sanguinale* (=*Digitaria sanguinalis*).

Between 5th October, 1916, and 26th, September, 1917, Skottsberg and his wife made a major Swedish expedition to explore and study the Juan Fernández Archipelago and Rapa Nui, which culminated in the publication of *The natural history of Juan Fernández and Easter Island* [17]. On 15th June, they arrived at La Pérouse Bay [19]. They collected 30 species that were probably indigenous or naturalized and four species that were semi-naturalized, but certainly introduced by the first inhabitants because of their usefulness, and 24 species accidentally introduced. This research increased by 23 the species mentioned by Fuentes, in which nine species of grasses are given. In 1927, the names of the plants collected in 1918 by Gusinde were also provided.

The Franco-Belgian mission exploring Rapa Nui from 29th July, 1934, to 3rd January, 1935, collected 61 species; the few that were not reported previously are obviously introduced, and known angiosperms number 142 [16]. The list mentions nine species of grasses, some new with respect to the Skottsberg list, and others that were missing, and notes that there are numerous plants without flowers to identify.

Subsequently, several researchers have conducted the collection of plants, which have been deposited in various herbaria, especially in Chile in the herbarium of the National Museum of Natural History (SGO) and the herbarium of the University of Concepción (CONC) [14]. In this work, 46 grass species have been reported.

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3. Material and methods

Specimens were collected and preserved in the herbarium of the National Museum of Natural History at Santiago (SGO). Specimens were identified and photographs were taken using a Zeiss Stemi 2000 C stereomicroscope equipped with an Axiocam ERc5s camera. Images were processed with the software Zen 2011.

A database of the species of grasses of Rapa Nui was constructed, based on the databases of two important Chilean herbaria: CONC (Herbarium of the University of Concepción) and SGO (Herbarium of the National Museum of Natural History, Santiago). Specimens deposited in these herbaria and those collected for this project were included. The database contains the following fields: 1. Genus; 2. Species; 3. Common names in Rapa Nui; 4. Origin (native/introduced/endemic); 4. Geographical origin; 5. Photosynthetic pathway; 6. Life cycle; 7. Subfamily; 8. Tribe; 9. Collector's name; 10. Collector's number; 11. Latitude; 12. Longitude; 13. Altitude; 14. Locality; 15. Date of collection (year); 16. Date (year) of first registration; 17. Herbarium; 18. Herbarium number; 19. Bibliographic citations. A total of 369 specimens were included.

A checklist is provided, including Latin name, origin (endemic, native, introduced), homeland, life cycle (annual, perennial, annual or perennial), photosynthetic pathway (C3/C4) and classification (subfamily, tribe); however, the biogeographic status is sometimes difficult or impossible to establish. Meyer's secondarization index was calculated as the number of native species/number of naturalized species [37].

The diversity of grasses of Rapa Nui was compared with the diversity of grasses of other oceanic islands (Galápagos, Pitcairn, Marquesas, Juan Fernández and Hawaii), using the regional diversity index (D). This index was calculated as D=S/log A, where S is the number of species in the region and A is the area in square kilometres [22]. The floristic affinity between these islands was compared by cluster analysis of presence-absence data for 349 species, using Jaccard coefficient as the similarity measure, UPGMA algorithm and the statistical software Infostat [23]. Species composition was taken from the literature [24-28]. Species accumulation curve and estimated richness was calculated using the software Estimates 8.0 [29].

4. Results

Our database for the island included a total of 369 specimens collected over 12 decades (1900-2013), representing 51 species, 37 genera, 11 tribes and seven subfamilies (Table 1 and 2), that is, approximately 10 % of the total Chilean (continental and insular) grass flora (523 species and 57 infraspecific taxa) [30]. The proportion of species relative to the number of genera is 1.36, similar to the proportion determined by Fuentes [10] for the entire flora of the island (135 species / 104 genera=1.29). Most of the genera are represented only by one or two species, *Paspalum* (five species), *Digitaria* (three species) and *Setaria* (three species) being the most diverse. Details of some Poaceae of Rapa Nui are illustrated in Figs. 1-3.

Only two species (3.9 %) of the family Poaceae are endemic to Rapa Nui (*Rytidosperma paschalis* and *Paspalum forsterianum*). Eight or nine species are most probably native (15 %) and at least 42 (81 %) are introduced (Table 1). Native species are distributed in seven genera (1.29) and alien species in 30 genera (1.4). Among native Poaceae, the genera *Dichelachne* and *Paspalum* include two native species each, whereas the rest of the genera include only one species (*Axonopus*, *Bromus*, *Digitaria*, *Lachnagrostis* and *Piptochaetium*). Among alien Poaceae, the most diverse genera are *Paspalum* (three spp.), *Setaria* (three spp.), *Cenchrus* (two spp.), *Digitaria* (two spp.), *Sorghum* (two spp.) and *Vulpia* (one sp. and one var.).

Although there are relatively few botanical specimens of Poaceae collected in Rapa Nui, the species cited in the botanical literature are well represented in Chilean herbaria. Moreover, only one species was collected for the first time in 2013, suggesting that the inventory of species is fairly comprehensive. The first herbarium specimens entered into our database correspond to those made by Alexander Agassiz, who in 1904 collected 16 specimens representing 12 different species, about 20 % of the currently known diversity of Poaceae in Rapa Nui. By the middle of the 20th century, with the botanical expeditions made by Fuentes, Skottsberg, Balfour, Williamson & Co., Drapkin and the Mission Franco-Belge, the number of known species reached nearly 50 % of the currently known species number (Fig. 5). An important increase in the number of known species occurred after the botanical trips made by Michel Etienne, who published 24 wild and two cultivated species of Poaceae in Rapa Nui [4] and by Georg Zizka, who reported 46 species of grasses, the most comprehensive list until today [13, 14]. In the decade 1981-1990, a total of 149 specimens of Poaceae were collected, most of them by Zizka. In general, the herbarium collections of Poaceae from Rapa Nui are limited. Our database for the island included a total of 369 specimens over 12 decades (1900-2013), including a total of 51 taxa, most of which were known previously [2], and in Zizka's [13, 14] papers.

Most of the species of grasses of the island are introduced, some of them cited very early in the botanical literature, such as *Cynodon dactylon*, *Cenchrus echinatus* and *Sorghum halepense*, as well as some cultivated species, such as *Zea mays*, *Triticum aestivum* and *Arundo donax* [10]. Some native species were collected very early by R. and G. Forster in 1774 [15], for example, *Paspalum forsterianum*, dedicated to them by Flüggé. In Rapa Nui, Forster also collected *Sporobolus indicus*, *Dichelachne micrantha*, *Bromus catharticus* and the type specimen of *Agrostis avenacea* (=*Lachnagrostis filiformis*) [14]. *Stipa horridula* was collected by Skottsberg in Mount Katiki in 1917; this specimen (Skottsberg 660) became the type (lectotype) of *Stipa horridula* published by Pilger in 1922, and considered endemic to the island for a long time. In 1990, Everett and Jacob [30] reduced it to the synonymy of *Stipa scabra* Lindl., later transferred to *Austrostipa* (*A. scabra*). Skottsberg also collected, in 1917, the type specimen (Skottsber 658) of *Danthonia paschalis* Pilg. [=*Rytidosperma paschale* (Pilg.) C.M. Baeza] [17]. This species is one of the two recognized endemic Poaceae from Rapa Nui.

In 1911, Francisco Fuentes collected, among other plants, a specimen published as the holotype of *Paspalum paschale*. This name was soon transferred to genus *Axonopus* (*A. paschalis*), a species considered for a long time endemic to the island. In addition, another 18 species of Poaceae were collected by Fuentes. In 1936, Guillaumin collected eight grass species, most of them

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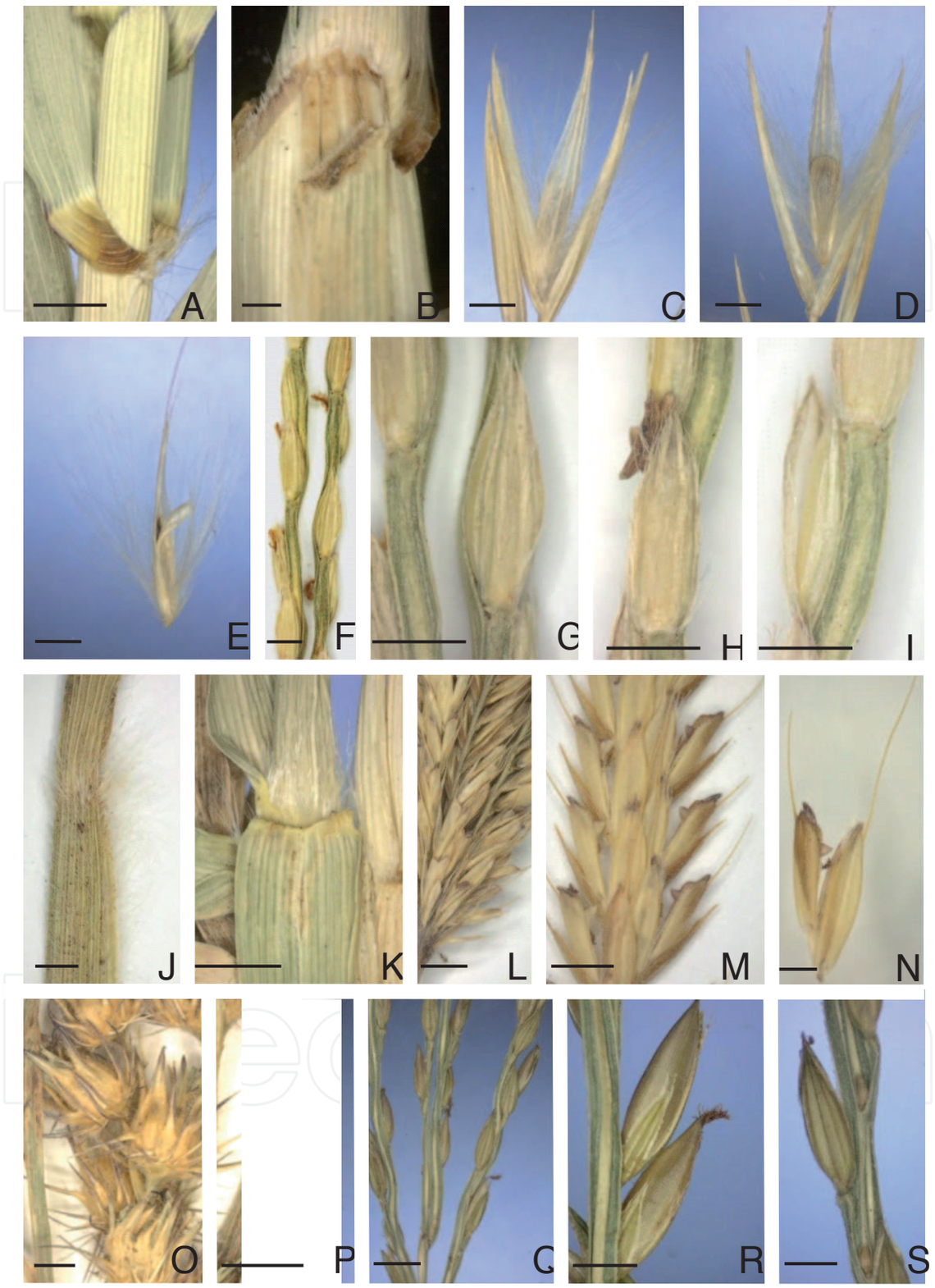

Figure 2. A-E.*Arundo donax* (Alves 34). F-J. *Axonopus compressus* (Zizka 357). K. *Cenchrus clandestinus* (Alves 57). L-N. *Chloris gayana* (Zizka 562). O-P. *Cenchrus echinatus* (Rodríguez 2202); Q-S. *Digitaria ciliaris* (Alves 13ª). Scale bars: A-B=5 mm; C-J, N, R-S=1 mm; K, O-P=2 mm; L-M, Q=3 mm

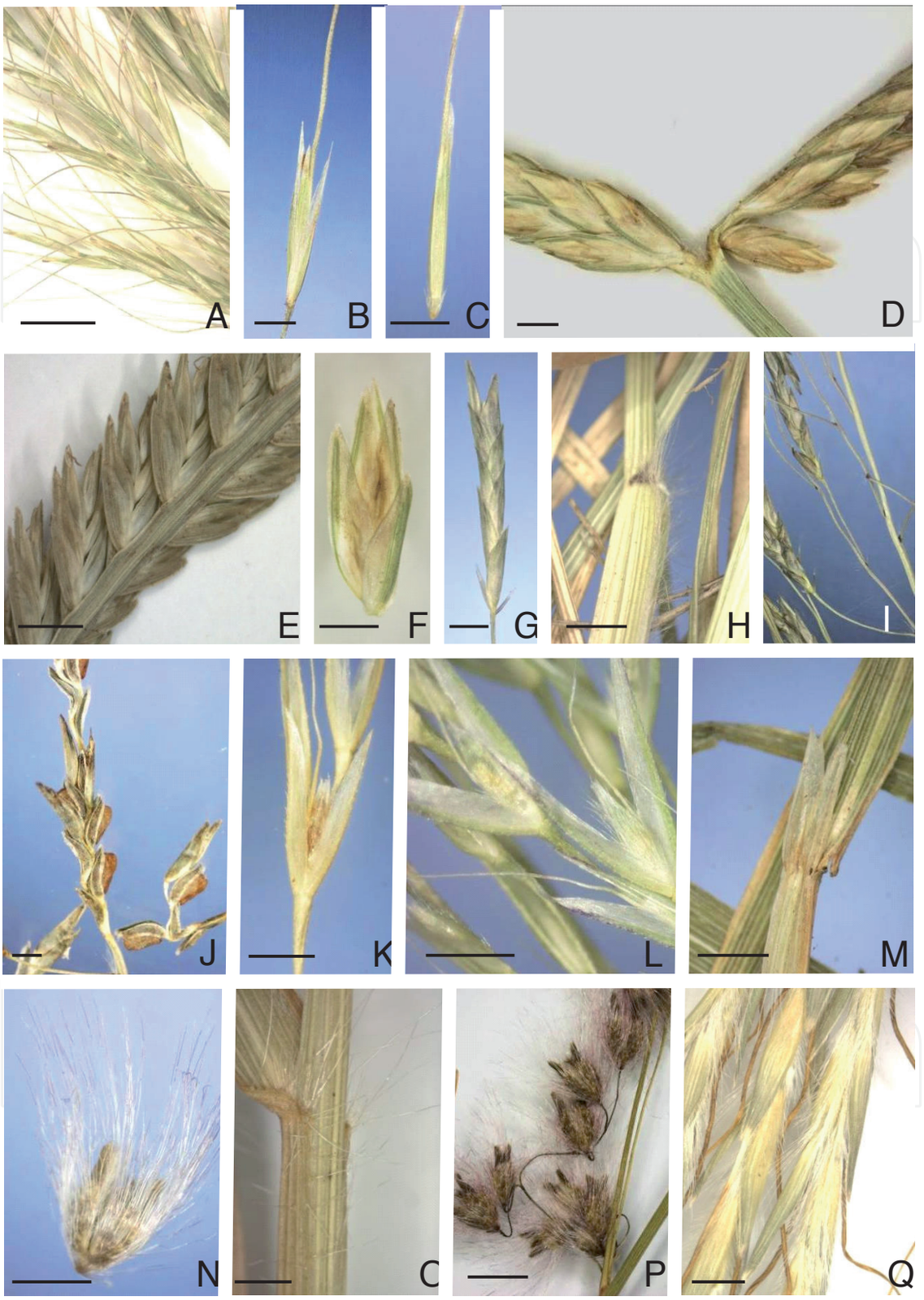

Figure 3. A-C. *Dichelachne micrantha* (Lücke 15). D-F. *Eleusine indica* (Zizka 330). G-J. *Eragrostis tenuifolia* (Alves 30). K-M. *Lachnagrostis filiformis*. N-P. *Melinis repens* (Zizka 586). Q. *Bothriochloa ischaemum* (Zizka 330). Scale bar: Q=2 mm. Scale bars: B-F, I-L=1 mm; G-H, M, P=2 mm; A, N-O=3 mm

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Figure 4. A-D. Melinis minutiflora (Alves 60). E-F. Ehrharta stipoides (Alves 32). G. Paspalum dilatatum (Stuessy 11008). H. Paspalum forsterianum (Vidal s.n.). I-J. Paspalum scrobiculatum (Alves 98). K. Sorghum halepense. L-O. Sporobolus indicus. Scale bars: A, C-E, J, L=1 mm; G-I, K, M-O=2 mm; B=3 mm

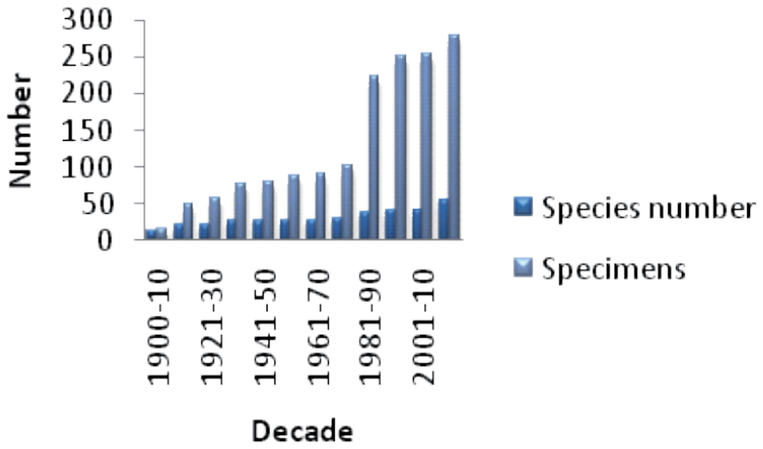

Figure 5. Number of specimens and species collected in Rapa Nui in 12 decades between 1904 and 2013

previously known from Fuentes' collection. Guillaumin collected, probably for the first time, *Briza minor*, nowadays naturalized all over the world [16]. Zizka [13, 14] collected and described 46 species representing the most important contribution to the knowledge of the grass family in Rapa Nui.

5. Taxonomic distribution of Poaceae in Rapa Nui

The taxonomic distribution of the species of Poaceae in Rapa Nui is shown in Table 1. Seven subfamilies are represented. In continental Chile, eight subfamilies are present [30], of which only species of the subfamily Aristidoideae are absent in Rapa Nui.

The subfamily Arundinoideae comprises only one species: *Arundo donax*, a perennial C3 reed-like species introduced from southern Europe, probably at the beginning of the 20th century or before. It was mentioned as a component of the Rapa Nui flora by Francisco Fuentes in 1913 [10]. According to our records and the literature [4], it is restricted to the crater of the Rano Kau volcano as a remnant of cultivation [14]. This species is recognized as invasive in Southern Africa, Australia, North America and the Pacific Islands [3].

The subfamily Bambusoideae is represented only by cultivated bamboos of the genus *Bambusa*.

The subfamily Chloridoideae comprises six genera and six species in Rapa Nui (Table 1), all belonging to the subtribe Cynodonteae, most introduced from Tropical Africa, such as *Chloris gayana*, *Cynodon dactylon*, *Eragrostis atrovirens* and *Sporobolus indicus*. Accordig to Zizka [13], the identity of the species of *Eragrostis* in Rapa Nui is not clear. This author mentions *E. spartinoides* (=*E. brownii*) and *E. leptostachya.* In this paper, we follow the revision of the genus *Eragrostis* by Escobar *et al*. [34]. According to these authors, the species of *Eragrostis* inhabiting Rapa Nui correspond to *E. atrovirens* and *E. tenuifolia*. *Eleusine indica* is a cosmopolitan Chloridoideae reported in Rapa Nui early in the 20th century.

The subfamily Danthonioideae comprises only two species in Rapa Nui. One of the species was mentioned only once in the literature dealing with Rapa Nui flora [11], under the name

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Gynerium argenteum a synonym for *Cortaderia selloana*. This species is native to South America and is probably alien in Rapa Nui. It seems that this plant was introduced for erosion control [3]. The second species is *Ritydosperma paschale*, endemic to the island. As was established by Zizka [13], and according to our database, this species is restricted to the slopes of the Rano Kau volcano. It was also collected previously in Pua Katiki [4], but it seems to now be restricted to Rano Kau [14].

The only species of the subfamily Ehrhartoideae known in Rapa Nui is *Ehrharta stipoides* (=*Microlaena stipoides*), a species growing in Africa, Tropical Asia, Australasia and the Pacific [32]. This species is important as forage, but it was reported as invasive in Hawaii and Réunion Island. It was reported in Rapa Nui as a species widely distributed in the island, advantaged by overgrazing [4].

The subfamily Panicoideae comprises 12 genera and 23 species, representing about 44 % of the grass flora of Rapa Nui (Table 1). This clearly contrasts with the total grass flora of Chile, where Panicoideae represents only *ca*. 10 % [30]. *Paspalum*, *Setaria* and *Digitaria* are the most speciose genera.

Panicoideae includes the second endemism of this family from the island, *Paspalum forsterianum*, a species whose conservation status is "Vulnerable" [3]. To this subfamily also belongs *Axonopus paschalis*, long considered endemic to the island. This species was recently included as a synonym of *A. compressus*. According to Morrone [unpublished data, Flora de Chile], *A. paschalis* is morphologically similar to *A. compressus* from which it differs by the size of the leaf blades, the longer, narrower and more rigid leaves, by the hairiness of the spikelets and by the brown superior floret. *Bothriochloa ischaemum* was collected for the first time shortly after it had been introduced to the island; this species behaves invasively [4]. Several other Panicoideae are found, some of them widely recognized as invasive (v. gr. *Setaria parviflora*, *Cenchrus echinatus*, *C. clandestinus*, *Paspalum scrobiculatum*, etc.), others cultivated, such as *Saccharum officinarum*.

Subfamily	Tribes	Genera	Species number	Species (%)
Arundinoideae	1	1	1	1.96
Bambusoideae	1	1	1	1.96
Chloridoideae	1	6	7	13.73
Danthonioideae	1	2	2	3.92
Ehrhartoideae	1	1	1	1.96
Panicoideae	2	12	23	45.09
Pooideae	4	15	16	31.37
Total	**11**	**37**	**51**	**100.00**

Table 1. Number of tribes, genera and species of Poaceae in Easter Island

The subfamily Pooideae comprises 16 species from 15 genera, being the second most diverse subfamily. Whereas Pooideae include most of the grasses of the Chilean flora (74.65 %) [30], in Rapa Nui it represents only *ca*. 31 % (Table 1). A list of the species, homeland, photosynthetic pathway, life cycle and classification (subfamily, tribe) is given in Table 2.

6. Phytogeographical origin of Poaceae in Rapa Nui

As in other oceanic islands, grasses are the most common alien plants occurring in Rapa Nui [3, 33, 35]. The number of endemic, native and alien species of the grass flora in the island is shown in Fig. 6, where we can see that alien plants represent the vast majority of the grass flora (Meyer's secondarization index=0.24). Introduced species are mainly of African, European and Asian origin (Fig. 7, Table 2).

The proportion of alien species in six Poaceae subfamilies (Bambusoideae was not included as it contains only one cultivated species) is shown in Figure 8. All Chlorodoideae seem to be alien, most of African origin. However, the identity of some species, mainly those of *Eragrostis*, is difficult to elucidate. *Eragrostis atrovirens*, *E. spartinoides* and *E. tenuifolia* have been mentioned, however, only *E. atrovirens* and *E. tenuifolia* were recently recognized in Rapa Nui [34]. *Sporobolus indicus* (Chloridoideae) was collected in cultivated field as agrestal weed (vineyards, pineapple).

Most of the species of subfamily Panicoideae and subfamily Pooideae, which constitute the bulk of the grass flora of the island, are alien. The only species of subfamily Ehrhartoideae, *Ehrharta stipoides*, seems to be invasive; this species is widely distributed in the island and expands in cases of overgrazing [4].

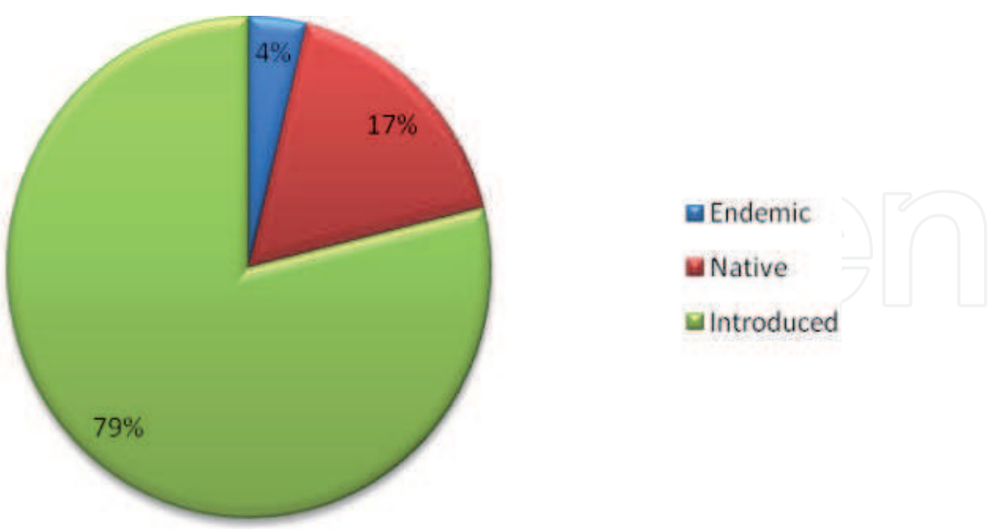

Figure 6. Percentage of native, endemic and introduced grass species in Rapa Nui

Rapa Nui belongs to the Polynesian Biogeographic Province [36] or Polynesian Floristic Region [37], included among the 25 biodiversity hotspots of the world [38, 39]. Specifically, it belongs

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to the Eastern Polynesia Subregion of Polynesia and represents the driest island of the subregion, with 1,325 mm of annual precipitation. In effect, there is no native vegetation on the island today and introduced plants outnumber native species due to the deforestation that occurred soon after the arrival of the first Polynesian inhabitants (38).

Introduced species that became naturalized or invasive represent one of the major threats to native species. It has been proposed that aboriginal people significantly modified the vegetation of the island [6] and the original vegetation communities were replaced by grasslands. In these plant communities, introduced species became increasingly abundant [40]. According to Aldén [2], the composition of the flora underwent a rapid change from the 18th century, when European people begin to visit the island.

On the other hand, around 70,000 tourists visit the island each year, causing environmental deterioration [41]. As shown in Figure 9, a sharp increase in the amount of alien species occurs in the 1990s; by this time, there are three times the number of alien species present compared to when Francisco Fuentes visited the island in 1911; nevertheless, in the 1910s, aliens already exceed the number of native species. Zizka [14] collected six species of grasses for the first time, all of them introduced. In some cases, nevertheless, we cannot be absolutely sure if certain species are indigenous or were accidentally introduced by man.

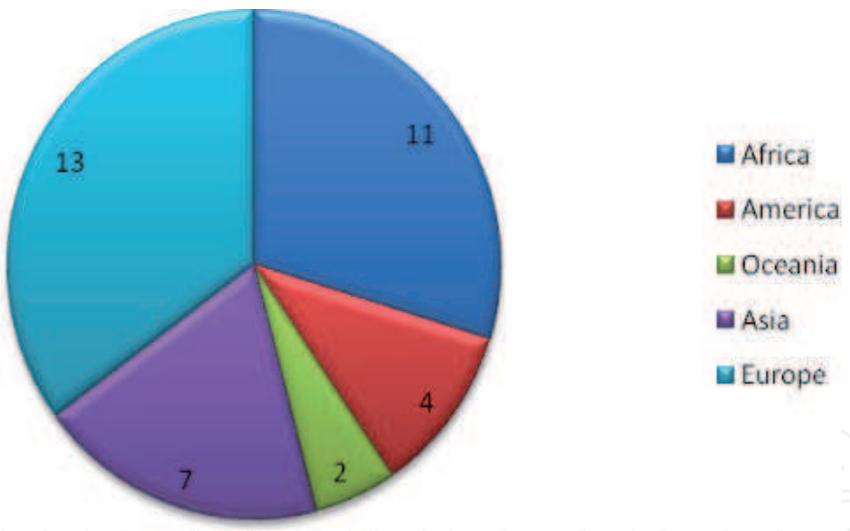

Figure 7. Geographic origin of the species introduced to Rapa Nui

From a physiological point of view, introduced species mostly show C4 photosynthesis (Fig. 10), and most of the species, both alien and native, are perennial (Fig. 11). It has been demonstrated that alien species distantly related to the native flora are more likely to become harmful weeds for regional ecosystems, supporting Darwin's naturalization hypothesis; thus, special attention should be paid to newly introduced species for which there are no close relatives in the regional flora [42]. In Rapa Nui, our data show that species from 30 genera and two subfamilies that do not include native species have been introduced.

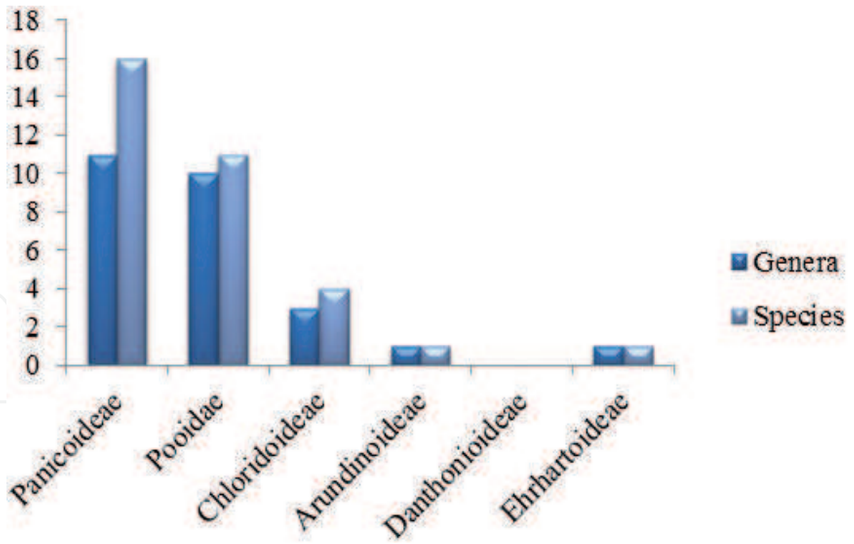

Figure 8. Taxonomic distribution of the alien species recorded for Rapa Nui

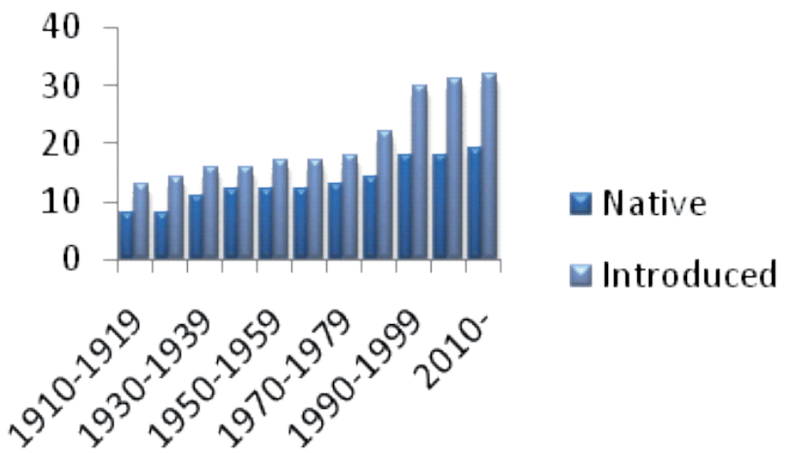

Figure 9. Number of native and introduced grass species in Rapa Nui in 12 decades of botanical collections

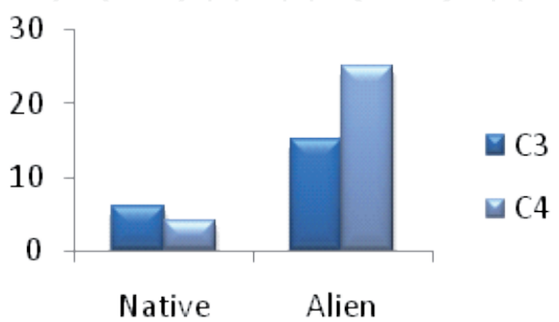

Figure 10. Number of C3 and C4 grass species in Rapa Nui

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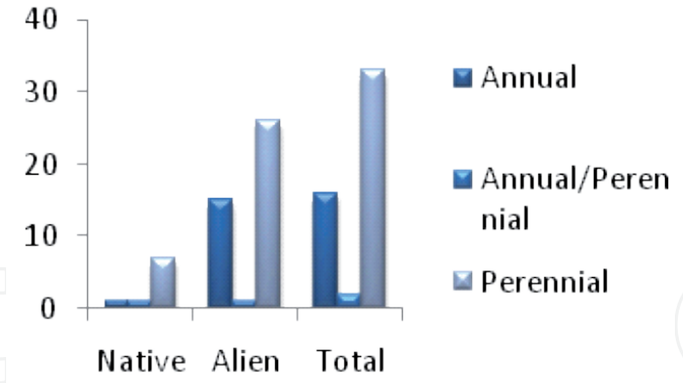

Figure 11. Life cycle of native and alien species of Poaceae in Rapa Nui

7. Comparing the diversity of Poaceae in Rapa Nui with other Pacific Islands

The diversity of grasses in Rapa Nui, calculated as the number of species per area expressed in square kilometres (regional diversity index) is slightly lower than that of the Juan Fernández Archipelago (Fig. 12). According to the literature, Poaceae in Juan Fernández Archipelago comprises 32 genera and 53 species [33, 43]. This number is relatively small compared with Hawaii (216 species) and Galápagos (94 species). From Desventuradas islands (San Félix, San Ambrosio), only two species have been recorded (*Eragrostis kuschelii* and *E. peruviana*), the first one endemic to Chile (Desventuradas Islands). If the identity of the species is considered, Rapa Nui is still more similar to Juan Fernández than to other Pacific islands (Fig. 13). However, taxonomic distribution of the flora of Poaceae is different in these two Chilean islands. C3 Pooideae dominated Poaceae in Juan Fernández, whereas in the more tropical Rapa Nui, C4 Panicoideae are more abundant. In both islands, perennial grasses dominate over annuals.

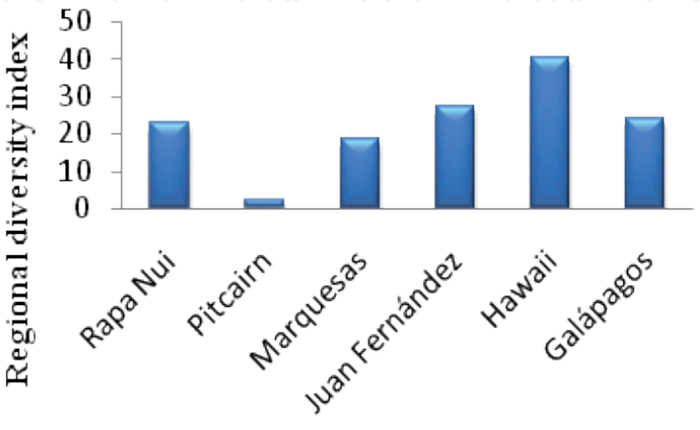

Figure 12. Diversity of Poaceae of Rapa Nui (Easter Island) compared to other oceanic islands

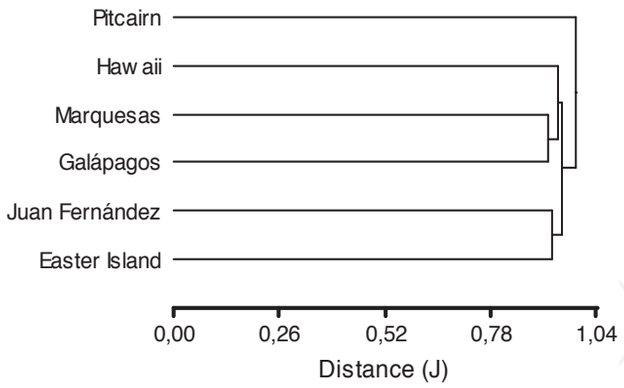

Figure 13. Poaceae floristic similarity between Rapa Nui (Easter Island) and other Pacific islands.

Species	Origin	Homeland	C3/C4	Life cycle	Subfamily	Tribe
1. *Agrostis stolonifera* L.	I	Europe	C3	P	Pooideae	Poeae
2. *Arundo donax* L.	I	Europe	C3	P	Arundinoideae	Arundineae
3. *Austrostipa scabra* (Lindl.) S.W.L. Jacobs & J. Everett	I	Australia	C3	P	Pooideae	Stipeae
4. *Avena fatua* L.	I	Europe	C3	A	Pooideae	Poeae
5. *Axonopus compressus* (Sw.) P. Beauv.	N	South America	C4	P	Panicoideae	Paniceae
6. *Bambusa* sp.	C	Asia	C3	P	Bambusoideae	Bambuseae
7. *Bothriochloa ischaemum* (L.) Keng	I	Asia	C4	P	Panicoideae	Andropogoneae
8. *Briza minor* L.	I	Europa	C3	A	Pooideae	Poeae
9. *Bromus catharticus*Vahl	N	America	C3	P	Pooideae	Bromeae
10. *Cenchrus clandestinus* (Hochst. Ex Chiov.) Morrone	I	Africa	C4	P	Panicoideae	Paniceae
11. *Cenchrus echinatus* L.	I	Cosmopolitan	C4	A	Panicoideae	Paniceae
12. *Chloris gayana* Kunth	I	Africa	C4	P	Chloridoideae	Cynodonteae
13. *Coix lacryma-jobi* L.	I	Asia	C4	P	Panicoideae	Andropogoneae
14. *Cortaderia selloana*	I	South America	C3	P	Danthonioideae	Danthonieae
15. *Cynodon dactylon* (L.) Pers.	I	Tropical Africa	C4	P	Chloridoideae	Cynodonteae
16. *Dichelachne crinita* (L. f.) Hook. f.	N	Australia, Asia & Pacific	C3	P	Pooideae	Poeae
17. *Dichelachne micrantha* (Cav.) Domin	N	Australia, Asia & Pacific	C3	P	Pooideae	Poeae
18. *Digitaria ciliaris* (Retz.) Koeler	N?	South America	C4	A	Panicoideae	Paniceae
19. *Digitaria setigera* Roth ex Roem. & Schult.	I	Australia, Asia & Pacific	C4	A	Panicoideae	Paniceae

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Species	Origin	Homeland	C3/C4	Life cycle	Subfamily	Tribe
20. *Digitaria violascens* Link	I	South America	C4	A	Panicoideae	Paniceae
21. *Eleusine indica* (L.) Gaertn.	I	Africa	C4	A	Chloridoideae	Cynodonteae
22. *Eragrostis atrovirens*	I	Australia	C4	P	Chloridoideae	Cynodonteae
23. *Eragrostis tenuifolia* (A. Rich.) Steud.	I	Africa	C4	P	Chloridoideae	Cynodonteae
24. *Gastridium ventricosum* (Gouan) Schinz & Thell.	I	Europa	C3	A	Pooideae	Poeae
25. *Hordeum murinum* L.	I	Europa	C3	A	Pooideae	Triticeae
26. *Lachnagrostis filiformis* (G. Forst.) Trin.	N	New Zealand, Australia, New Guinea, Rapa Nui	C3	A/P	Pooideae	Poeae
27. *Lepturus repens* (G. Forst.) R. Br.	I	Africa	C4	P	Chloridoideae	Cynodonteae
28. *Lolium perenne* L.	I	Europe	C3	P	Pooideae	Poeae
29. *Megathyrsus maximus* (Jacq.) B. K. Simon & S. W. L. Jacobs var. *pubiglumis* (K. Schum.) B. K. Simon & S. W. L. Jacobs	I	Africa	C4	P	Panicoideae	Paniceae
30. *Melinis minutiflora* P. Beauv.	I	Africa	C4	P	Panicoideae	Paniceae
31. *Melinis repens* (Willd.) Zizka	I	Africa	C4	A/P	Panicoideae	Paniceae
32. *Ehrharta stipoides* Labill.	I	Australia	C3	P	Ehrhatoideae	Ehrharteae
33. *Paspalum conjugatum* P. J. Berg.	I	America	C4	P	Panicoideae	Paniceae
34. *Paspalum dilatatum* Poir.	I	America	C4	P	Panicoideae	Paniceae
35. *Paspalum forsterianum* Flüggé	E	Rapa Nui	C4	P	Panicoideae	Paniceae
36. *Paspalum notatum* Flüggé var *saurae* Parodi	N?	South America	C4	P	Panicoideae	Paniceae
37. *Paspalum orbiculare* G. Forst.	I	Africa	C4	P	Panicoideae	Paniceae
38. *Poa annua* L.	I	Europe	C3	A	Pooideae	Poeae
39. *Rostraria cristata* (L.) Tzvel.	I	Europe	C3	A	Pooideae	Poeae
40. *Rytidosperma paschale* (Pilg.) C. M. Baeza	E	EI	C3	P	Danthonioideae	Danthonieae
41. *Saccharum oficinarum* L.	I	Asia	C4	P	Panicoideae	Andropogoneae
42. *Setaria* cf. *palmifolia* (Koenig) Stapf	I	Asia	C4	P	Panicoideae	Paniceae
43. *Setaria parviflora* (Poir.) Kerguélen var. *parvilfora*	I	America	C4	P	Panicoideae	Paniceae
44. *Setaria sphacelata* (Schumach.) Stapf & C. E. Hubb. ex M. B. Moss	I	Africa	C4	P	Panicoideae	Paniceae
45. *Sorghum bicolor* (L.) Moench.	I	Asia	C4	A	Panicoideae	Andropogoneae
46. *Sorghum halepense* (L.) Pers.	I	Europe	C4	P	Panicoideae	Andropogoneae

Species	Origin	Homeland	C3/C4	Life cycle	Subfamily	Tribe
47. *Sporobolus indicus* (L.) R. Br.	I	Africa	C4	P	Chloridoideae	Cynodonteae
48. *Triticum aestivum* L.	I	Asia	C3	A	Pooideae	Triticeae
49. *Vulpi amyuros* (L.) C. C. Gmel var. *myuros*	I	Europe, Asia, Africa	C3	A	Pooideae	Poeae
50. *Vulpia myuros* var. *megalura* (Nutt.) Auquier	I	Europe, Asia, Africa	C3	A	Pooideae	Poeae
51. *Zea mays* L.	I	America	C4	A	Panicoideae	Andropogoneae

Table 2. List of the species of Poaceae in Rapa Nui. Life cycle: A=annual; P=perennial; Origin: EI=Rapa Nui; e=endemic; i=introduced; n=native

8. Taxonomic sampling effort

The collection effort (sampling) is an important part of the taxonomic work on which the knowledge of species richness and, ultimately, the knowledge of biodiversity are based. Although collectors try to find all the species in a region, this goal is almost impossible, or at least very difficult to achieve; thus, the real number of species can only be estimated from the number of observed (collected) species (48). As shown in Table 3 and Figure 14, for a total of 50 observed species, the species richness estimated by different estimators ranges from 58.3 (Bootstrap) to 86.8 (Chao). An increased collection effort for Poaceae in Rapa Nui could yield between eight and 36 additional hitherto unsampled species. As shown in Fig. 15, collections are concentrated only in a few localities, chiefly in Rano Kau, near Hanga Roa, Anakena, and Rano Raraku.

Diversity Estimator	Species Richness
Sobs (Mao Tau)	50
ACE	70.6
ICE	73.7
Chao 1	86.8
Chao 2	86.8
Jack 1	69.3
Jack 2	82.2
Bootstrap	58.3
Michaelis-Menten	66.06

Table 3. Estimated species richness of Poaceae in Rapa Nui, using eight different estimators.

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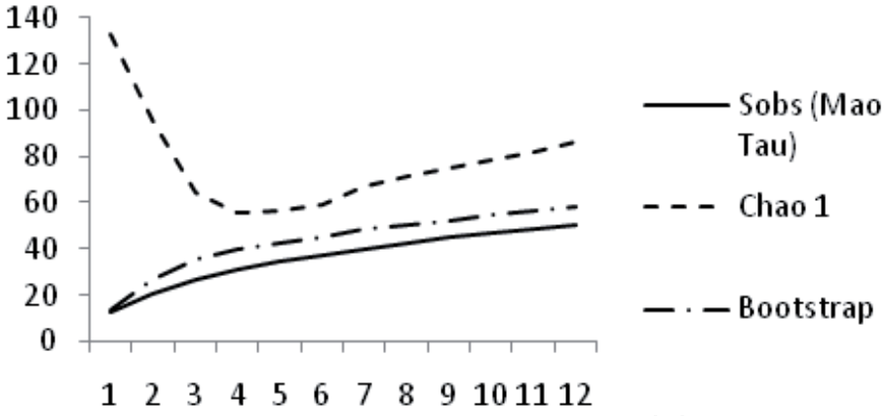

Figure 14. Species accumulation curve (Sobs) and estimated species curves for 12 decades of sampling, based on Chao 1 and Bootstrap estimators.

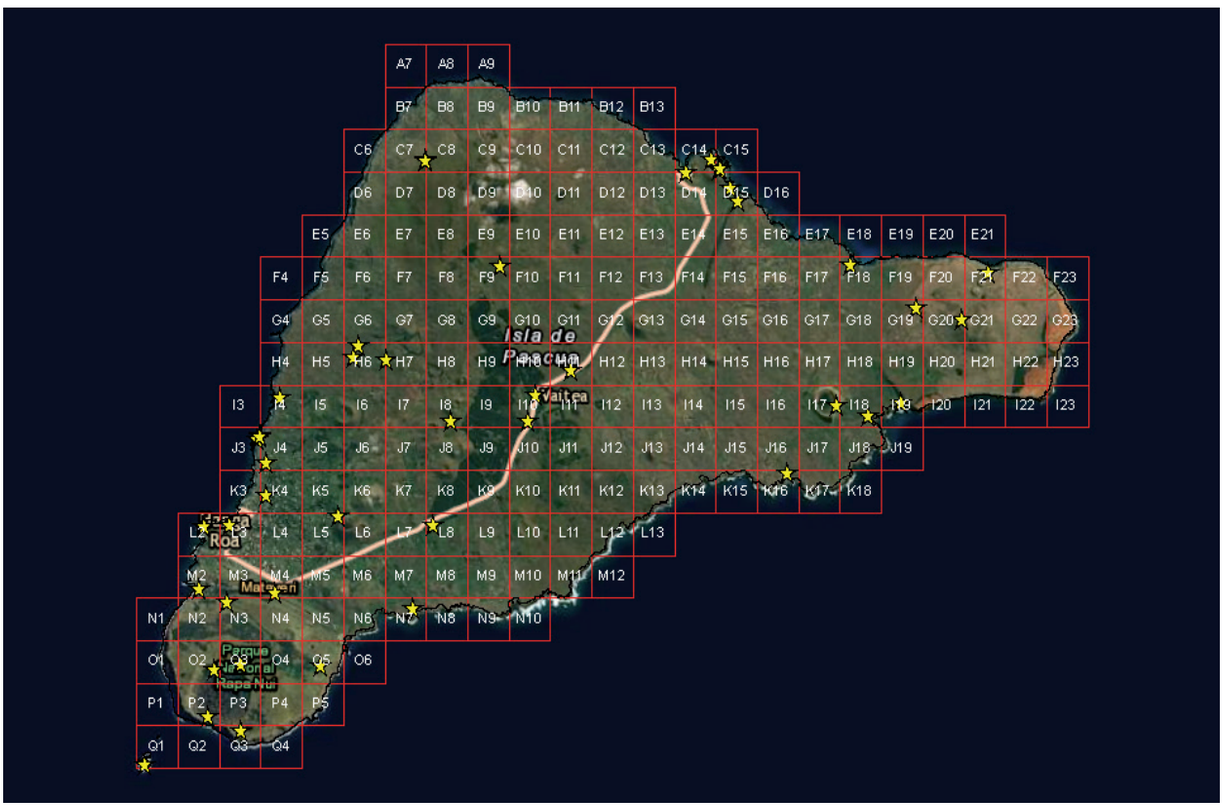

Figure 15. Map of the localities of Poaceae collected in Rapa Nui. Each point represents at least one collected specimen.

9. Concluding remarks

The floras of the oceanic islands are especially prone to serious threats from alien invaders [44], because they have a propensity to include highly adapted specialist rather than generalist

species [45]. This is of particular interest, as these ecosystems comprise high numbers of endemic plants, in contrast with continental regions of similar size [6]. For these reasons, it is necessary to have on hand complete lists of the flora indicating alien plants that could be agricultural weeds and invasive species that can put pressure on native ecosystems.

Poaceae contains an important number of species that behave as weeds in natural environments (invasive), as well as in ruderal and agricultural habitats all over the world. In Rapa Nui, grasses are the most diverse family of vascular plants; nearly 90 % of the island is covered by grasslands and alien grasses represent nearly 80 % of the Poaceae of the island. A similar situation occurs in other oceanic islands [33]. Several alien species introduced to Rapa Nui are noxious weeds (*Agrostis stolonifera*, *Hordeum murinum*, *Sorghum halepense*, *Lolium perenne*, *Setaria parviflora*), probably introduced accidentally, mostly from Europe. As was previously established [38], Rapa Nui shows the greatest (<1) secondarization index (number of native species/number of naturalized species=0.68) when compared with many other Easter Polynesian islands. For Poaceae, this index is greater still (0.24).

On the other hand, only two Poaceae endemic to Rapa Nui are recognized. Another two Poaceae considered endemic in previous studies have been the object of taxonomic studies that demonstrate their non-endemic status: *Axonopus paschalis* (=*Axonopus compressus*) and *Stipa scabra* (*Austrostipa scabra*).

Herbarium specimens provide valuable information to appreciate regional plant diversity, as well as to understand plant invasions and geography [46, 47]. A wide array of data (phenology, flowering periodicity, distribution, altitude, morphometry, minimum residence time, new distributional records, etc.), that are important to biodiversity monitoring can be obtained from herbarium specimens [49]. However, herbarium collections in Rapa Nui are relatively scarce.

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