Fens and bogs in the Galápagos Islands

Syuzo Itow and Daniel Weber

伊藤秀三・D. Weber：ガラパゴス諸島の湿原

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Introduction

The Galápagos Islands are situated on the equator in the eastern Pacific, about 1000 km west of the South American coast (Fig. 1). Since the 19th century, botanical explorations have been made by many botanists and visitors, and recently the floristic setting of the islands has been comprehensively systematized by Wiggins & Porter (1971). The features of the vegetation and its habitat, especially of low and middle altitudes, have also been reported upon in a number of reports. The high altitudes, however, were less explored because of the difficulty of traversing barren lava fields on some islands and penetrating dense bushes on others, combined with waterless condition on most of them. Even when the highlands are visited, explorations and observations usually meet with difficulty owing to limited sight due to clouds and fog enveloping the areas. Only in such high altitudes, are Sphagnum species found in the archipelago.

From the Galápagos Islands, Sphagnum erythrocaryx Hampe was first reported by Williams (1924) on the basis of a collection from San Cristóbal by A. S. Stewart, a member of the 1905–1906 California Academy of Science expedition. The second species of the genus, Sph. cuspidatum Ehrh. var. serrulatum Schlieph., was reported by Bartram (1933) from Santa Cruz, together with the first species, based on a collection by J. T. Howell, the botanist of the 1932 Templeton-Crocker Expedition from the same Academy. W. Weber (1966), a member of the 1964 Galápagos International Scientific
Project (GISP) expedition, also reconfirmed the presence of the two species from the Santa Cruz highland.

![Map of the Galápagos Islands showing Sphagnum-bearing areas](image)

Fig. 1. Map of the Galápagos Islands showing *Sphagnum*-bearing areas (For details, see Figs. 2, 7 and 8).

The present paper deals only with the *Sphagnum*-bearing plant communities found in the highland areas. The field work of the senior author was made in 1964 as a member of the GISP expedition and again in 1970 on thirteen major islands; that of the junior author was from 1966 to 1971 on all the islands excepting the northernmost two. During the field work, not only were plant specimens collected, but also the topographic maps of the Santa Cruz highland and southern Isabela, which accompany the present paper, were compiled for the present and future studies of the vegetation and plant distribution. A bundle of plant specimens pertaining to the present study were identified by Dr. Ira L. Wiggins; many of the determination were made by the senior author at Stanford University in 1970 with the aid
of the sheets stored in Dudley Herbarium that were determined by Dr. Wiggins and the other contributors to "Flora of the Galápagos Islands" (Wiggins & Porter 1971), and also made at Nagasaki University thereafter. These determinations are the responsibility of the senior author. The scientific names of plants used here are according to Wiggins and Porter's Flora (1971). Specimens of *Sphagnum* were sent to Dr. H. Suzuki for identification.

We wish to express our sincere thanks to Dr. Ira L. Wiggins, Professor of Botany Emeritus, Stanford University, for his identification of some difficult groups of ferns and flowering plants, his generous permission for access to the determined sheets and the typescript of Flora and for his critical reading of our manuscript; and to Dr. Hyoji Suzuki, Professor of Botany, Hiroshima University, for his identifications of *Sphagnum* specimens and his comments on the fen and bog vegetation. Thanks are also due to Mr. Roger Perry, the former Director of the Charles Darwin Research Station at Santa Cruz, for his cooperative arrangements for our field work and accommodations.

**Climatic setting of plant life**

The Galápagos Islands lie in the South Equatorial Current and in the Southeast Trade Wind Zone. This setting largely controls not only the weather and climate but the plant life in the islands. The air temperature is low for the equatorial area owing to the cool water of the Humboldt Current. Based on the records made at Charles Darwin Research Station on the south coast of Santa Cruz (6 m above sea level), April is the warmest month when the mean air temperature is 25°C and October is the coldest with mean temperature of 15°C. No records are available for the air temperature of the highlands. It must be cooler than in the coastal region because of the higher altitude and limited duration of sunshine owing to clouds and fogs enveloping the area.

There are two seasons in the Galápagos: rainy season from January through May and dry season from June to December (Alpert 1963, Wiggins & Porter 1971). Records of the precipitation at different altitudes on the southern side of Santa Cruz (Table 1) show that the high altitude receives the greatest amount of rainfall throughout year
Table 1. Mean monthly precipitation in mm at three different altitudes on southern side of Isla Santa Cruz.*

<table>
<thead>
<tr>
<th></th>
<th>CDRS 6 m</th>
<th>Devinc's farm 315 m</th>
<th>Media Luna 620 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>31</td>
<td>116</td>
<td>141</td>
</tr>
<tr>
<td>February</td>
<td>35</td>
<td>163</td>
<td>86</td>
</tr>
<tr>
<td>March</td>
<td>51</td>
<td>225</td>
<td>247</td>
</tr>
<tr>
<td>April</td>
<td>51</td>
<td>23</td>
<td>77</td>
</tr>
<tr>
<td>May</td>
<td>45</td>
<td>59</td>
<td>136</td>
</tr>
<tr>
<td>June</td>
<td>13</td>
<td>43</td>
<td>177</td>
</tr>
<tr>
<td>July</td>
<td>13</td>
<td>71</td>
<td>131</td>
</tr>
<tr>
<td>August</td>
<td>11</td>
<td>49</td>
<td>148</td>
</tr>
<tr>
<td>September</td>
<td>16</td>
<td>77</td>
<td>230</td>
</tr>
<tr>
<td>October</td>
<td>17</td>
<td>53</td>
<td>138</td>
</tr>
<tr>
<td>November</td>
<td>12</td>
<td>60</td>
<td>163</td>
</tr>
<tr>
<td>December</td>
<td>11</td>
<td>73</td>
<td>129</td>
</tr>
<tr>
<td>Year</td>
<td>306</td>
<td>1012</td>
<td>1803</td>
</tr>
</tbody>
</table>

* Data from Conservation and Scientific Report, Charles Darwin Research Station, nos. 8, 11, 16 and 19.

and that the lesser rainfalls at low and middle altitudes show a marked difference between the rainy and dry season. The seasonal variation is closely associated with the viscidity of the southeast trade wind that prevails in the Galápagos region all the year. In a normal year, the wind is weak in the rainy season, the air temperature rises, as stated before, and more than half of the annual precipitation occurs in low and middle altitudes; the rainfall in the highland also is great. In the dry season, the trade wind is strong, the temperature drops low for the equatorial latitude and the precipitation is usually in the form of drizzle in the low and middle altitudes, when it occurs. On the other hand, the highlands, especially on the southern side of the island, are enveloped by clouds and fogs in daytime and receive a considerable amount of precipitation. This seems a result of the condensation of air moisture into droplets by the trade wind that blows up along the southern island slope.

The variation in rainfall with altitudes is reflected by the altitudinal
vegetation zonation. On the southern side of Santa Cruz, for example, there are six vegetation zones, ranging from Arid Coastal Zone, through Transition, Scalesia Forest and Brown Zones, to Miconia Belt (420 m–580 m in altitude) and Fern-Sedge or Grassland Zone (580 m–860 m) (Bowman 1963; Itow 1965, 1971; Wiggins & Porter 1971). On the northern side of the same island, however, the Brown Zone and the Miconia Belt are absent and the Scalesia Zone is directly contiguous to the Fern-Sedge Zone (Itow 1971). The zonation of the other islands is not the same but the rainfall distribution at different altitudes must be similar. The Sphagnum-bearing plant communities are scattered only in the high-altitude zones that receive much precipitation.

Ecology of fens and bogs

Based on our field surveys, Sphagnum species were found on San Cristóbal, Santa Cruz, San Salvador and southern Isabela (Fig. 1).
They reach altitudes over 700 m, and therefore, are hit rather strongly by the southeast trade wind. The highlands of these islands are usually enveloped by clouds all the year and wet and moist habitats, on which the bog moss grows, are abundant. On the remaining islands, no *Sphagnum* were found.

*Sphagnum erythrocalyx* was collected from the aforementioned four islands (new records for San Salvador and Isabela); *Sph. cuspidatum* var. *serrulatum* was found on San Cristóbal, Santa Cruz and Isabela (new record for San Cristóbal and Isabela but specimens from Isabela missing).

![Fig. 3. Schematic cross-section of the Santa Cruz highland showing the wind direction and the distribution of fens and bogs.](image)

The vegetation of fens and bogs is basically characterized by *Sphagnum* species. In the Galápagos, they are most abundant in the Fern-Sedge Zone of the Santa Cruz highland (Fig. 2). Unless otherwise noted, the descriptions given below are based on the studies in this highland that is easy of access. Three types of the *Sphagnum*-bearing community were recognized.

1. Fens

The plant community described as 'fen' was found in shallow depressions on gentle slopes in the highland. The ground layer of the community is filled by water that runs down from the upper slopes when rain is heavy or continuous (Fig. 3), or drenched even in rainless periods. *Sphagnum cuspidatum* var. *serrulatum* is characteristic to the fens. In January and February of 1964, the fens in the Santa Cruz highland were found in good condition with a plentiful supply of water, while in January to May of 1970, which were nearly rainless even in the rainy season, the bog mosses were killed by extreme dryness in some of the fens.
In floristic composition, the fens are distinguished from the other plant communities by the presence of *Rhynchospora rugosa*, *Rh. corymbosa*, *Polygonum opelousanum* in the herb layer of the community and that of *Sph. cuspidatum* var. *serrulatum* in the ground layer. Other species common or frequent in the fens are *Ludwigia leptocarpa*, *Eleocharis nodula*, *E. fistulosa*, *Paspalum conjugatum*, *Scleria pterota* (Fig. 4; Table 2).

**Table 2. Summary of floristic composition of fen, raised bog and vertical bog.**

<table>
<thead>
<tr>
<th>Species</th>
<th>Fen</th>
<th>Raised bog</th>
<th>Vertical bog</th>
<th>Other habitats</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Sphagnum cuspidatum</em> Ehrh. var. <em>serrulatum</em> Schlieph.</td>
<td>+++</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td><em>Polygonum opelousanum</em> Riddel ex Small</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td><em>Rhynchospora corymbosa</em> (L.) Britt.</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td><em>Rhynchospora rugosa</em> (M. Vahl) Gale</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td><em>Ludwigia leptocarpa</em> (Nutt.) Ham</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td><em>Eleocharis nodula</em> (Roth) Schult.</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td><em>Paspalum conjugatum</em> Bergius</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td><em>Sphagnum erythrocalyx</em> Hampe</td>
<td>+++</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td><em>Histiopteris incisa</em> (Thunb.) J. Smith</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td><em>Elaphoglossum firmum</em> (Mett.) Urban</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td><em>Elaphoglossum engelii</em> (Karst.) Christ.</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td><em>Nephrolepis cordifolia</em> (L.) Presl.</td>
<td>+++</td>
<td>++</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td><em>Pteridium aquilinum</em> (L.) Kuhn var. <em>arachnoideum</em> (Kaulf.) Herter</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td><em>Lycopodium clavatum</em> L.</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td><em>Dicranopteris flexuosa</em> (Schrad.) Underw.</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td><em>Pernettya howellii</em> Sleumer</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td><em>Lycopodium cernuum</em> L.</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td><em>Cyathea weatherbyana</em> (Morton) Morton</td>
<td>+++</td>
<td>++</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

+++ common, ++ frequent, + infrequent.
Plants found infrequently in the fens are *Centella asiatica*, *Vigna luteola*, *Drymaria cordata* and *Commelina diffusa*, although they can be seen commonly in the Fern-Sedge Zone. The peat underlying the bog moss is thin.

The fen is abundant on south-facing highland slopes of the Fern-Sedge Zone and upper parts of the Miconia Belt on Santa Cruz. They were not found on the northern slope (Fig. 2). The altitudinal range on the southern slope is from 540 m to 650 m. In the San Cristóbal highland, two fens were seen in the highland area between Cerro El Junco and Cerro San Joaquin (Fig. 7), but they were heavily disturbed by free-ranging cattle. On Isabela, a small fen was found at an altitude of 500 m (at the site called Los Tanques), about 4 km west of Santo Tomás (Fig. 8). It is also located on the southern island slope. Major species found there are *Eleocharis mutata*, *Polygonum opelousanum*, *Ludwigia repens*, *Vigna luteola*, *Azolla microphylla*, and *Sph. cuspidatum*.

2. Raised bogs

The plant community described as ‘raised bog’ is a bog formation having the general shape of an upset watchglass, and, therefore, the water is supplied only by rain or drizzle (Figs. 3 and 5). The ground layer of the vegetation is dominated by *Sphagnum erythrocalyx*. Other species found in the raised bogs were *Nepthrolepis cordifolia*, *Lycopodium clavatum*, *L. cernuum*, *Pteridium aquilinum var. arachnoidum*, *Dicranopteris flexuosa*, *Elaphoglossum engelii*, *E. firmum*, *Histiopteris incisa*, *Ludwigia leptocarpa*, *Eleocharis fistulosa*, *E. nodula*, *Pernettya howellii*, *Hibiscus diversifolia*, *Vigna luteola* and *Commelia diffusa* (Table 2). Many of the

Fig. 5. Profile of a raised bog. E: *Eleocharis fistulosa* Link and *E. nodula* Schult., El: *Elaphoglossum engelii* Christ and *E. firmum* Urban, Hi: *Histiopteris incisa* J. Smith, Ly: *Lycopodium cernuum* L. and *L. clavatum* L., Ne: *Nepthrolepis cordifolia* Presl., Pe: *Pernettya howellii* Sleumer, Sph. e.: *Sphagnum erythrocalyx* Hampe. Other abbreviations are the same as in Fig. 4.
bogs are fringed by a narrow band of *Paspalum conjugatum* and *Ludwigia leptocarpa* accompanying *Sph. cuspidatum var. serrulatum*. In some cases, a complex formation is made up of hummocks of *Sph. erythrocalyx* and hollows of *Sph. cuspidatum*. These facts suggest that the raised bog is an advanced phase of the plant succession that took place in the fen. According to Colinvaux (1968), the peat underlying the living bog moss is 5 m thick at center of a bog in the Santa Cruz highland.

On Santa Cruz, several of the raised bogs were found in the floor of small craters of low cinder cones that are scattered in the Fern-Sedge Zone, south of the Cerro Crocker ridge (Fig. 2). The bog size ranges from 4 m to more than 50 m across. The altitudinal range is from 650 m to 800 m. On Isabela, a raised bog was found at an altitude of 850 m, 1 km south of El Mirador, on the southern slope of Volcán Sierra Negra (Fig. 8).

3. Vertical bogs

The second type of the bog formation is the 'vertical bog.' As it literally means, this bog formation is seen on vertical and nearly vertical topography such as cliffs and inner walls of craters. *Sphagnum erythrocalyx* is 20 cm to 50 cm thick on the vertical cliff. In terms of water supply that is essential to the growth of the bog moss, the vertical bog is a type of raised bogs, because the water is supplied only by the precipitation. The habitat condition that supports the vertical bogs is created by a specialized situation, as mentioned below. In many of the cinder cones in the highlands, the crater rim is lower at the southern or southeastern side than at the other sides. (This is probably because the ash, scoria and other ejecta from the crater were driven to leeward by winds when the volcano was active in the past.) As air is forced to blow up along the southern side of the island, it becomes saturated with moisture or nearly so. Then the saturated air is adiabatically expanded and cooled over the crater and the moisture condensed into droplets, that are driven to hit directly the south- or southeast-facing inner wall of the crater (Fig. 6). This phenomenon was actually seen on a cloudy day in April, 1970. This is why the south- or southeast-facing cliffs of the craters are usually moistened even in daytime and vertical cliffs support the bog formation. (This
Fig. 6. Profile of a vertical bog on inside wall of a small crater. Cy: Cyathea weatherbyana Morton. Other abbreviations are the same as in Figs. 4 and 5.

Fig. 7. Map of the San Cristóbal highland showing the location of fen (triangle) and vertical bog (square).

is also the reason why many of the craters of cinder cones support the raised bog in the floor.

The dominant species of the vertical bogs is Sph. erythrocalyx. The most prominent is Cyathea weatherbyana, a tree fern endemic to the Galápagos Islands. This fern can be seen not only growing from the vertical bogs but in other wet or moist habitats like stream beds (many of which are usually waterless but seepy), inside of craters and valley-like topography. Other common and frequent species are the same
as those in the raised bogs (Table 2).

The vertical bogs were found in highlands of San Cristóbal, Santa Cruz, San Salvador and Isabela (Volcán Sierra Negra) (Figs. 2, 7 and 8). In the Santa Cruz highland, two vertical bogs were seen at two craters situated between Cerro El Camote and Cerro Crocker (Fig. 2). The larger one is more than 10 m wide and 10 m high. Besides the two bogs, a small patch of Sph. erythrocalyx, about 30 cm in diameter, was seen on a rock edge on a crater rim. This suggests that the Sphagnum-favored habitat is created by very delicate air flow affected by topography.

On San Cristóbal, two vertical bogs were found on a south-facing cliff at Cerro San Joaquin, the highest peak of the island (Fig. 7). The larger one is about 10 m wide and 10 m high. It looked like a waterfall when seen from a distance. Since the crater rim is largely broken at its southern side, the air moisture seems to be condensed into fog and drizzle when it is forced to blow up along a small cinder cone located about two hundred meters south of the vertical cliff. Plants found in the bogs are nearly the same as those in Santa Cruz.

Fig. 8. Map of southern Isabela showing the location of major parasitic cones, fen (triangle), raised bog (dot) and vertical bog (square). The mark ? is a locality at which a Sphagnum species was found but no collections were made.
On San Salvador, two vertical bogs were found in the highland. The cliffs supporting the bogs are facing south. The altitude is 760 m. Plants found there are *Cyathea weatherbyana*, *Elaphoglossum engelii*, *Nephrolepis cordifolia* and some others. On Isabela, a small patch of *Sph. erythrocalyx* (1 m in diameter) was found on a very steep slope (not vertical) at an altitude of 1000 m, 1 km east of Cerro El Mirador, on the southeastern slope of the Volcán Sierra Negra caldera.

**Summary**

1. The *Sphagnum*-bearing plant communities were studied ecologically on Islas San Cristóbal, Santa Cruz, San Salvador and Isabela of the Galápagos Islands. *Sphagnum cuspidatum* Ehrh. var. *serrulatum* Schlieph. was collected from the first two of the above-mentioned islands (new record for San Cristóbal). *Sph. erythrocalyx* Hampe was collected from the four islands (new for San Salvador and Isabela).

2. The *Sphagnum*-bearing communities were found only in the highland areas that receive abundant precipitation. They can be classified into fen, raised bog and vertical bog.

3. The fens are found in shallow depressions that are filled with water or drenched. It is characterized by *Sph. cuspidatum* var. *serrulatum*.

4. The raised bogs are shaped like an upset watchglass, to which the water is supplied only in the form of rain or drizzle. *Sph. erythrocalyx* is dominant in the vegetation.

5. The vertical bogs are seen on vertical or nearly vertical cliffs that are hit and moistened by droplets or moisture-saturated air driven by the southeast trade wind. The vertical bogs are restricted to the cliffs facing to south and southeast. The bog formation is basically made up by *Sph. erythrocalyx*.

6. Topographic maps of the Santa Cruz highland and southern Isabela were compiled for the present and future studies of the vegetation.

**References**


Bartram, E. B. 1933. Mosses of the Templeton Crocker Expedition, collected by


摘 要

ガラパゴス諸島は、東太平洋の赤道下、南東貿易風帯の中にある。ミズゴケを生ずる湿原は、4つの島（サンクリストバル・サントカルス・サンサルバドル・イザベラ南部）の海拔500 m以上の高地に限られる。そこは南東貿易風の影響をもっても強くうけて、乾期（5～12月）にも雨期（1～4月）と同じように、雨または霧雨によって水分が供給される。調査により、次の結果を得た。

1. Sphagnum cuspidatum Ehrh. var. serrulatum Schlieph. はサンクリストバル島（新記録）とサンタカルス島に、Sphagnum erythrocalyx Hampe は前記の4島（うちサンサルバドル島とイザベラ島は新記録）に生ずる。

2. ミズゴケを生ずる湿原群落は、立地・群落形態・種組成から、低層湿原・高層湿原・垂直湿原（新称）に分類され、いずれも高地に生ずる。

3. 低層湿原は、斜面上部から水が流下する浅い凹地に発達し、Sph. cuspidatum var. serrulatum によって特徴づけられる。

4. 高層湿原は Sph. erythrocalyx に特徴づけられる。ミズゴケ生育に基本的な水分は降水（雨または霧雨）によって供給される。本種の小隆起と Sph. cuspidatum の小凹地の複合するものもあり、充分に発達したものでは時計皿状の形状をなす。サンタカルス島高地では、低い火口の底にも発達している。

5. 垂直湿原は、垂直またはほとんど垂直な崖状地形にのみ発達する。高層湿原と同じく、Sph. erythrocalyx によって特徴づけられるほか、他の構成種もほとんど共通する。垂直湿原は、すべて雨または南東向きの風にあり、南東貿易風が運ぶ水分飽和に近い空気、または、それから凝結した水滴、および雨や霧雨が直接に吹きつけ、それによってミズゴケ生育の水分が供給されている。南または南東に向いている火口内
Explanation of plates

Plate I
Top: Highland landscape of Santa Cruz, as seen from the highest point of Cerro Crocker toward ESE. A. Cerro El Camote; B. Crater supporting vertical bog on its inside wall; C. Crater having a raised bog in the floor. (Photo by S. Itow)
Middle: A corner of a raised bog in the floor of a crater. Notice the narrow band of *Paspalum conjugatum* fringing the bog. Santa Cruz. (Photo by S. Itow)
Bottom: A close view of raised bog. *Blechnum polypondioides* at left and right and *Pernettya howellii* at center. (Photo by S. Itow)

Plate II
Top: Two vertical bogs on inside wall of a crater, facing to southeast. Santa Cruz. (Photo by S. Itow)
Below left: A closer view of vertical bog. Santa Cruz. (Photo by D. Weber)
Below right: Patches of *Sphagnum erythrocalyx* on vertical cliff in the San Salvador highland. *Cyathea weatherybana* at center. (Photo by D. Weber)