Cryptogams of the Galapagos Islands (lichens, bryophytes, and fungi): New records, threats, and potential as bioindicators – a first evaluation

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Introduction

Lichens, fungi, and bryophytes are frequently referred to as *lower plants*, *non-vascular plants*, or *cryptogams*. All terms are partially incorrect but used for convenience. Strictly speaking only bryophytes are plants. Although lacking conductive tissues, they are photosynthetic. Fungi are not photosynthetic, typically penetrating their substrate as threads of cells. Lichens are fungi in close association with algae. Their algae photosynthesize, supplying the fungus with nutrients, while the fungus provides the structural component.

A) ***Graphis subchrysocarpa***, a crustose lichen with reddish fruiting bodies.

B) ***Bryopteris filicina***, a characteristic liverwort of the humid highlands.

C) ***Podaxis pistillaris***, a characteristic species of dry Galapagos lowlands.

Cryptogams are a diverse group (Figure 1) present in all terrestrial Galapagos ecosystems and dominant in some vegetation zones. Coastal lava is covered by thick crusted lichens that cause weathering. In the dry zone, trees are encrusted with lichens - a protective layer against overheating. In the transition zone, pale green lichens droop from branches, collecting mist and rainfall. Moss and liverwort carpets drape trees throughout the humid zone in the highlands, collecting the fine mist (garúa) that occurs duing the dry season and producing drip pools on the forest floor. In the humid highlands, *Sphagnum bogs* and lichen heaths are locally common.

Fungi are crucial for soil fertility. They disintegrate organic litter or live within plant roots enhancing nutrient supply. Other fungi are pathogens, and their potential as biocontrol agents is being investigated for blackberry (*Rubus niveus*) and lantana (*Lantana camara*), two of the more aggressive invasive species.

Despite their importance and abundance, Galapagos cryptogams have been neglected in the past. Very few studies document which species are known, rare, or threatened. Their potential as bioindicators has been ignored and their distribution and ecological requirements remain largely unknown. Without this information, understanding of terrestrial ecology is at best fragmentary.

Baseline inventory

Lichen inventories date back to the 1960s (Weber, 1966; Weber & Gradstein, 1984; Weber *et al.*, 1977), culminating in a preliminary checklist (Weber, 1986) with brief updates (Elix & McCarthy, 1998; Weber, 1993). Weber (1966) also published the first checklist of bryophytes, which has been updated (Gradstein & Weber, 1982; Weber, 1976). Reports of macrofungi date back to Darwin (Berkeley, 1842). Subsequent reports are scattered (Bonar, 1939; Evans, 1916; Martin, 1948), with the most current checklist published by Reid *et al.* (1981). Recent surveys have significantly increased our knowledge (Figure 2).

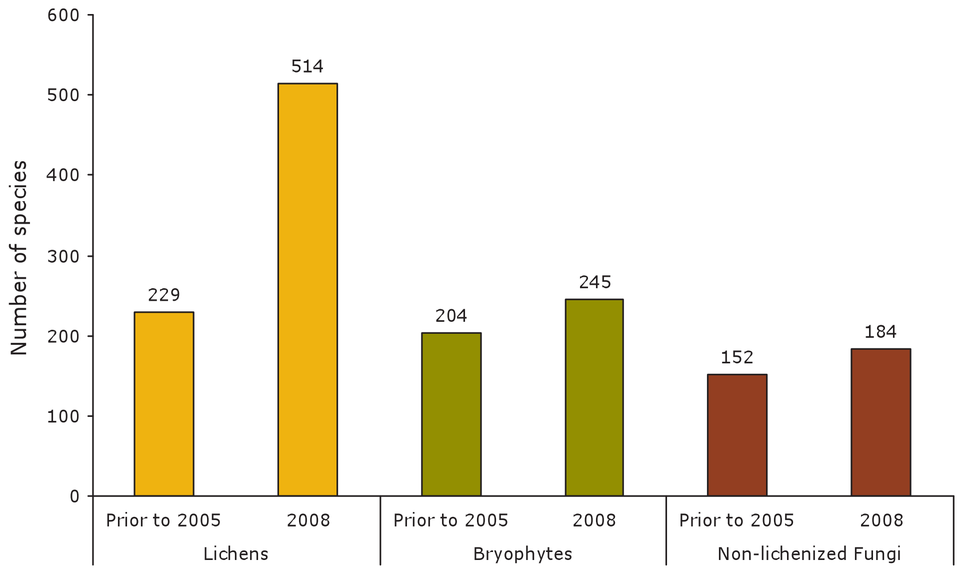

Figure 2. Number of species of Galapagos non-vascular plants (lichens, bryophytes, and fungi) from publications prior to 2005 and current total records (including both records prior to 2005 and from recent surveys).

From December 2005 to January 2008, lichens and bryophytes were collected on Bartolomé, Gordon Rock, Isabela (Sierra Negra, Volcán Alcedo, Volcán Darwin), Pinta, Pinzón, Plaza Norte, Plaza Sur, Rábida, San Cristóbal, Santa Cruz, Santa Fe, and Santiago (Figure 3). A few previous collections are available from Bainbridge Rock No. 6, Daphne Major, Española, Fernandina, Floreana, Seymour Norte, and Wolf. Due to their high dispersal capabilities, the inventory of fungi has been restricted to Santa Cruz. In total, ca. 9000 specimens are now deposited at the Charles Darwin Research Station.

Figure 3. Islands visited during the 2005-08 species inventory of lichens, fungi, and bryophytes.

The large islands have a much wider range of vegetation zones and support higher diversity (Figure 4); however, data must be interpreted with caution as Santa Cruz has been more intensively studied than the other islands.

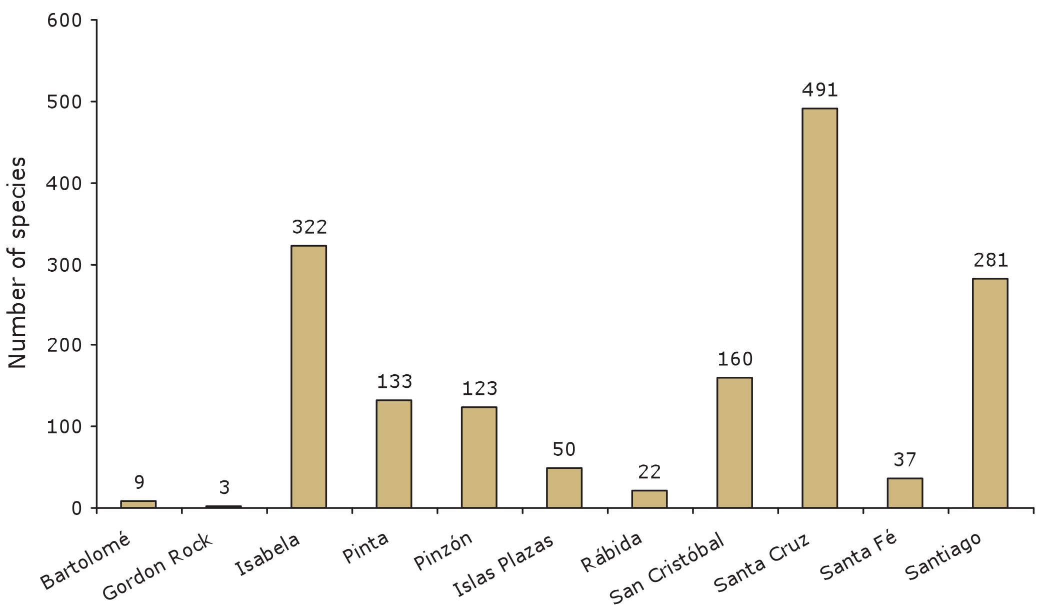

Figure 4. Number of non-vascular plant species (excluding non-lichenized fungi) collected in Galapagos during the 2005-08 inventory.

Most specimens are preliminarily identified (Figure 5). Taxonomic revisions have been published or submitted for: Collemataceae (five records new to Galapagos; Bungartz, 2008), *Ramalina* (four species new to science, nine new records; Aptroot & Bungartz, 2007), crustose Roccellaceae (two species new to science, twenty new records; Aptroot & Sparrius, 2008), *Roccella* (one species new to science;

Tehler *et al.*, 2008), and Graphidaceae (four species new to science, 23 new records; Bungartz *et al.*, 2008).

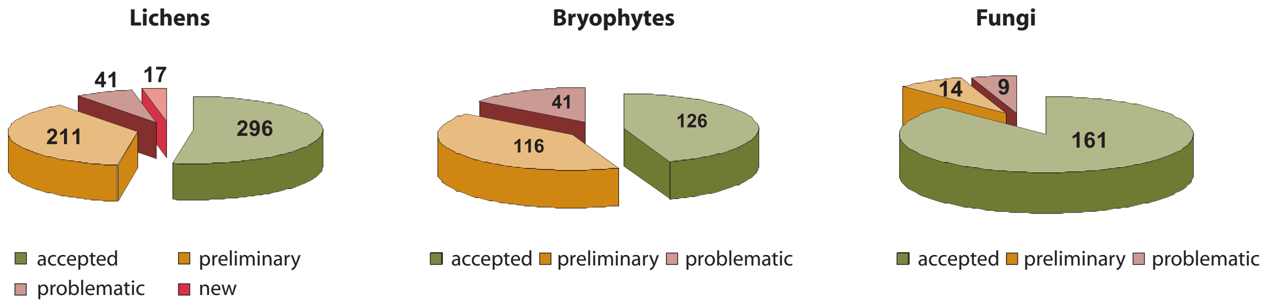

Figure 5. Number of species identifications of herbarium specimens by identification status: a) lichens, b) bryophytes, and c) fungi. Accepted = confirmed using literature and chemical and microscopic analysis. Preliminary = requiring further studies. Problematic = identification does not concur in all aspects with literature references. New = species new to science, either published, or publication in progress.

Though species are generally distributed throughout all habitats, lichen diversity appears highest within the humid zone, followed by the transition, dry, and coastal zones (Figure 6). Again, these figures must be treated with caution. In the humid zone, diversity is disproportionably higher. Because of anthropogenic disturbance, agricultural areas now include species adapted to open habitat originally typical for drier zones.

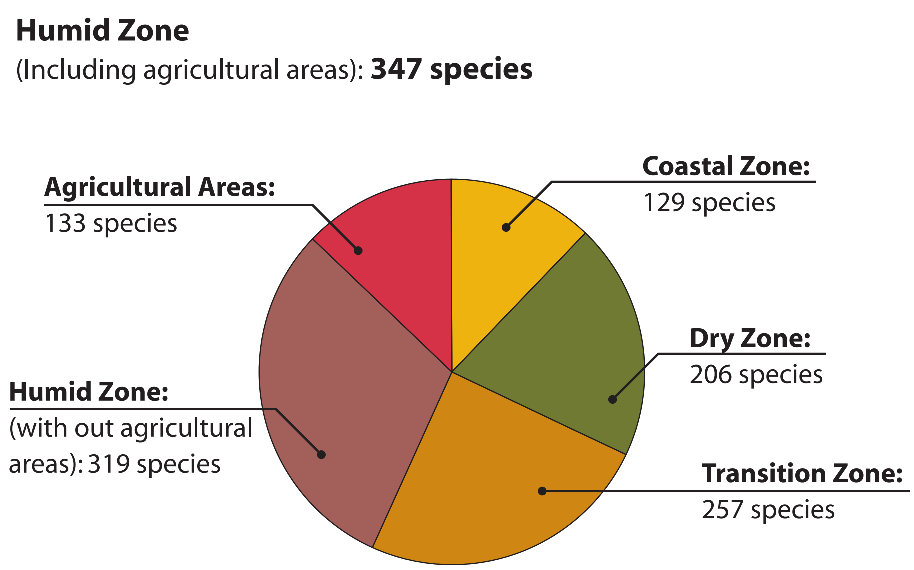

Figura 7. Species diversity of lichens according to Galapagos vegetation zones. Note: there are species that are distributed both in the humid and agricultural zone.

A preliminary estimate suggests that approximately 8-10% of all lichens are endemic, mostly in the coastal and dry zone. Despite lack of historical data, the majority of species is considered native, although preliminary studies indicate higher affinities for some epiphyte species to introduced trees (Nugra-Salazar, 2008).

Both diversity and abundance of bryophytes is highest in the humid zone. Very few species are naturally adapted to dry, open habitat and less than 4% are believed endemic.

Fungi are the least studied group (Arturo-López, 2008) and the existing data do not allow comparison across different zones. The increase of known species (Figure 2) can be attributed to a recent survey of Agaricales (Arturo-López, 2008) and collections of phytopathogenic fungi.

Potential as bioindicators

Lichens and bryophytes obtain water and nutrients directly from the air. They are slow-growing, adapted to mature habitat with high ecological continuity, and sensitive to environmental change. Both groups have been used in other parts of the world as indicators of air pollution, forest health, and climate change (Gries, 1996; Nash & Wirth 1988; Rose, 1976; Rose, 1992; Rose & Wolseley, 1984).

Climate change has the potential to create greater weather extremes, with prolonged and more intense droughts and increasing frequency of El Niño events. If these changes occur, effects should be most pronounced for the following potential bioindicators:

1) Coastal and Arid Zones: lichens on twigs and branches, in particular *Ramalina spp.*

2) Transition Zone: pendulous species contributing to the natural water supply (e.g., *Ramalina* spp., *Usnea* spp., *Teloschistes chrysophthalmus*); some rare species (e.g., *Lobaria dissecta*).

3) Humid Highlands: species that rely on high humidity (lichens: *Leptogium*, *Pseudocyphellaria*, *Coccocarpia*, *Acantholichen*, *Dictyonema*; bryophytes: *Frullania*, *Bryopteris*).

Species rarity and conservation

The considerable increase in known species results from more comprehensive surveys and improved taxonomy. Despite intense surveys, five historically documented species were not relocated and a disproportionately high number is considered extremely rare or rare (Figure 7). The observations are alarming. Potential causes include:

Habitat fragmentation and disturbance: on inhabited islands natural forests have been considerably altered by agricultural land use.

Forest degradation from introduced herbivores: e.g., the destruction of vegetation on Santiago and Volcán Alcedo by goats.

Climatic effects: Weber & Beck (1985) observed drastic population collapses for some species whereas some common bryophyte species became much more abundant after the 1982-83 El Niño; Galapagos species should be adapted to these events but re-establishment has been slow. The cumulative effects of disturbance, habitat degradation, and climate change may have delayed recovery.

Invasive species control: herbicides (e.g., at Los Gemelos on Santa Cruz) are detrimental to cryptogam diversity (Arturo-López, 2008; Nugra-Salazar, 2008).

Restoration of native vegetation: recovery is a slow process; within young forests epiphytes have not yet re-established; the reservoir of rare species may be insufficient for a rapid recovery, which may only occur over the long term.

Locally problematic areas include:

Trash burning at the waste deposit at km 27 on Santa Cruz causes air pollution on a local scale; in the immediate vicinity lichens and bryophytes are no longer present, resulting in a "*cryptogam desert.*"

The cinder cone above Mina Granillo Rojo on Santa Cruz is the only known site for some extremely rare species. This part of the transition zone is characterized by exceptionally high diversity; the open quarry already contributes to dust contamination and habitat destruction; further expansion will have a detrimental impact.

Photograph: Frank Bungartz

Recommendations

A series of recommendations have resulted from this study. These include:

Complete the species inventories; expand the fungal inventory to include all vegetation zones of Santa Cruz.

Monitor recovery following goat eradication on Santiago, Volcán Alcedo, and Pinta; identify species that recover rapidly vs. ones that recover slowly.

Monitor long-term effects from climate change and El Niño events, with particular emphasis on disturbed sites.

Investigate the effects of eradication and control regimes for invasive plant species on the cryptogam vegetation.

Monitor population recovery during restoration of native vegetation.

Abolish or minimize trash burning.

Reduce and restrict mining to areas of low species diversity (e.g., alternative sites like the Mina Granillo Negro).