We will examine adaptive radiations, in the context of the Hawaiian Islands.
Hawaiian archipelago - the example for adaptive radiations

“Getting there is half the problem . . . but then they can’t go home again”

Sherwin Carlquist, 1965
Hawaiian archipelago - *the example for adaptive radiations*

“If one were to stand at the top of Mauna Loa, he could see all the climes of the world at a single glance of the eye”

Mark Twain, 1866

4,169 m OR 13,679 ft
Hawaiian archipelago - *the example for adaptive radiations*

“Assume nothing in Hawaiian natural history”

Frank Howarth, 1992
Hawaiian archipelago - *the example* for adaptive radiations

Most remote island system in the world

- settled in 1st millennium by Polynesians
- made known to science by Captain Cook in 1778
Hawaiian Biota

Hawaiian biota: most are found nowhere else in the world and exhibit traits uncharacteristic of their taxa

- around 1,000 species of flowering plants
- 225 species of ferns and allies
Hawaiian biota: most are found nowhere else in the world and exhibit traits uncharacteristic of their taxa

- nearly 5,800 species of insects
- 130 species of spiders
Hawaiian Biota

Hawaiian biota: most are found nowhere else in the world and exhibit traits uncharacteristic of their taxa

- 230 species of birds
- 800 species of terrestrial molluscs
Hawaiian Biota

Hawaiian biota: most are found nowhere else in the world and exhibit traits uncharacteristic of their taxa

- no amphibians
- no terrestrial mammals

Hawaiian bat

Hawaiian monk seal
Hawaiian Biota

Hawaiian biota: extinction on-going process both in past and present

Hawaiian hoary bat
- arrived 10,000 years ago

Extinct small Hawaiian bat
- arrived 320,000 years ago
- extinct 1,100 years ago
Hawaiian biota: extinction on-going process both in past and present

Extinct snail, flightless duck, lobeliad

Hawaiian honeycreepers
Hawaiian Archipelago

- 132 islands, reefs, & shoals
- 2,580 km on SE-NW line
- 99% of land lies on 8 main islands near the hot spot below Lo’ihi
Hawaiian Archipelago

- hot spot stationary relative to Pacific Plate motion
- forms hot spot trace
- potassium-argon dating indicates oldest islands furthest from hot spot
- newest island Loihi still underwater - seamount
Hawaiian Archipelago

- plate motion changed 43 mya
- oldest seamounts subducted into Aleutian Trench
Hawaiian Archipelago

- Islands (and shoals) are simply emergent tops of great underwater volcanoes
- up to 10 km above ocean floor

Mauna Kea – 10.2 km (4.2 km)

Maua Loa - 37 m lower but most massive
Hawaiian Archipelago

- actually double hot spot 30km apart
- Lo’ihi to Mauna Loa
- Kilauea to Mauna Kea

Oahu

Hawaii
Hawaiian Climate

- primary weather pattern is northeasterly trade winds
- severe kona winds come from leeward side

Hilo (windward and wet) vs. Kona Coast in Hawaii (leeward and dry)
Hawaiian Climate

rainfall patterns

- double mountain system (as in Oahu) sets up complex rainfall gradient and a diversity of ecosystems
Hawaiian Climate

• extraordinary rich and diverse habitats available
• 38 community types recognized
Hawaiian Climate

rainfall patterns

- Wai’ale’ale on oldest (most eroded) island of Kauai is wettest spot in Hawaii and possibly in the world

- 11.5 m of rain and presence of the Alakai Swamp
Hawaiian Climate

rainfall patterns

- **Pu’ukukui** (5,788 ft) on west Maui is 2nd wettest spot; xeric summit of **Haleakala** on east Maui is 10,023 ft

Greensword bog - west Maui
Flora of Hawaii

• since so isolated, it has a *depauperate* flora and consists entirely of *waif* elements derived from LDD

*native* or *weeds*

*Argyroxyphium sandwicense* - Haleakala silversword
*Passiflora mollissima* - Banana poka
Flora of Hawaii

- individual islands tend to fit the expected number of species based on area - except most recent Hawaii

**Figure 5** Species–area regression for whole islands. Abbreviations are given in Table 2.
Flora of Hawaii

- **endemism** high in flowering plants (highest in world)

956 native species
- 89% endemic

216 native genera
- 15% endemic

87 native families
- 0% endemic

1,817 including introduced

649 including introduced

146 including introduced

*Brighamia* (Lobeliaceae)
Flora of Hawaii

- Disharmonic flora

- Only 3 native orchid species

- But many introduced orchids that become naturalized

*Dendrobium* & honey bees
Flora of Hawaii

- disharmonic flora

- only 1 native palm genus

- native gymnosperms and primitive angiosperms absent

Pritchardia beccariana
Flora of Hawaii

- **disharmonic flora** - 15 largest families of native species

<table>
<thead>
<tr>
<th>Family</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campanulaceae</td>
<td>110</td>
</tr>
<tr>
<td>Asteraceae</td>
<td>92</td>
</tr>
<tr>
<td>Rutaceae</td>
<td>55</td>
</tr>
<tr>
<td>Lamiaceae</td>
<td>54</td>
</tr>
<tr>
<td>Rubiaceae</td>
<td>54</td>
</tr>
<tr>
<td>Gesneriaceae</td>
<td>53</td>
</tr>
<tr>
<td>Poaceae</td>
<td>47</td>
</tr>
<tr>
<td>Cyperaceae</td>
<td>45</td>
</tr>
<tr>
<td>Caryophyllaceae</td>
<td>33</td>
</tr>
<tr>
<td>Piperaceae</td>
<td>25</td>
</tr>
<tr>
<td>Malvaceae</td>
<td>24</td>
</tr>
<tr>
<td>Euphorbiaceae</td>
<td>21</td>
</tr>
<tr>
<td>Fabaceae</td>
<td>20</td>
</tr>
<tr>
<td>Solanaceae</td>
<td>9</td>
</tr>
<tr>
<td>Myrtaceae</td>
<td>8</td>
</tr>
</tbody>
</table>

- **large source area families under represented**
- **small Campanulaceae - lobeliads and bellflowers - over represented**
Flora of Hawaii

• **immigrants**: 270 (or less!) gave rise to 956 native angiosperms

- 1/10<sup>th</sup> of colonist generates 1/2 of species!

**TABLE 3. Twenty most speciose genera of Hawaiian flowering plants and presumed numbers of colonists.**

<table>
<thead>
<tr>
<th>Genus</th>
<th>Number of species</th>
<th>Presumed number of colonists</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyrtandra</td>
<td>53</td>
<td>4–6</td>
</tr>
<tr>
<td>Cyanea</td>
<td>52</td>
<td>1</td>
</tr>
<tr>
<td>Pelea</td>
<td>47</td>
<td>1</td>
</tr>
<tr>
<td>Phyllostegia</td>
<td>27</td>
<td>1</td>
</tr>
<tr>
<td>Peperomia</td>
<td>25</td>
<td>3–4</td>
</tr>
<tr>
<td>Clermontia</td>
<td>22</td>
<td>—</td>
</tr>
<tr>
<td>Schiedea</td>
<td>22</td>
<td>1</td>
</tr>
<tr>
<td>Dubautia</td>
<td>21</td>
<td>1</td>
</tr>
<tr>
<td>Lipochaeta</td>
<td>20</td>
<td>2 (polyphyletic)</td>
</tr>
<tr>
<td>Stenogyne</td>
<td>20</td>
<td>—</td>
</tr>
<tr>
<td>Myrsine</td>
<td>20</td>
<td>1–2</td>
</tr>
<tr>
<td>Hedyotis</td>
<td>20</td>
<td>1–2</td>
</tr>
<tr>
<td>Bidens</td>
<td>19</td>
<td>1</td>
</tr>
<tr>
<td>Pritchardia</td>
<td>19</td>
<td>1</td>
</tr>
<tr>
<td>Chamaesyce</td>
<td>15</td>
<td>1–2</td>
</tr>
<tr>
<td>Labordia</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>Sicyos</td>
<td>14</td>
<td>1</td>
</tr>
<tr>
<td>Coprosma</td>
<td>13</td>
<td>2</td>
</tr>
<tr>
<td>Lobelia</td>
<td>13</td>
<td>2</td>
</tr>
<tr>
<td>Wikstroemia</td>
<td>12</td>
<td>1</td>
</tr>
</tbody>
</table>

**Totals**: 469 | 26–32
Flora of Hawaii

- **immigrants**: similar story with other biota
- one American finch gave rise to 33 extant and 14 extinct species of honeycreepers
Flora of Hawaii

• **immigrants**: similar story with other biota
  
  • 800 land molluscs from 20 colonists
  • 5,800 insects from 250 colonists
Flora of Hawaii

- **immigrants**: but different story for ferns!

- 168 ferns from 135 colonists - implying constant immigration (lack of genetic isolation) and/or few speciation events

\[
\text{Sadleria} - 6 \text{ species} \quad \text{vs.} \quad \text{Polypodium} - 1 \text{ species}
\]
Flora of Hawaii

- **LDD mechanisms**

<table>
<thead>
<tr>
<th>%</th>
<th>Mechanism</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>air</td>
</tr>
<tr>
<td>39</td>
<td>BI</td>
<td>internal</td>
</tr>
<tr>
<td>13</td>
<td>BM</td>
<td>mud</td>
</tr>
<tr>
<td>10</td>
<td>BV</td>
<td>viscid</td>
</tr>
<tr>
<td>12</td>
<td>BB</td>
<td>barbs/hooks</td>
</tr>
<tr>
<td>14</td>
<td>DF</td>
<td>drift</td>
</tr>
<tr>
<td>9</td>
<td>DR</td>
<td>drift - rare</td>
</tr>
</tbody>
</table>

74% - Leptocophylla BI

74% - Argyroxiphium BB

74% - Acacia - koa DR

74% - Viola BM
Flora of Hawaii

• floristic affinities

Despite proximity of Hawaii to N America, almost half of colonists are of Austral-asian origin
Flora of Hawaii

- floristic affinities

- few from Arctic-Beringia

Viola

Plantago - plantain
Flora of Hawaii

- floristic affinities

Viola

Viola langsdorfii

- woody violets once considered closely related to South American violets

- all native Hawaiian violets are polyploid and derived from polyploid races of one Beringian tundra species - the Alaskan violet
Flora of Hawaii

- floristic affinities

- 18-22% from western North America
Flora of Hawaii

- **adaptive radiation** of Hawaiian silverswords

- silversword alliance of 3 genera and 28 species

- trees, shrubs, subshrubs, rosette plants, cushion plants, vines
Flora of Hawaii

• adaptive radiation of Hawaiian silverswords

• B. Baldwin verified that the Hawaiian silversword radiation derived from California

• the closest species is now called Carlquistia muirii

• this origin occurred about 5 mya

• rapid radiation at base
Flora of Hawaii

- **inter-island biogeography** [“island hopping” – “stepping stones”]
  - most speciation events occur on individual islands
  - few successful inter-island colonizations
  - movement is from older to younger islands
Flora of Hawaii

- **extinction**: on-going process on islands (as well as immigration)
  
- but due to humans . . .
  
- 107 of 956 angiosperm species — 11% extinct
- 423 of 956 species — 38% extinct or threatened
Flora of Hawaii

- extinction: rogue gallery of exotics

Passiflora mollissima - banana pokal
Flora of Hawaii

- extinction: rogue gallery of exotics

*Miconia* introduced into Hawaii as ornamental

*Miconia calvescens* “green cancer”
Hawaiian Lobeliads

Why the Hawaiian lobeliads?

- largest group: 6 genera, 115 species
- 1/9th of native flora
- considered derived from 3-5 separate colonizations
- phenomenal variation in habitat, life form, flowers, and fruits
Hawaiian Lobeliads

Why the Hawaiian lobeliads?

- appear to have co-evolved with the endemic Hawaiian honeycreepers
- honeycreepers represent a separate adaptive radiation
The Hawaiian lobeliads represent a single lineage/colonization!
Hawaiian Lobeliads

The Hawaiian lobeliads – most *spectacular adaptive radiation*
Hawaiian Lobeliads

Two approaches for dating and placing the Hawaiian colonization

1. Calibration using an external phylogeny of the order Asterales and 5 well characterized fossils outside the family Hawaiian lobelioids
Hawaiian Lobeliads

Two approaches for dating and placing the Hawaiian colonization

2. Calibration using geological island dates for between island shifts

- Nihau vs. Kauai
- Kauau vs. Ohau
- Ohau vs. Maui
- Maui vs. Hawaii
Hawaiian Lobeliads

Two clock calibrations - using Asterid fossils or using Hawaiian Island ages - place the differentiation of Hawaiian lobeliads at 13-14 mya.
Hawaiian Lobeliads

Two clock calibrations - using Asterid fossils or using Hawaiian Island ages - place the differentiation of Hawaiian lobeliads at 13-14 mya.

Original colonist arrived in LaPerouse/Gardner Pinnacles - large volcanic islands 10-15 mya.
Hawaiian Lobeliads

Two clock calibrations - using Asterid fossils or using Hawaiian Island ages - place the differentiation of Hawaiian lobeliads at 13-14 mya

Original colonist arrived in LaPerouse/Gardner Pinnacles - large volcanic islands 10-15 mya

Figure 3. Island configurations at 5 Myr intervals. We adjusted a rough digital elevation model of the estimated pre-erosion surface according to height estimates for different points in time. Ku, Kure; PH, Pearl and Hermes; Li, Lisianski; La, Laysan; Ma, Maro; G, Gardner; LP, LaPerouse; Ne, Necker; Ni, Nihoa; Ka, Kauai; Oa, Oahu; MN, Maui Nui; Ha, Hawaii.
Hawaiian Lobeliads

One of the oldest radiations of extant Hawaiian biota - honeycreeper pollinators would not arrive for another 7-9 my
Hawaiian Lobeliads

But . . . a 2008 paper shows that the 5 recently extinct Hawaiian Honeyeaters – thought to be recently derived from AustralAsian Honeyeaters – are in fact 14-17 my old and derived from an American clade - waxwings, silky flycatchers, and palm chats

Hawaiian lobeliads 13-14 mya

Hawaiian Honeycreepers 7 mya
Hawaiian Lobeliads

• Early lobeliads had initial radiation with Hawaiian honeyeaters

• later radiation of two large genera (Cyanea and Clermontia) primarily with Hawaiian honeycreepers