Plant evolution of islands

1. Islands as evolutionary laboratories – Darwin and the Galápagos

2. Colonization and establishment: the reproductive biology and genetics of island plants

3. A glimpse of Caribbean islands and cays

4. Island hopping: Juan Fernández, New Caledonia and Australia

Island biology

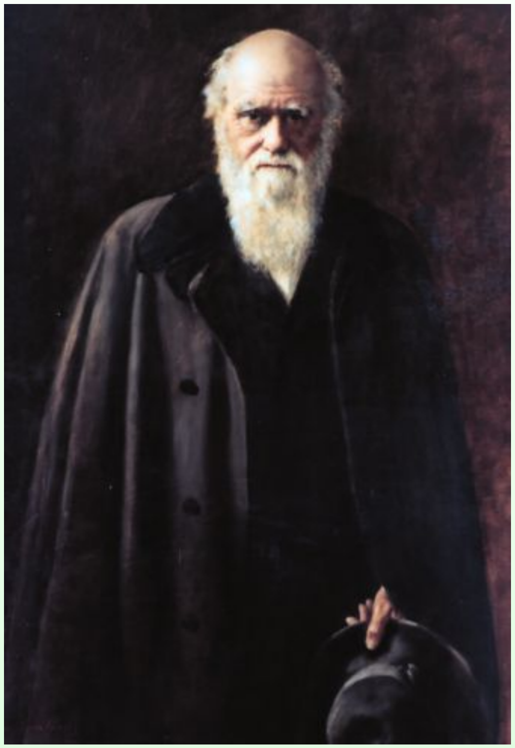
1. Main influences on diversity: island age & size, distance from mainland, environmental heterogeneity and intensity of human disturbance

2. Geographical isolation & novel environments result in evolutionary diversification (= adaptive radiation) and high levels of endemism

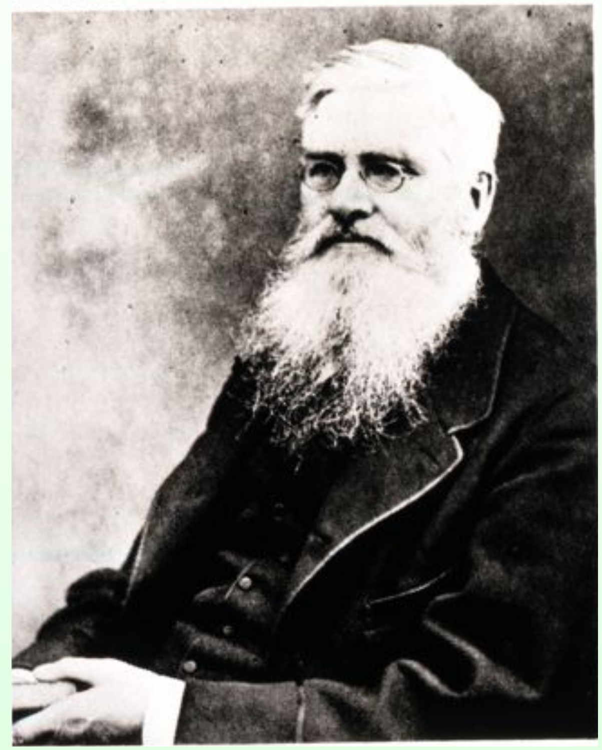
3. Founder effects and genetic bottlenecks a prominent feature of island populations

4. Island novelty includes: evolution of woodiness, high incidence of dioecy, transitions to selfing and wind-pollination

Islands as evolutionary laboratories



Darwin



Wallace

Charles Darwin & Alfred Russell Wallace gained numerous insights into evolutionary diversification from studies of island biogeography

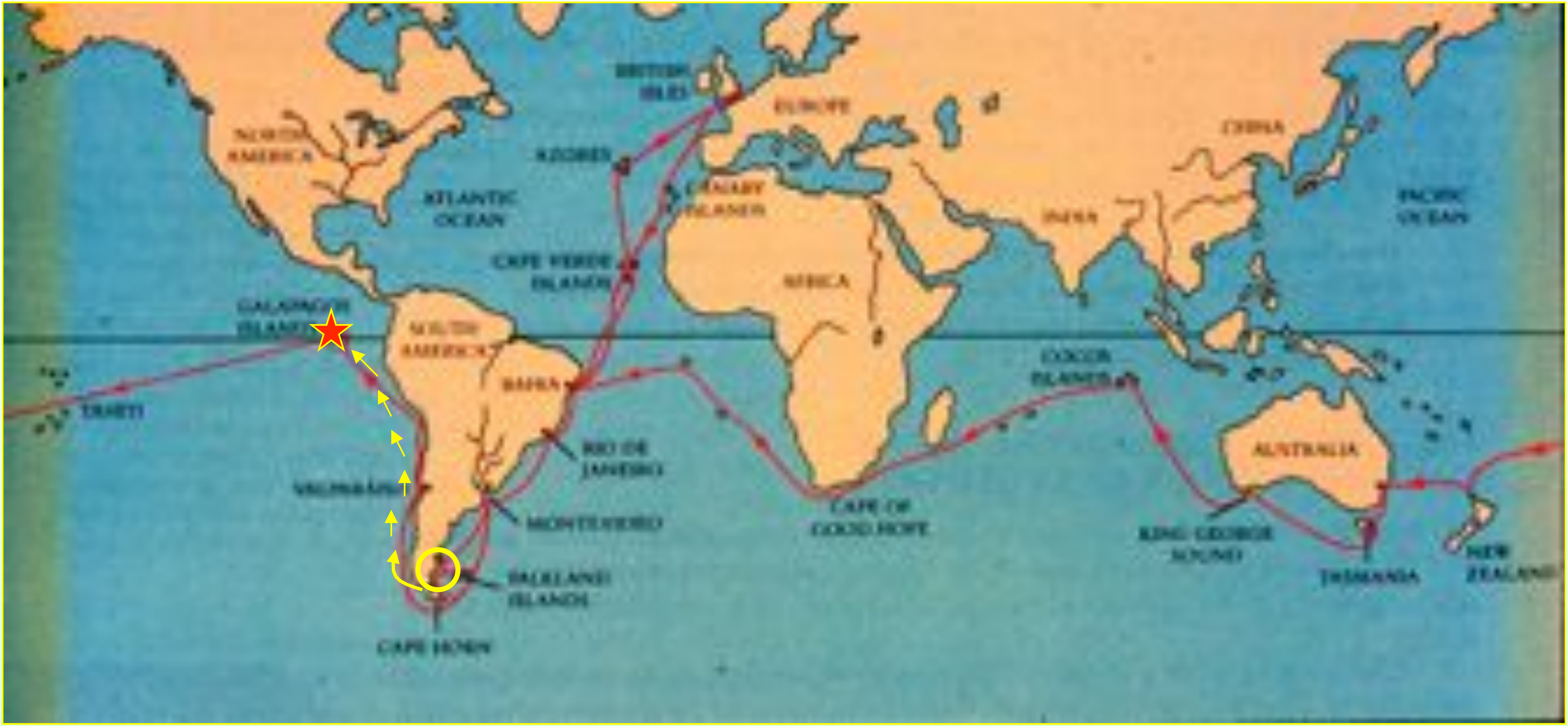
Island exploration and the development of Darwin's ideas on evolution

- Voyage on H.M.S. Beagle around the world (1831-1836) as ship's naturalist

- Made numerous observations and collections of plants, animals & fossils

- His observations on patterns of variation in the Galápagos islands were particularly influential

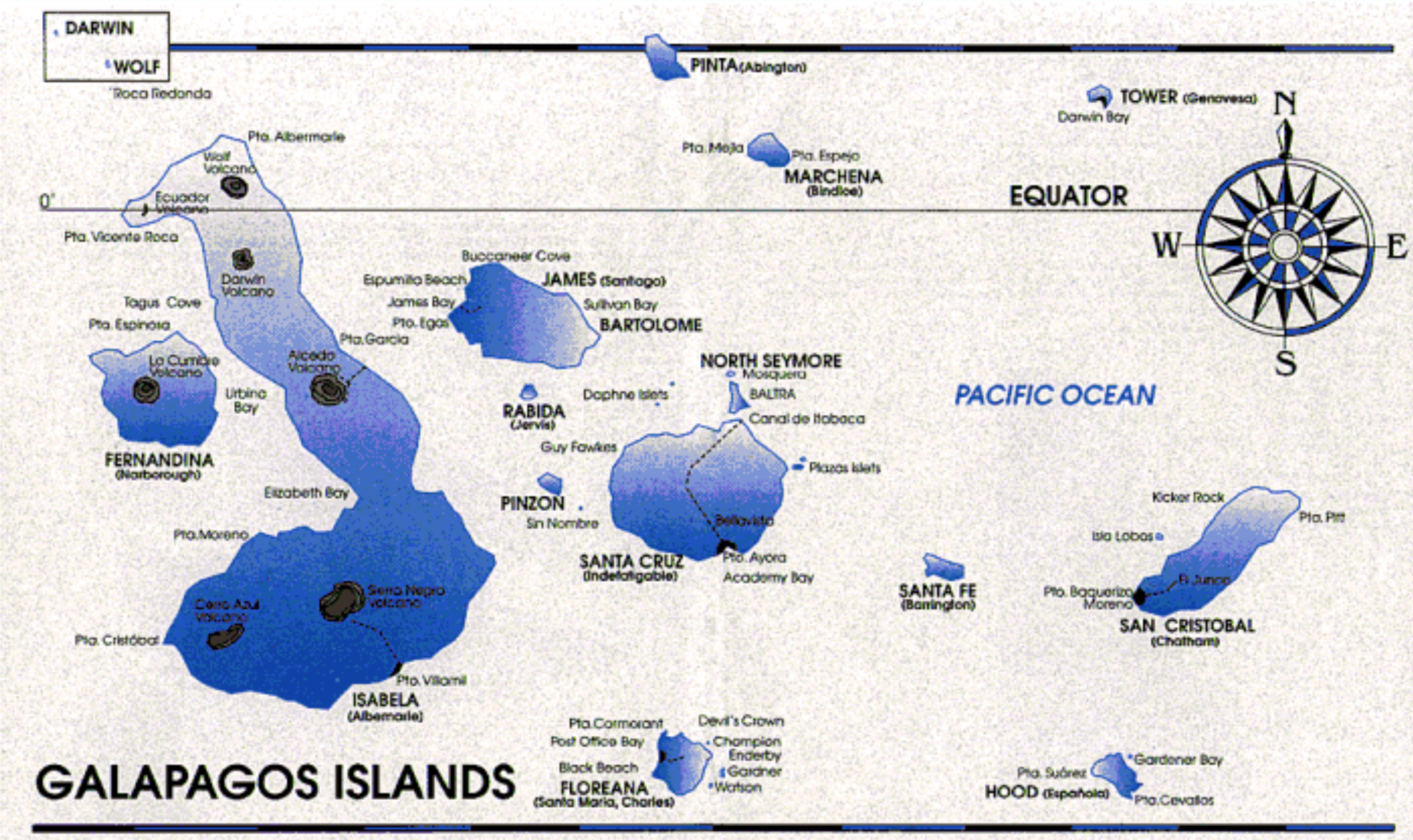
- Darwin saw many 'incipient species' and geographical races and this caused him to doubt the 'fixity' of species and their origin by special creation



H.M.S. Beagle sails to Galápagos Islands

Galápagos Islands

- 15 main islands of volcanic origin; oldest 5-10 million years old; youngest more recent
- Flora and fauna colonized by species capable of long-distance dispersal from South American mainland
- Distinct races and species on different islands provide evidence of early stages of speciation
- Darwin spent only 5 weeks on the islands but his observations formed the foundation for his theory of evolution

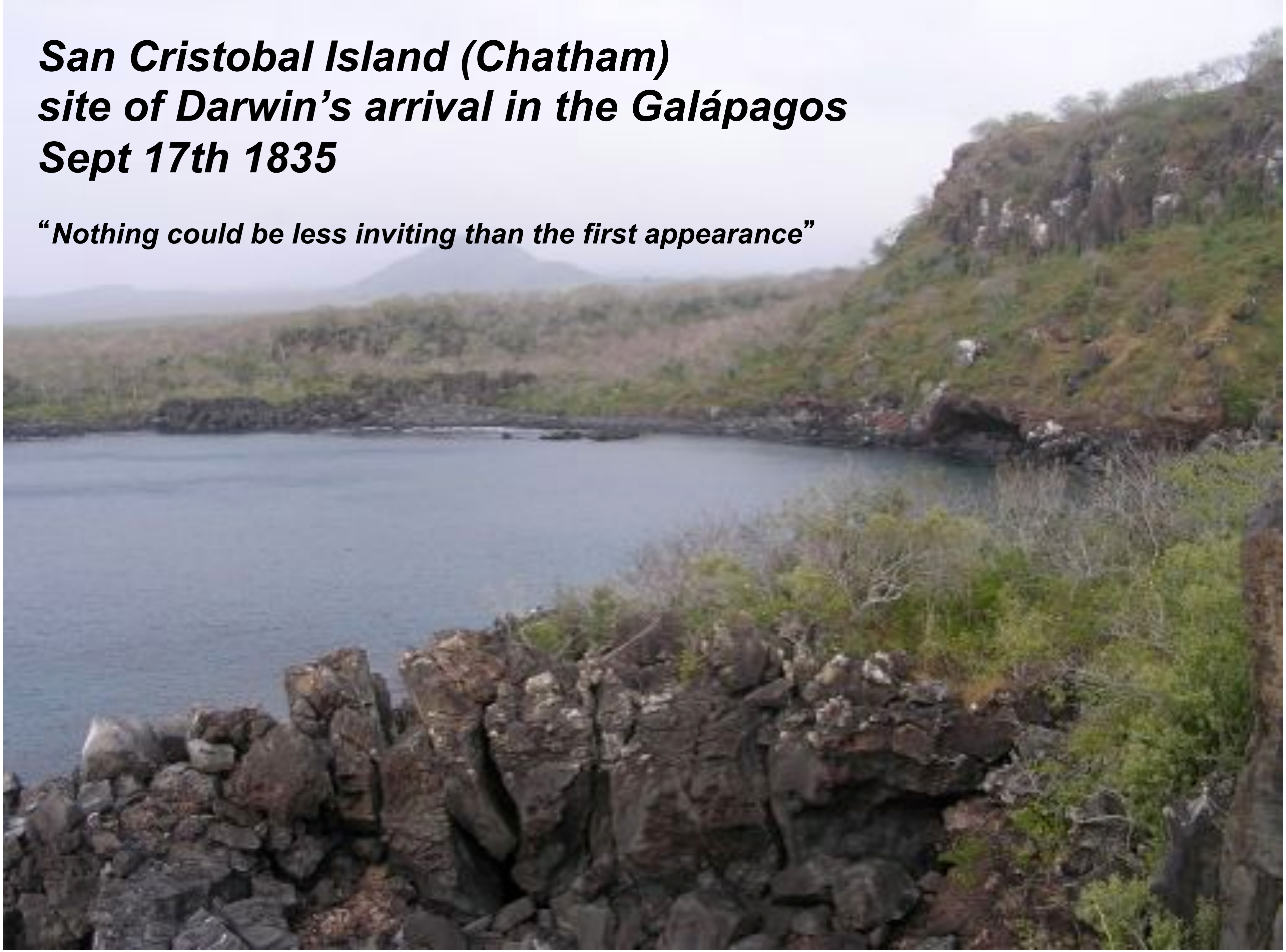


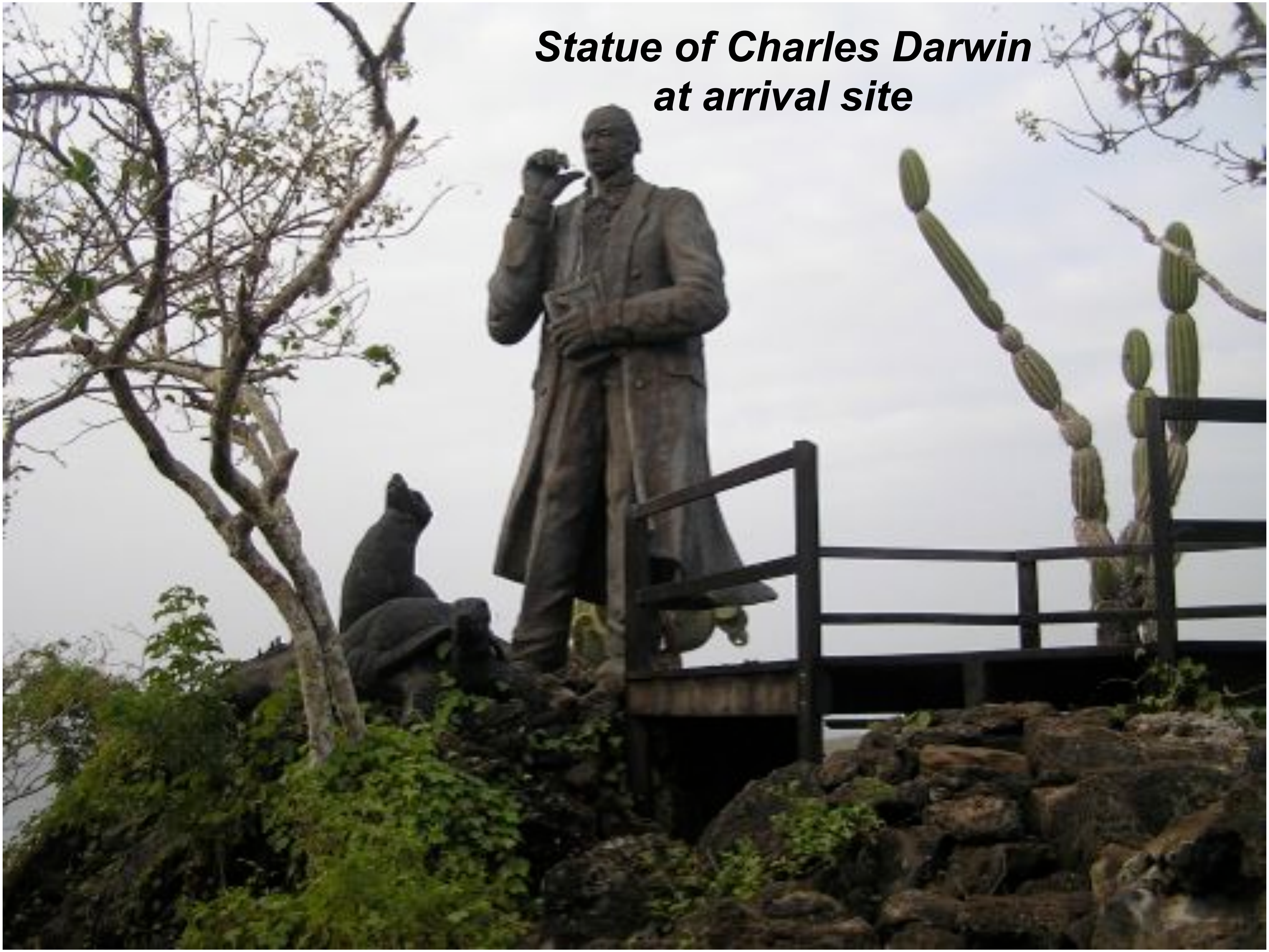
DARWIN
WOLF
Roca Redonda
PINTA (Abington)
TOWER (Genovesa)
Darwin Bay
Pta. Mejia
Pta. Espejo
MARCHENA
(Bindloe)
EQUATOR
N
S
W
E
0°
Pta. Albermarle
Wolf Volcano
Ecuador Volcano
Pta. Vicente Roca
Darwin Volcano
Tagus Cove
Pta. Espinosa
La Cumbre Volcano
Urbina Bay
Alcedo Volcano
Pta. Garcia
FERNANDINA
(Narborough)
Elizabeth Bay
Pta. Moreno
Cerro Azul Volcano
Sierra Negra Volcano
Pta. Cristóbal
Pto. Villamil
ISABELA
(Albemarle)
Buccaneer Cove
Espumilla Beach
JAMES (Santiago)
James Bay
Pto. Egas
Sullivan Bay
BARTOLOME
NORTH SEYMORE
Mosquera
BALTRA
Canal de Itabaca
RABIDA
(Jervis)
Daphne Islets
Guy Fawkes
Plazas Islets
PINZON
Sin Nombre
Bellavista
SANTA CRUZ
(Indefatigable)
Pto. Ayora
Academy Bay
PACIFIC OCEAN
SANTA FE
(Barrington)
Kicker Rock
Pta. Pitt
Isla Lobos
El Junco
Pto. Baquerizo Moreno
SAN CRISTOBAL
(Chatham)
Pta. Cormorant
Post Office Bay
Black Beach
FLOREANA
(Santa Maria, Charles)
Devil's Crown
Champion
Enderby
Gardner
Watson
Gardener Bay
Pta. Suárez
HOOD (Española)
Pta. Cevallos
GALAPAGOS ISLANDS

Galápagos Islands now a UNESCO World Heritage site and a major ecotourism destination

San Cristobal Island (Chatham)
site of Darwin's arrival in the Galápagos
Sept 17th 1835

"*Nothing could be less inviting than the first appearance*"





Statue of Charles Darwin at arrival site

Animals groups observed by Darwin on the Galápagos Islands illustrating important evolutionary principles

Adaptive radiation

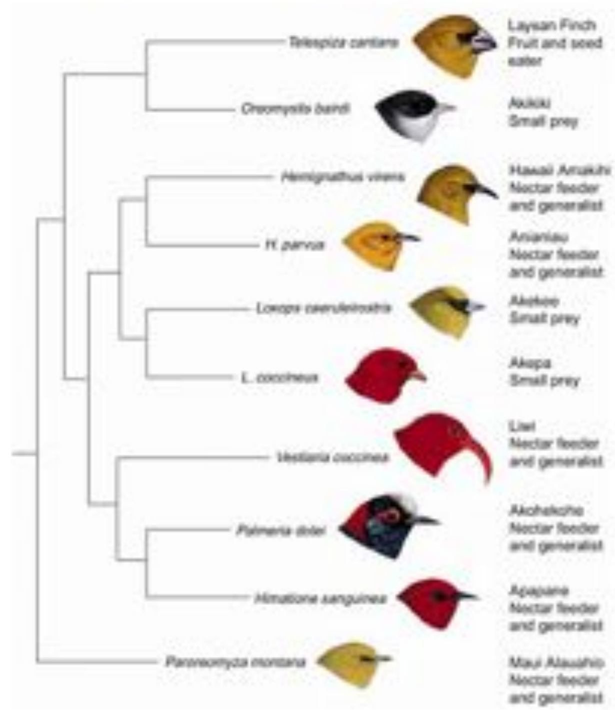
• the evolution of ecological and phenotypic diversity within a rapidly multiplying lineage as a result of speciation

• From a single common ancestor the process results in an array of species that differ in traits allowing exploitation of a range of habitats and resources

• Four features commonly identify an adaptive radiation

1. Recent common ancestry from a single species
2. Phenotype-environment correlation
3. Trait utility
4. Rapid speciation

Honeycreeper phylogeny



Hawaiian honeycreepers have all descended from a single species of finch in the last 10 million years

How did this occur?

What causes adaptive radiations?

1) **Ecological opportunity** – abundant resources and few competitors often occur on oceanic islands or their aquatic counterparts e.g. African rift lakes

2) **High rates of speciation characterize the clade** – can be tested by looking at mainland clade, e.g. Darwin's finches & Hawaiian honeycreepers also radiated on mainland (although not as much), whereas Galápagos mockingbirds have not radiated on islands or continents

3) **Origin of a key innovation** – e.g. toepad in Anoles; floral nectar spur in Columbines (dealt with in next Lecture)

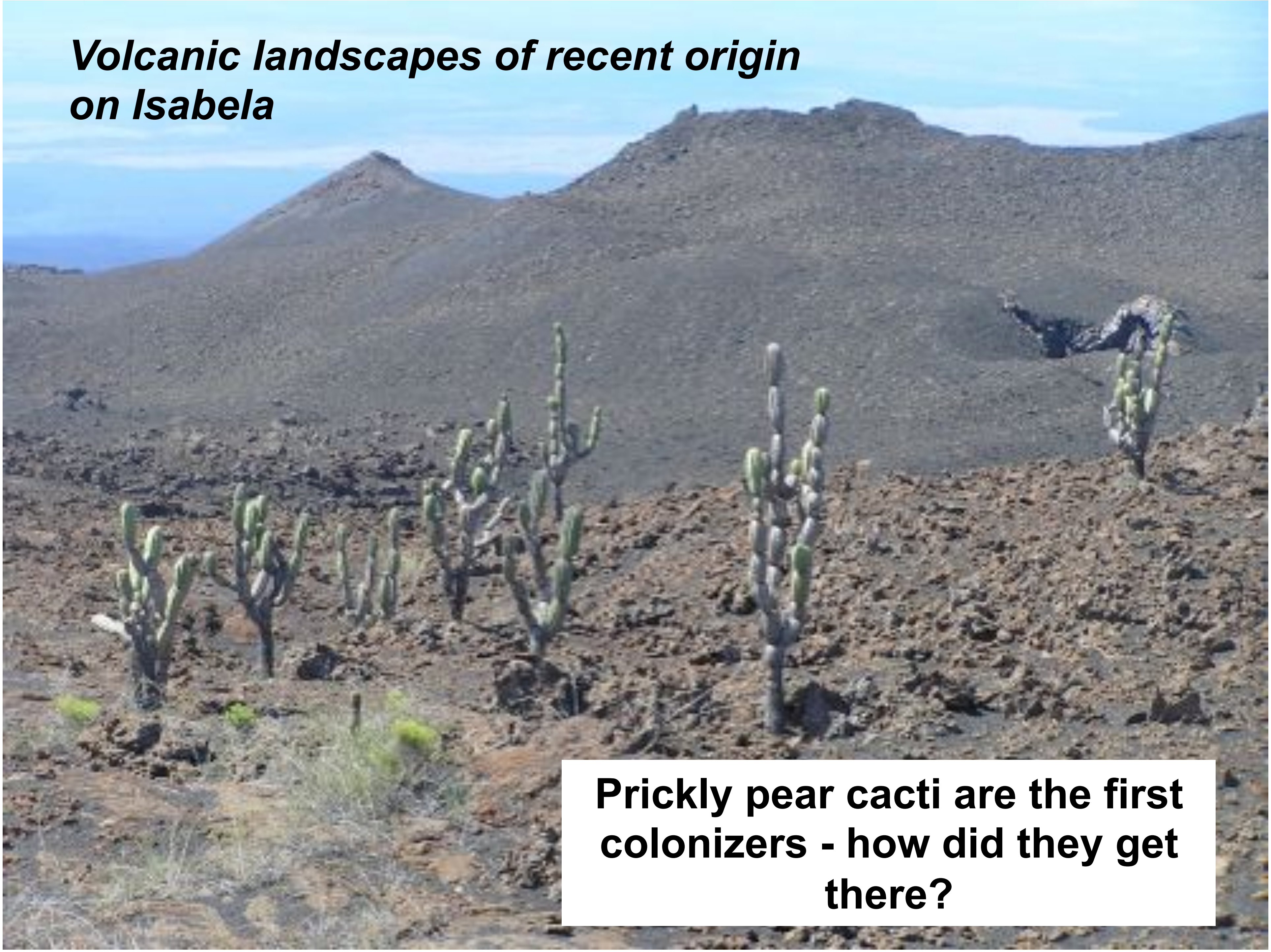
Flora of Galápagos

Native species ~ 500 spp.

Endemic* species ~ 450 spp.

Alien species ~ 749 spp.

* A species restricted to a geographical area


Volcanic landscapes of recent origin on Isabela
Prickly pear cacti are the first colonizers - how did they get there?

Cacti have fleshy bird dispersed fruits and are capable of long-distance dispersal

The islands and cays of the Caribbean

Red mangrove Rhizophora mangle (*Rhizophoraceae*)

- **Outstanding shoreline colonizer**
- **Adaptations include: prop roots, vivipary and hydrochory**
- **Unspecialized pollination system involving wind and self-pollination**


Long Island, Bahamas

Palms fruits are dispersed to many Caribbean islands by birds

Cuscuta (Dodder) – a parasitic flowering plant

Passiflora floral diversity in the Bahamas

Major Evolutionary Transitions in Plant Reproductive Systems

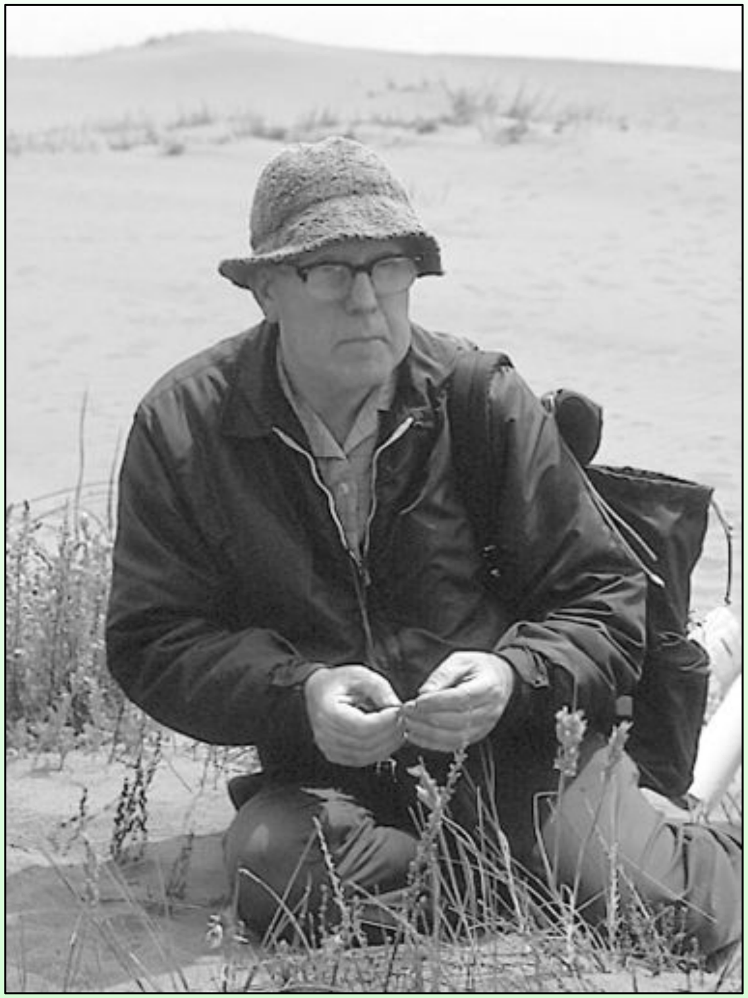
Hermaphroditism
animal pollination
outbreeding

Decreased flower size	Spread of sterility mutations	Loss of adaptations for animal pollination
↓	↓	↓
Selfing	Separate sexes	Wind Pollination

Evolution of selfing

- **Many independent transitions from outcrossing to selfing in angiosperms**
- **Associated with evolution of selfing syndrome**
- **Commonly results in reproductive isolation & speciation**
- **Important genetic, demographic & biogeographical consequences**

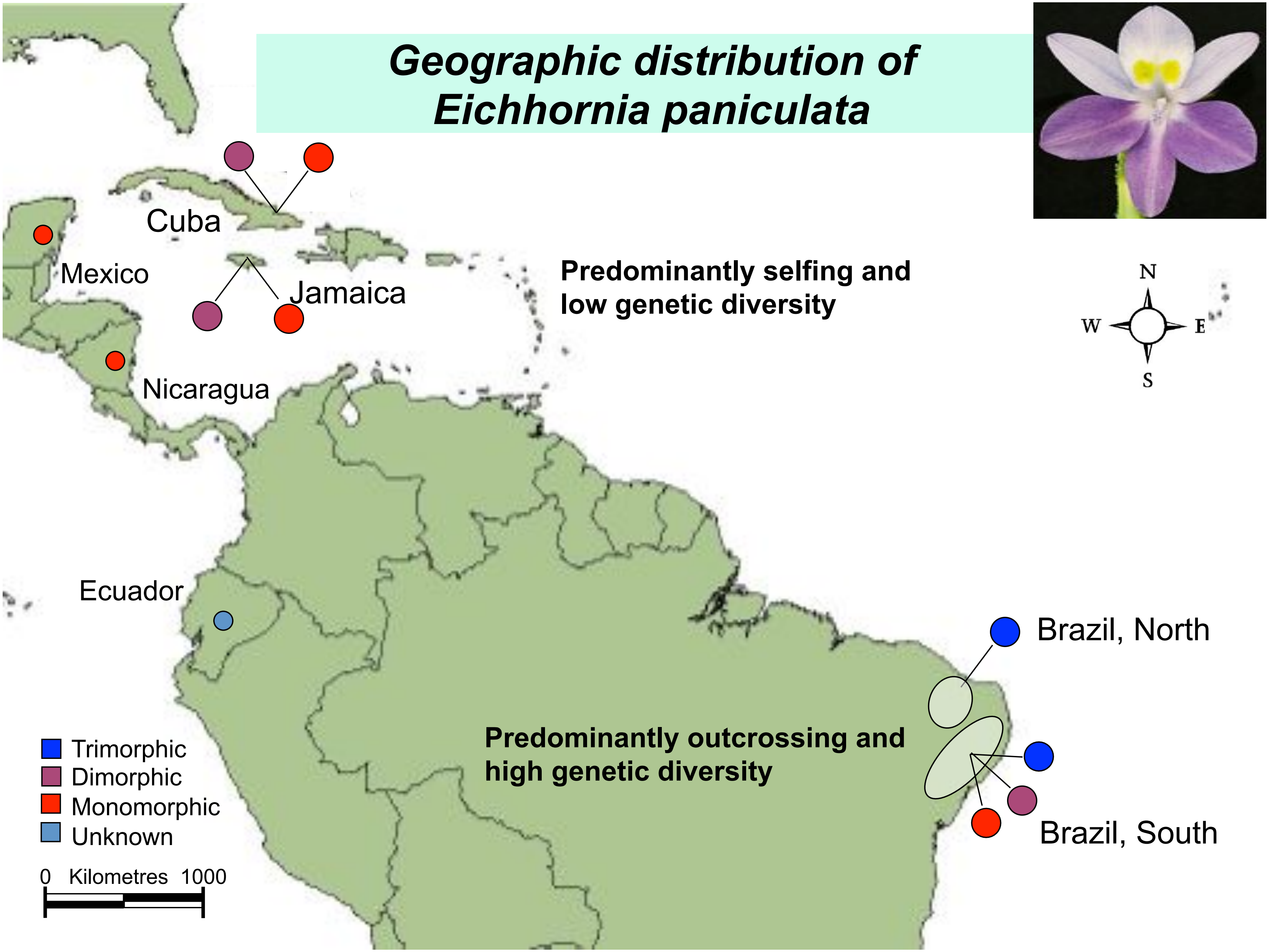
Baker's Law



Herbert G. Baker – California 1973

- Establishment following long-distance dispersal favours self-compatible rather than self-incompatible individuals, because a single individual is sufficient to found a new population
- Predicts that island colonization should favour individuals with the capacity to self-fertilize
- Also predicts that colonizing species including invasives should have the capacity for uniparental reproduction by selfing or clonal propagation

Geographic distribution of Eichhornia paniculata



Evolution of selfing from outcrossing in annual water hyacinth

Large-flowered bee-pollinated outcrosser from Brazil

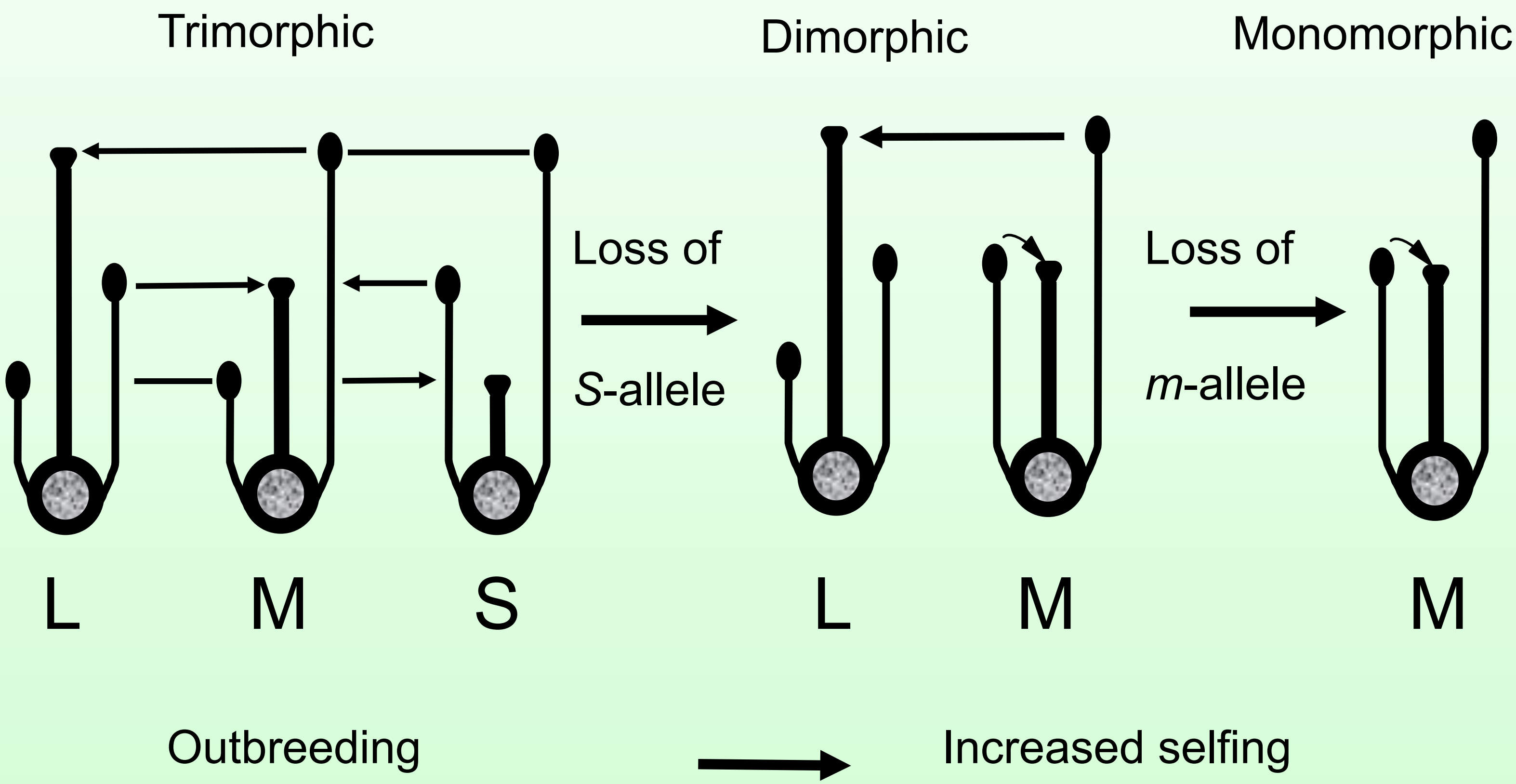
Small-flowered selfer from Jamaica

• populations in Brazil are mostly outcrossing and visited by long-tongued bees although selfing forms do occur

• long-distance dispersal favours selfing forms because a single individual can start a colony without mates or pollinators this is known as 'Baker's Law'

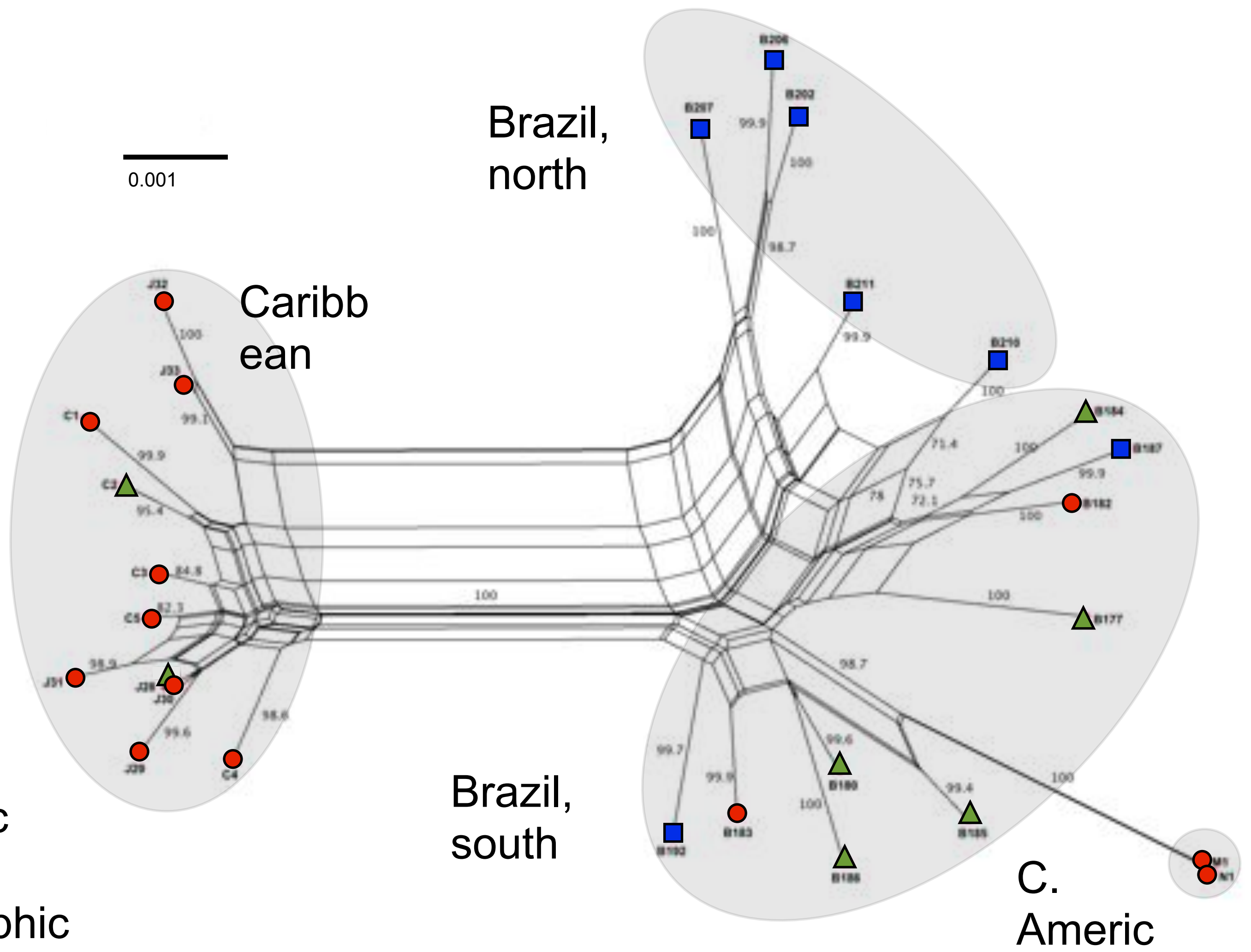
• Jamaican and Cuban populations are largely selfing

Evolution of selfing from outcrossing through genetic drift & natural selection



Evolution (1989)

Neighbour network of genetic relationships among range-wide samples indicates multiple origins of selfing



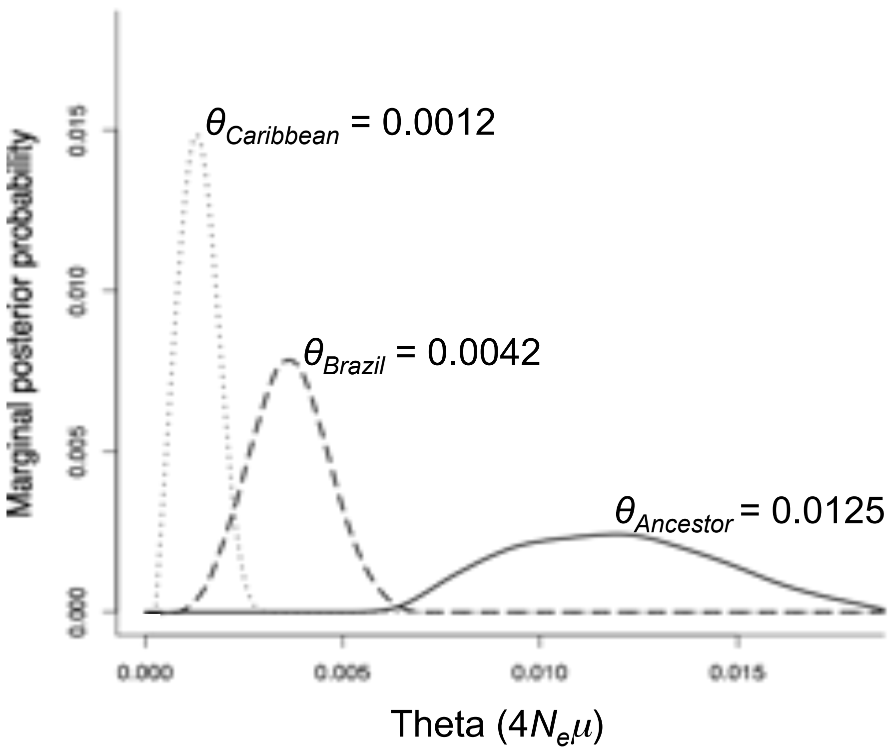
- Trimorphic
- Dimorphic
- Monomorphic

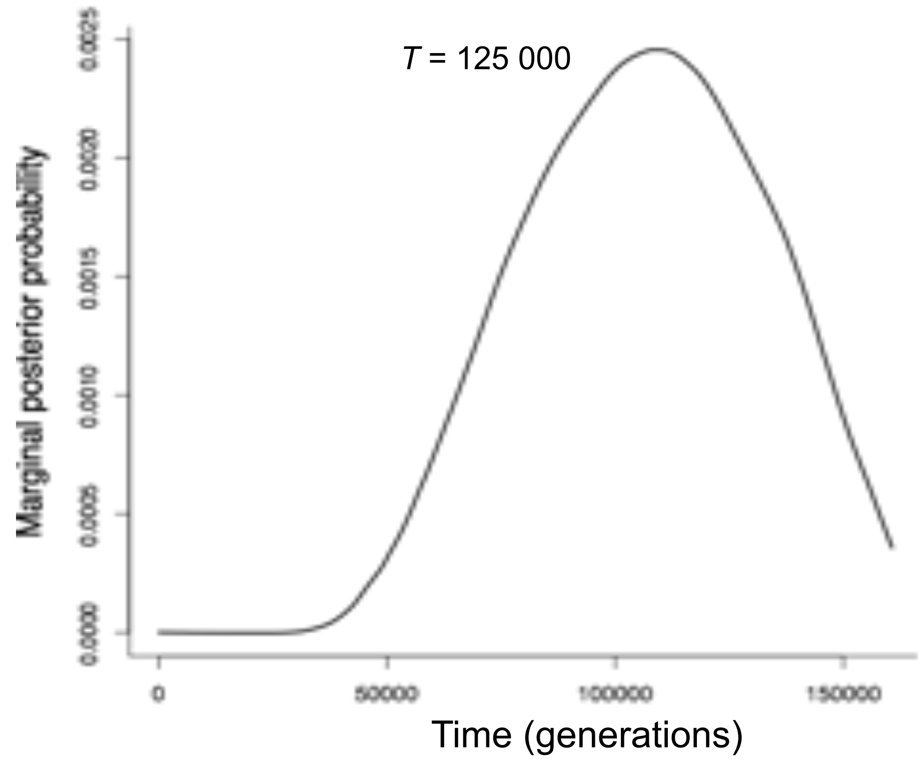
New Phytologist (2009) 183: 546-556

Neighbour network based on sequences of 10 EST-derived nuclear loci.
Generated with SplitsTree

Understanding Colonization History through Coalescent Simulations: Bayesian Estimates of 4Nem for Eichhornia paniculata from Brazil & Caribbean

RW Ness, SI Wright & SCH *Barrett unpubl. data*





Colonization of Caribbean estimated at 125,000 yrs BP and therefore **not** associated with agriculture

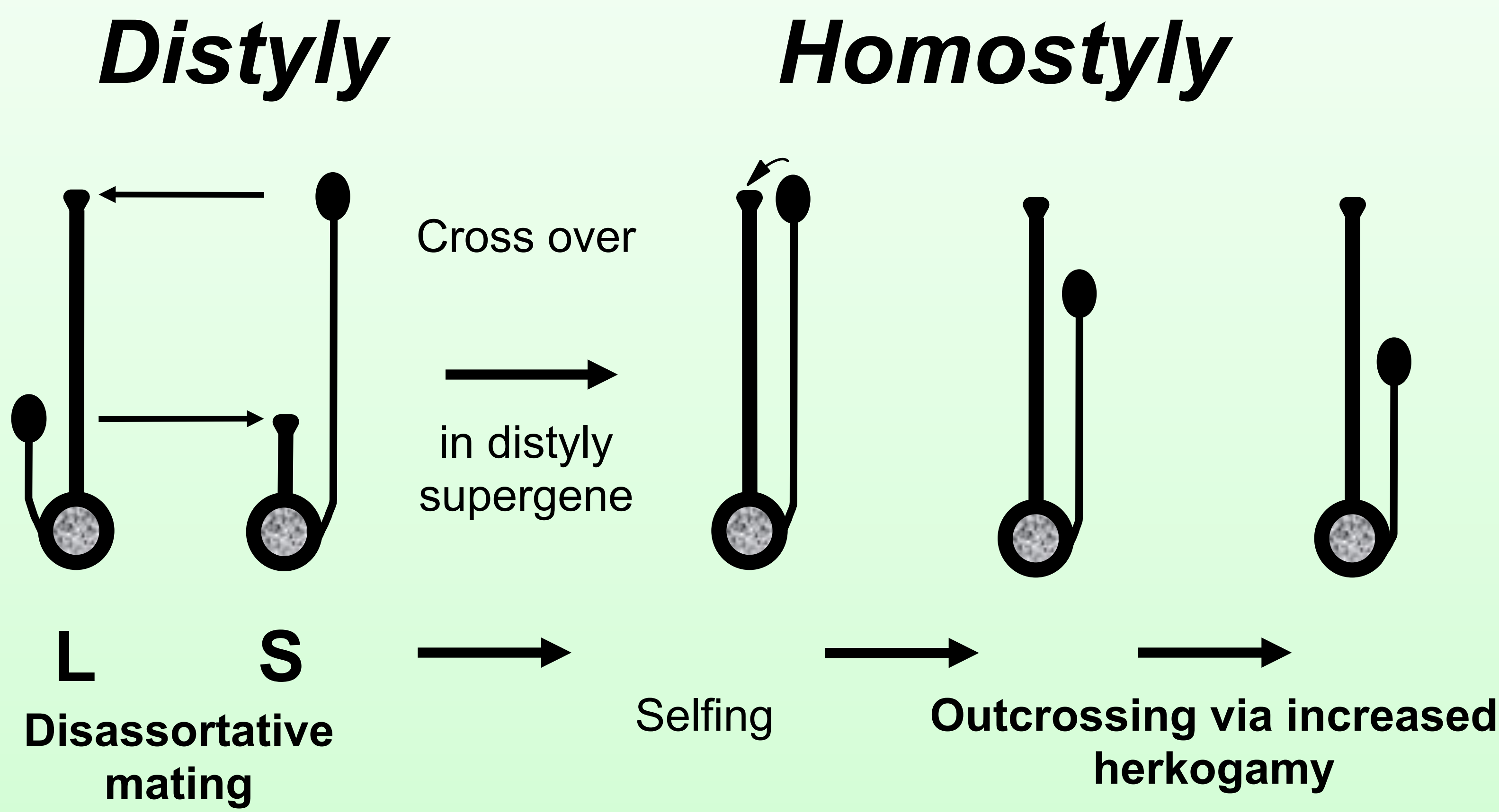
MIMAR: *Becquet & Przeworski* (2007)

Evolution of mating systems in Turnera (Turneraceae)

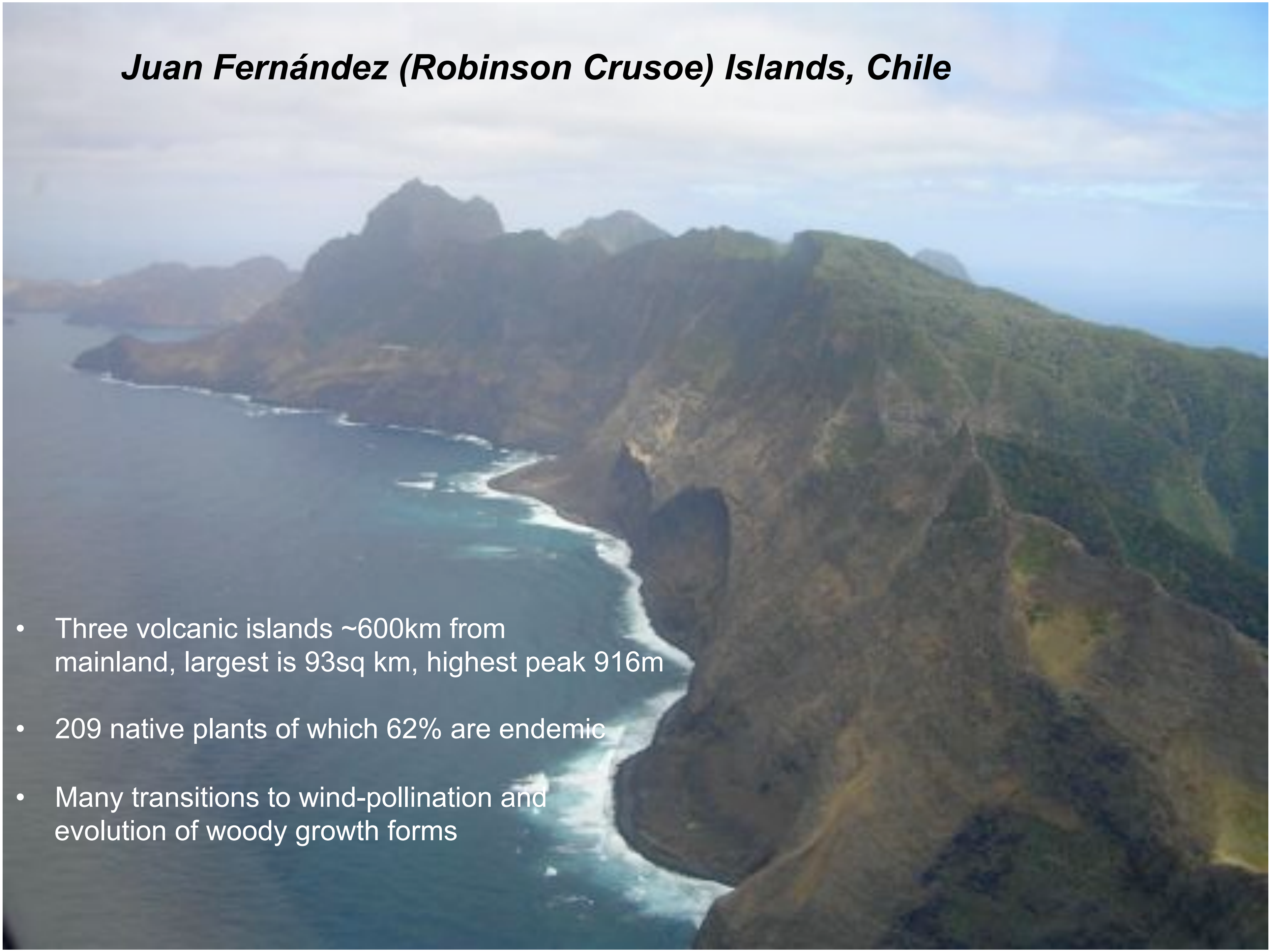
Mainland South and Central America
distylous and outbreeeding

Caribbean Islands
homostylous and selfing

Evolutionary breakdown of distyly and island colonization in Turnera ulmifolia

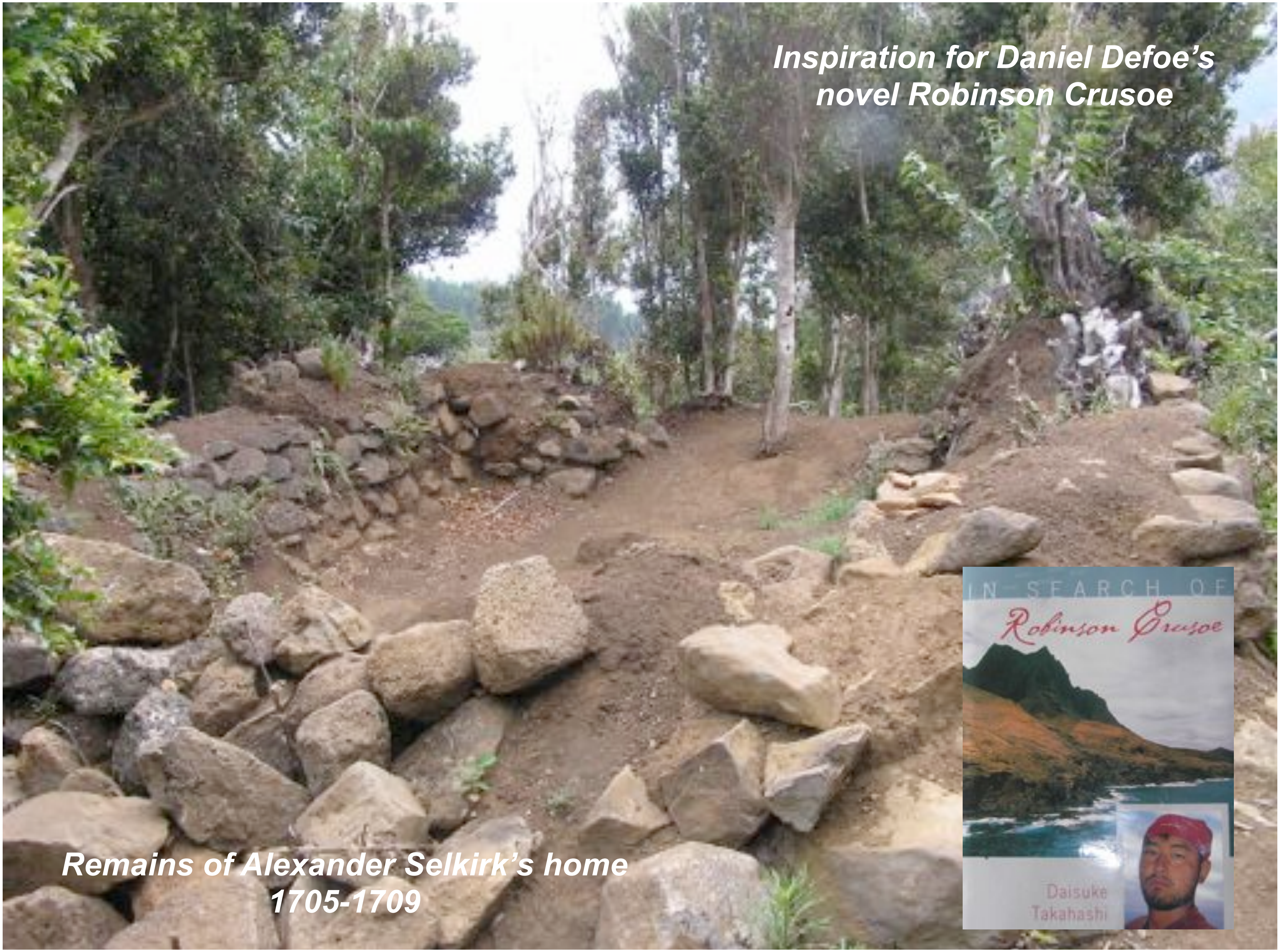


Juan Fernández (Robinson Crusoe) Islands, Chile



- Three volcanic islands ~600km from mainland, largest is 93sq km, highest peak 916m
- 209 native plants of which 62% are endemic
- Many transitions to wind-pollination and evolution of woody growth forms

Fern-rich dwarf woodland


Inspiration for Daniel Defoe's novel Robinson Crusoe
IN SEARCH OF
Robinson Crusoe
Daisuke Takahashi
Remains of Alexander Selkirk's home 1705-1709

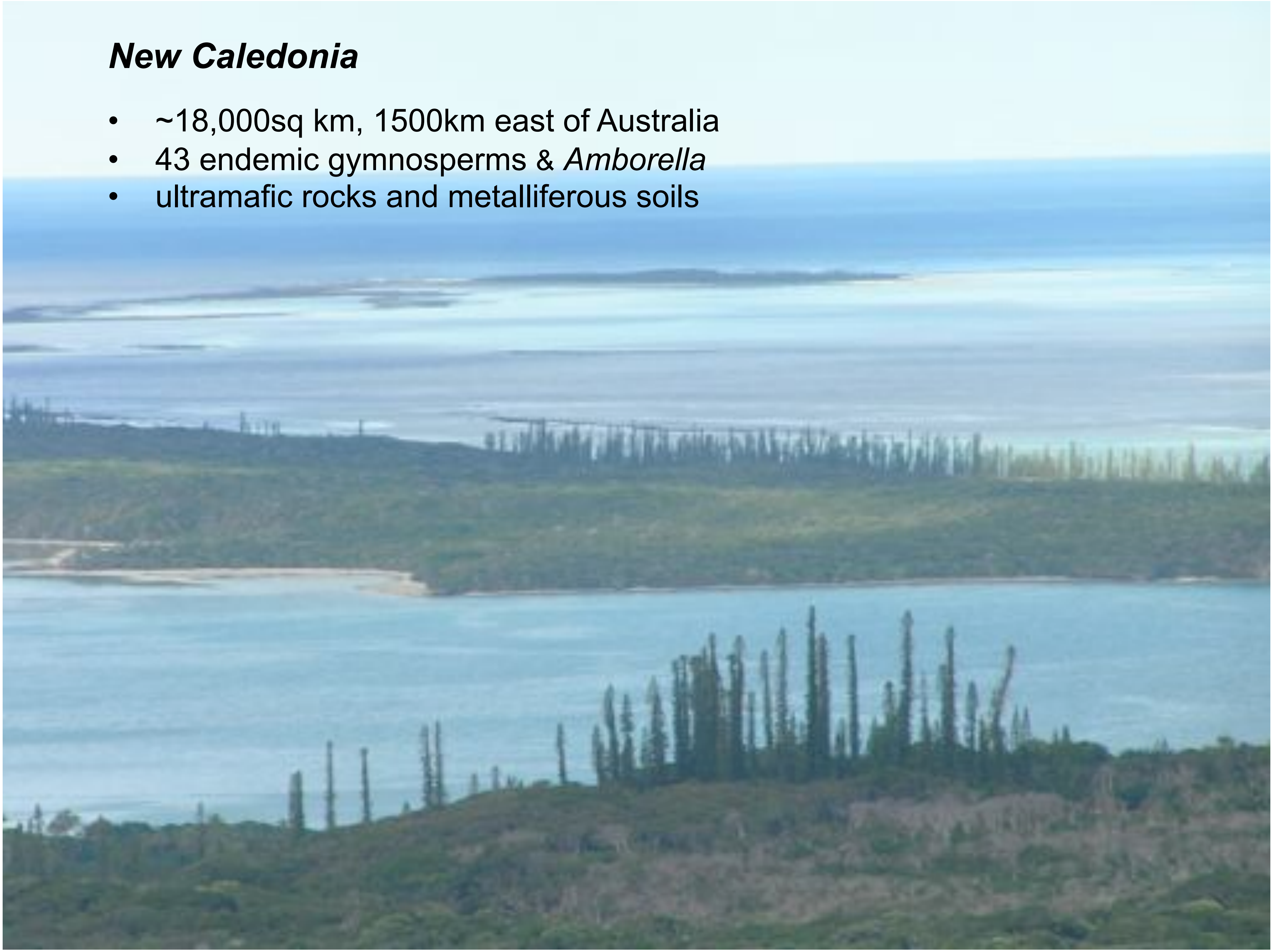

Dendroseris litoralis
Asteraceae

Endemic hummingbird Sephanoides fernándensis (Juan Fernandez Firecrown) pollinating Dendroseris litoralis

The giant Gunnera peltata (Gunneraceae) which has been described as wind pollinated

New Caledonia

- ~18,000sq km, 1500km east of Australia
- 43 endemic gymnosperms & *Amborella*
- ultramafic rocks and metalliferous soils




Smooth-bark Kauri, Agathis robusta
(Araucariaceae) New Caledonia

Cook Pine, Araucaria columnaris (Araucariaceae)
Isle of Pines, New Caledonia

Chandelier Cypress, Neocallitropsis pancheri (Cupressaceae)
La Réserve de la Madeleine, New Caledonia

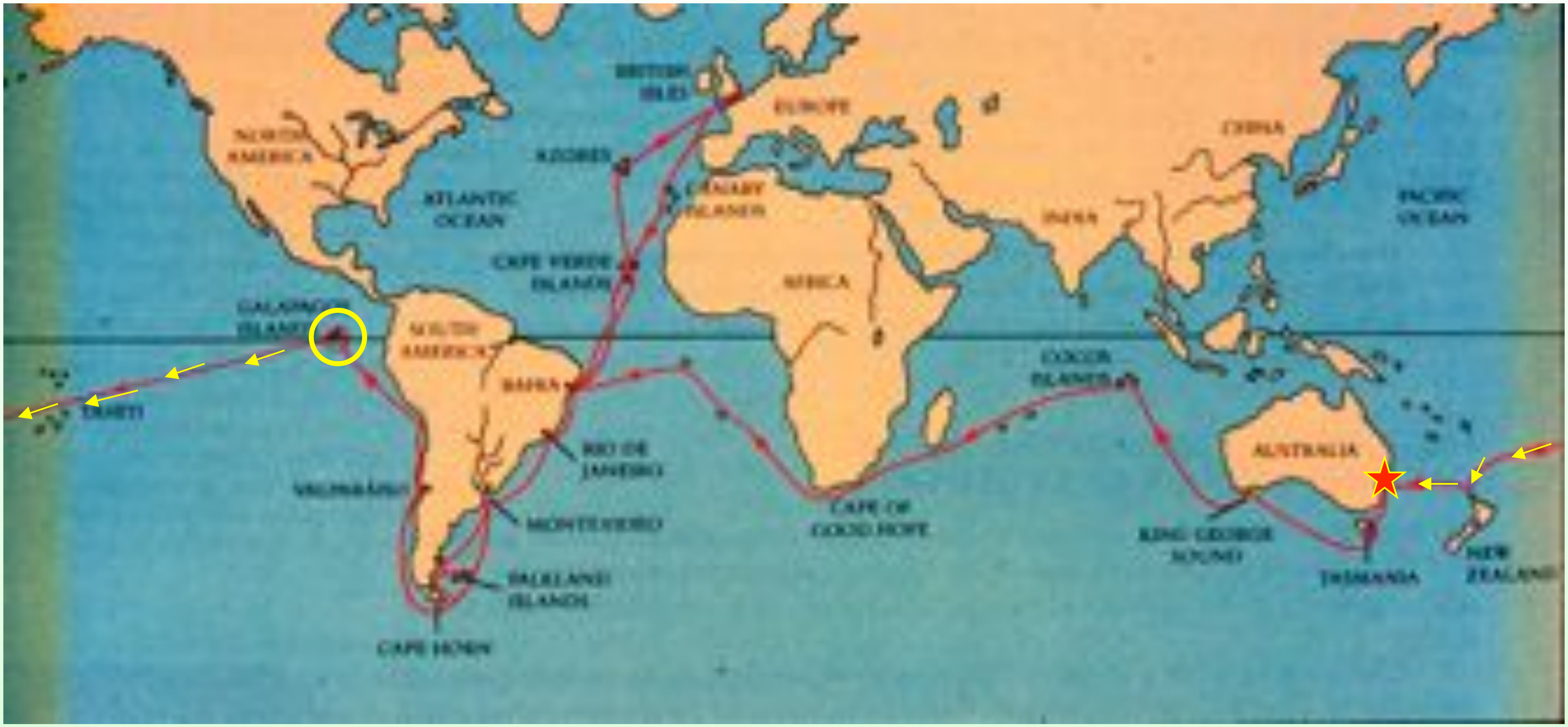

Serious loss of endemic biodiversity by nickel mining
New Caledonia has ~25% of the world's reserves


Amborella trichopoda (Amborellaceae)
The most basal extant flowering plant

Screw Pine, Pandanus sp. (Pandanaceae)
New Caledonia

Deplanchea speciosa (Bignoniaceae)
Grand Terre, New Caledonia


Endemic Pitcher Plant, Nepenthes vieillardii
(Nepenthaceae), New Caledonia

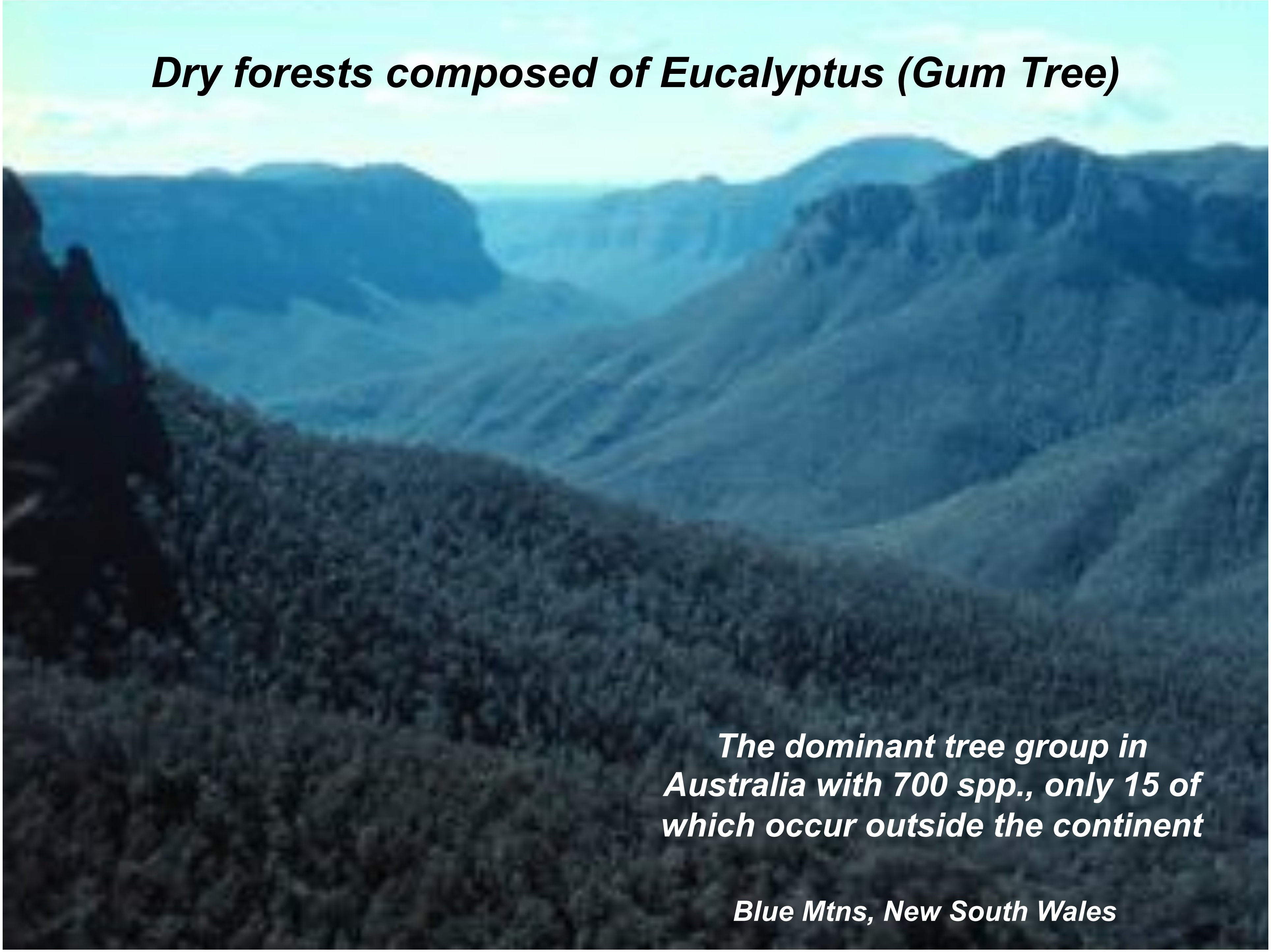


H.M.S. Beagle sails to Australia
spends two months there; ours will be a flying visit

Australia

- Distinct flora and fauna with high levels of endemism* and many unique adaptations
- Biological uniqueness due to long history of isolation from other land masses
- Although a continent Australia is also an island and shows many island characteristics e.g. endemism, radiations & unique adaptations

*Endemic species are restricted to a particular geographical region or habitat


Dry forests composed of Eucalyptus (Gum Tree)
The dominant tree group in Australia with 700 spp., only 15 of which occur outside the continent
Blue Mtns, New South Wales


Epiphytic fern
Tropical forest - Queensland, Australia

Rodent pollinated Banksia

Although the plant is a shrub the flowers are produced on the ground where rodents forage

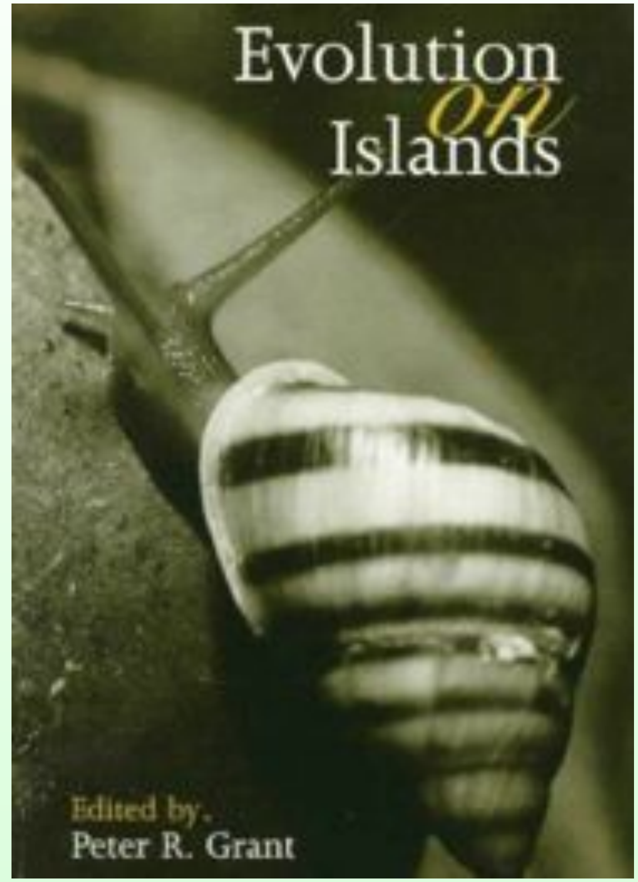
Today's General Messages

- **Islands have long held a fascination for evolutionary biologists since Darwin's time**

- **Islands are characterized by many unique adaptations and high levels of endemism**

- **Human disturbance and invasive species are a major threat to island biodiversity**

Further Reading



Barrett, S.C.H. (1996). The reproductive biology and genetics of island plants. *Philosophical Transactions of the Royal Society Ser. B*. 351: 725-733