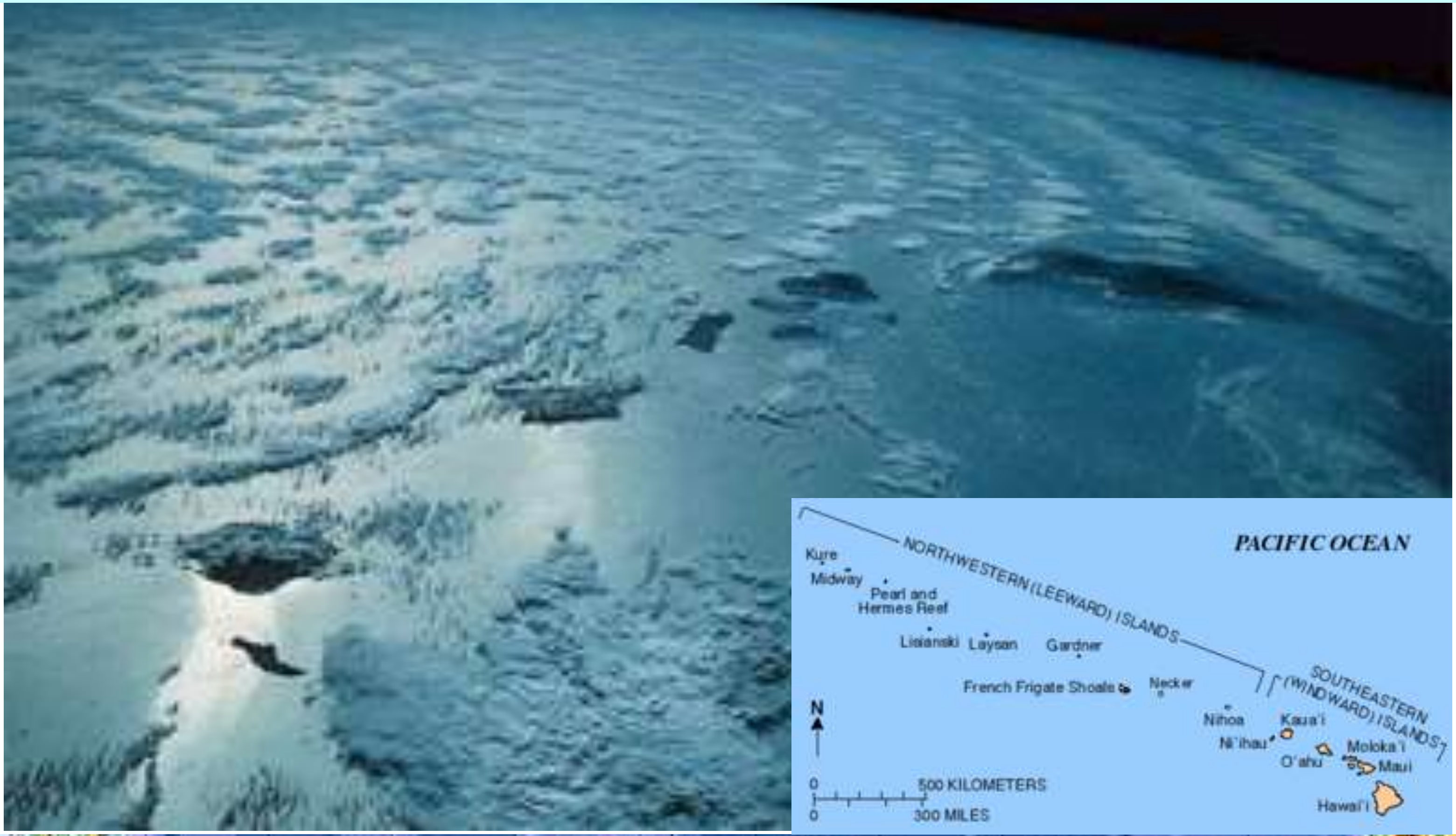
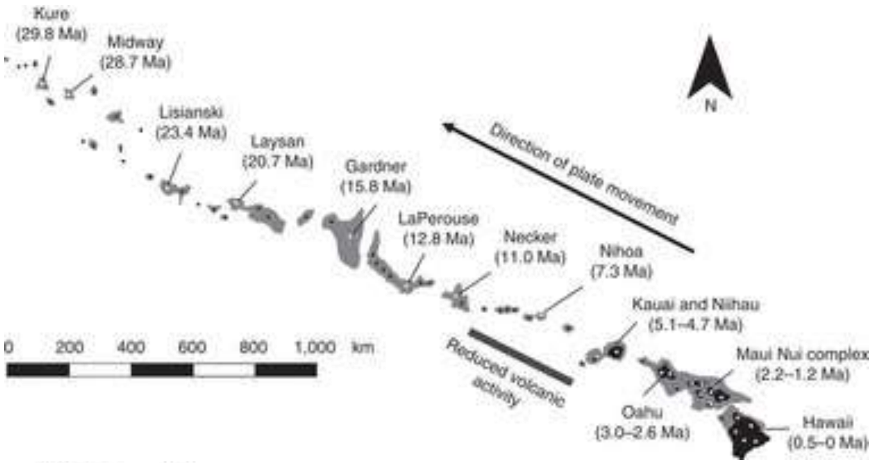
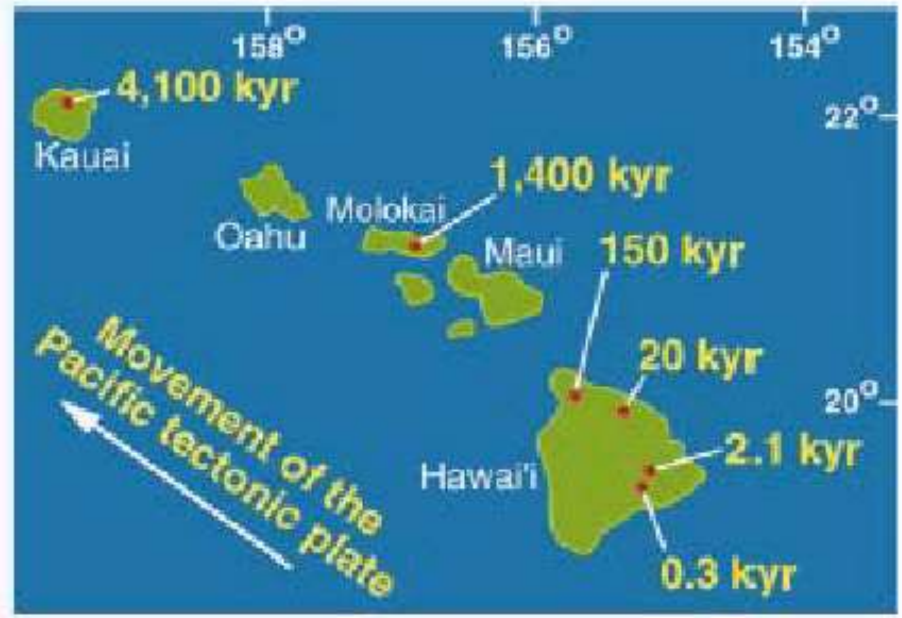
Tropical islands, speciation & distribution of biodiversity

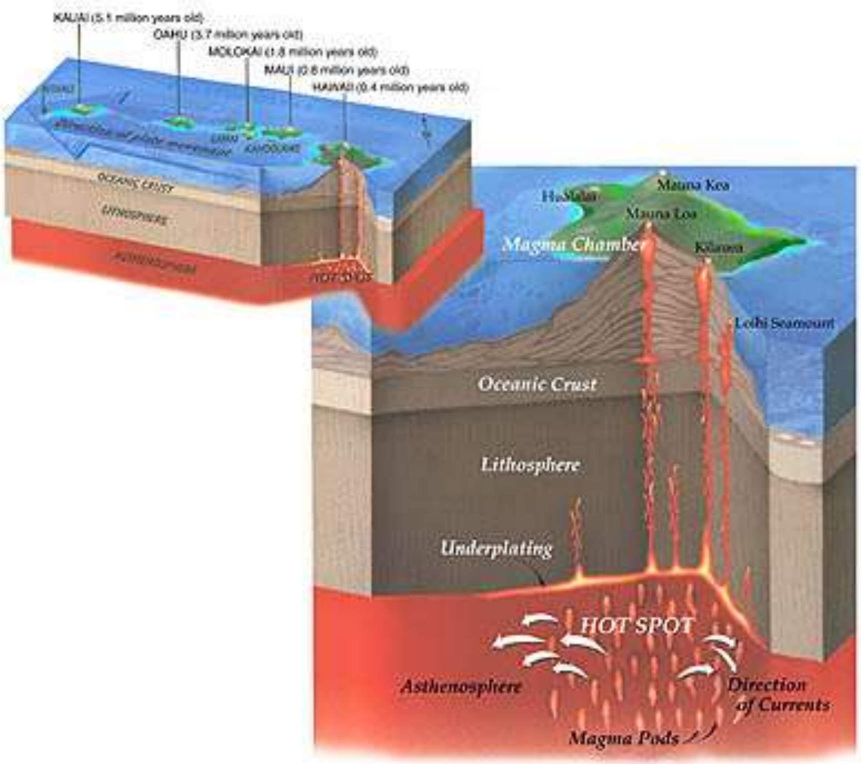
Hawaii Islands - a classic study site



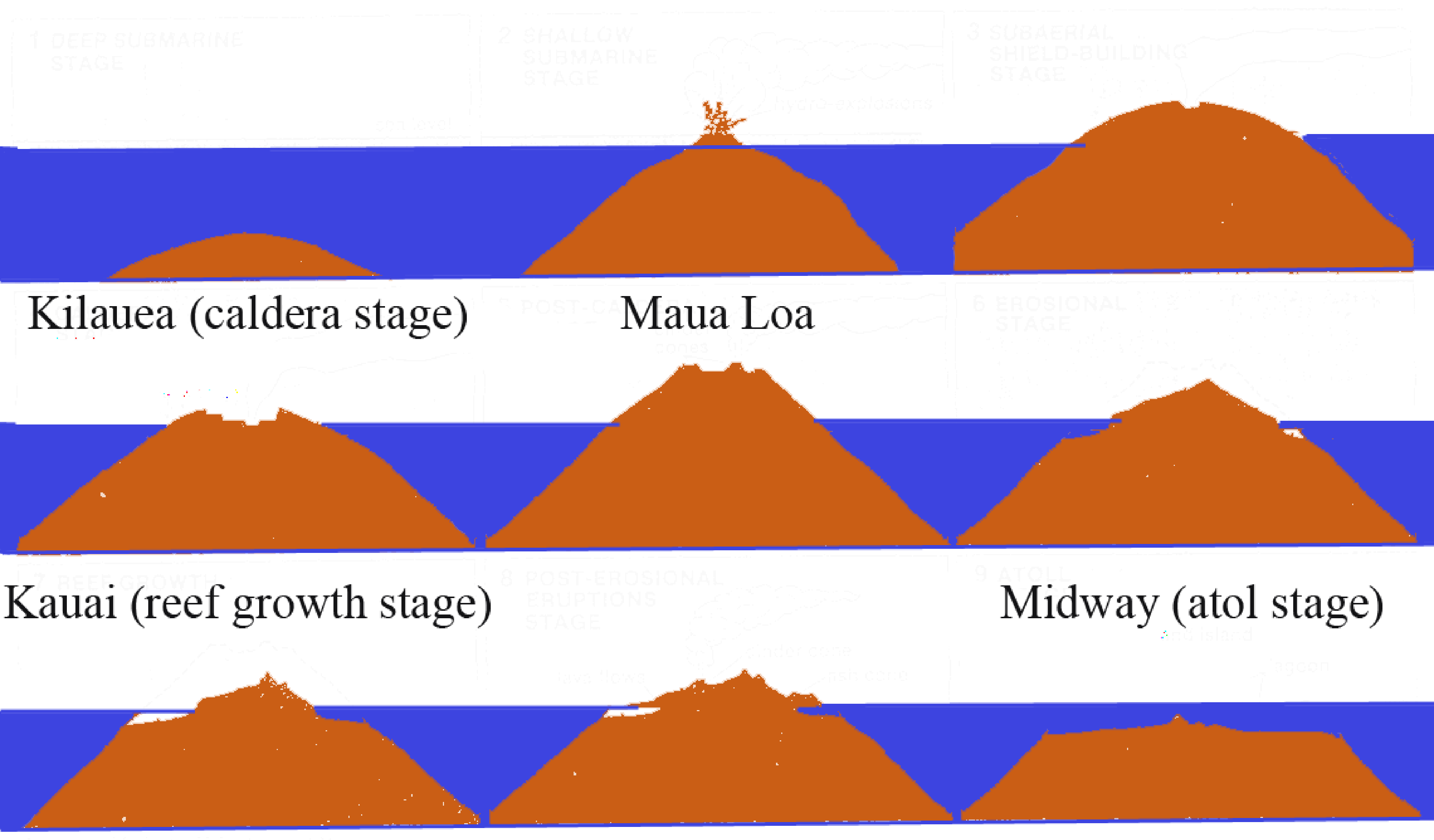
Hawaii island is sitting on a magmatic hotspot







Development of a typical oceanic volcanic island




Hawaii: the creation of new ground (hot lava flow meets the ocean)

Molokai: 1.4 million years of erosion

Kauai: 4 million years of erosion

Key features of island biota

- semi-random taxonomic composition

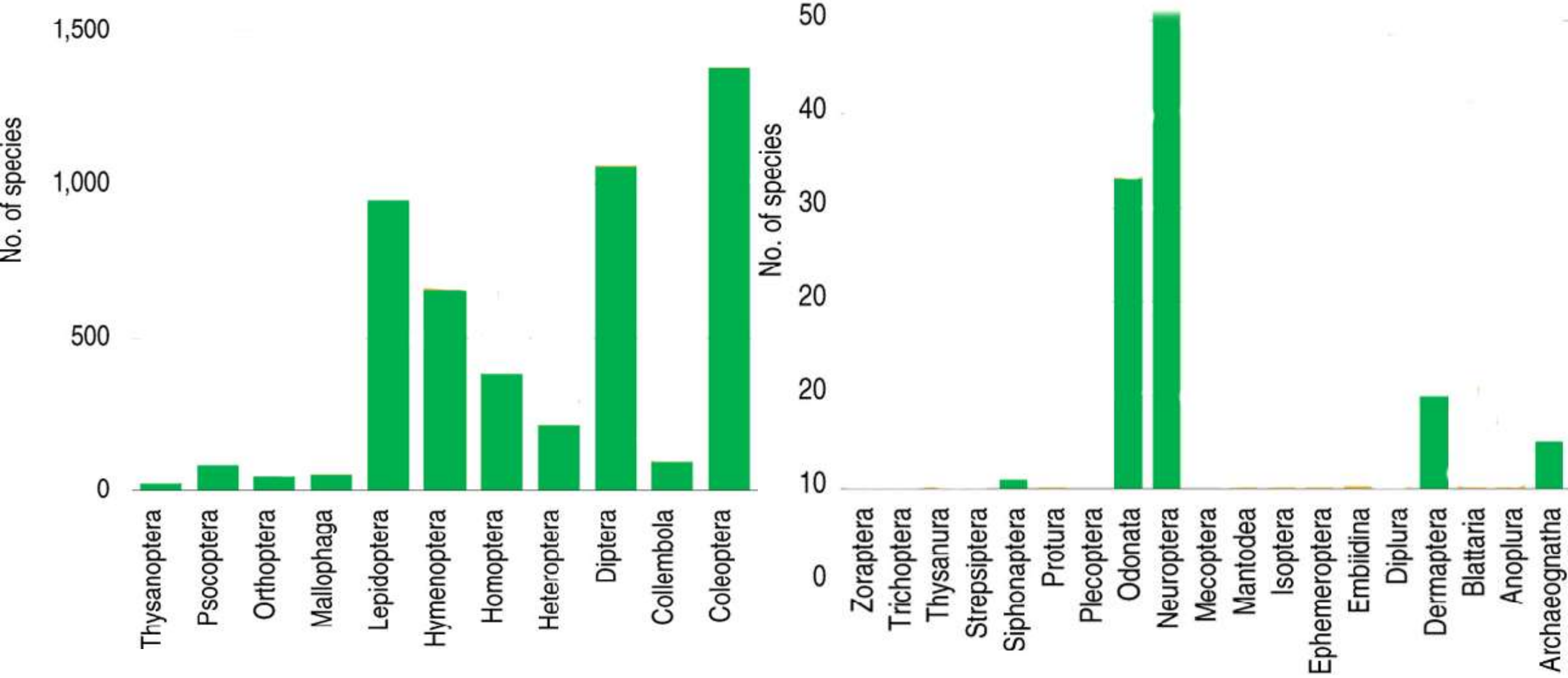
(chance plus dispersal ability)

- empty niches → explosive radiation
- empty niches → wide niches
- empty niches → unusual shifts of ecological niches
- empty niches → susceptibility to invasive species

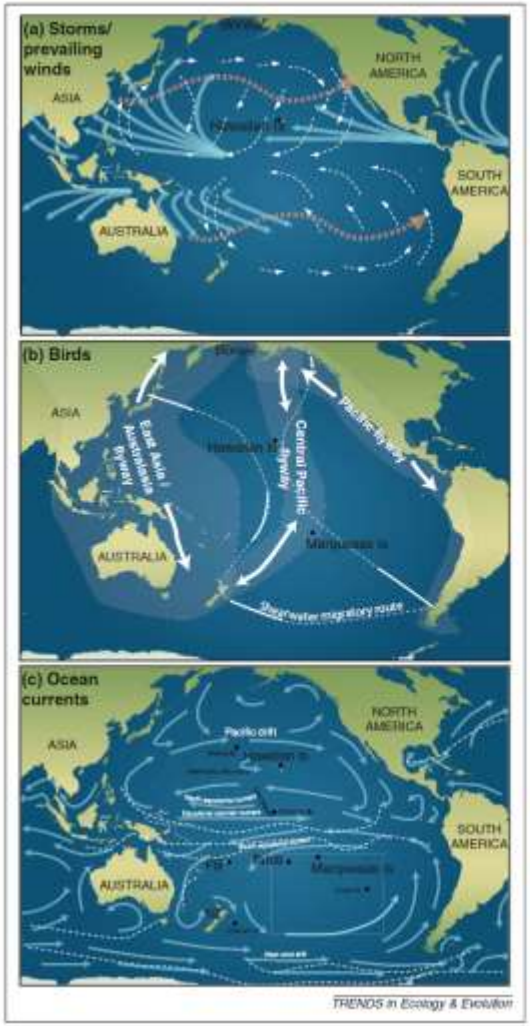
• random taxonomic composition

Hawaii: only 50% of insect orders present

- no Ephemeroptera, Plecoptera, Trichoptera (freshwater larvae)
- no termites
- no ants

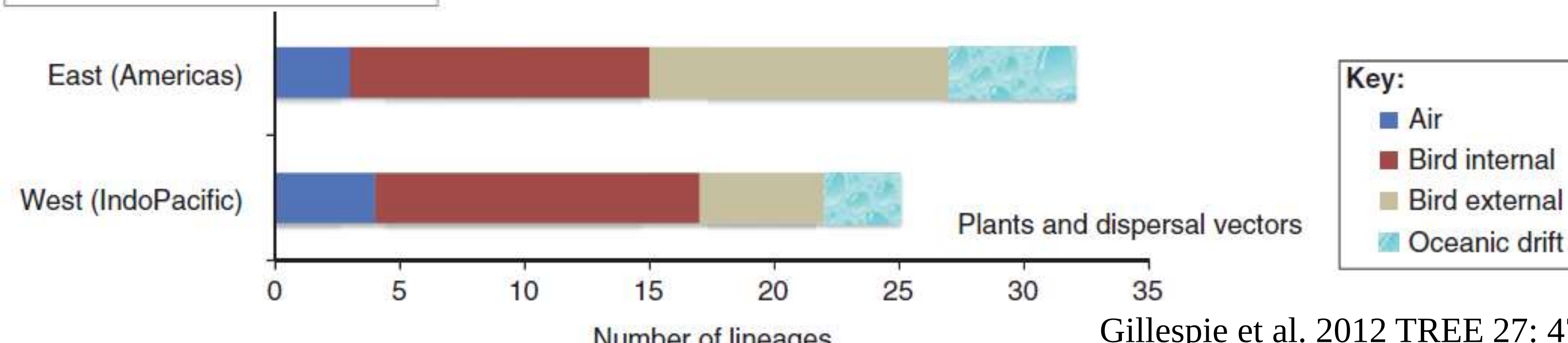


Dispersal options for Hawaii



Modes of long-distance dispersal.
(a) Storms and prevailing winds; eastward subtropical jet streams (orange); prevailing trade winds (white).
(b) Bird migratory routes: major migratory pathways; routes by shearwaters and petrels (broken lines).
(c) Oceanic currents.

Plant lineages colonizing Hawaii from East and West by different means of dispersal

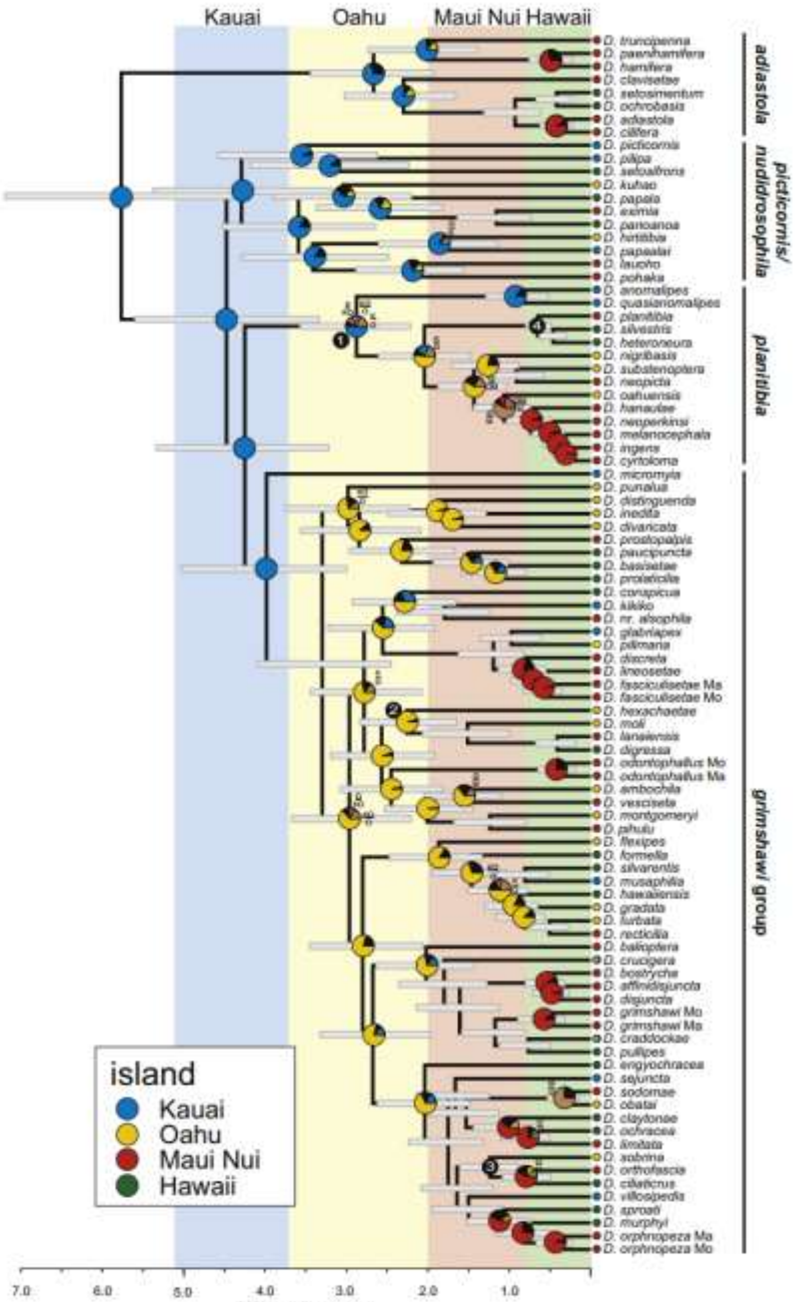


Gillespie et al. 2012 TREE 27: 47

• explosive radiation

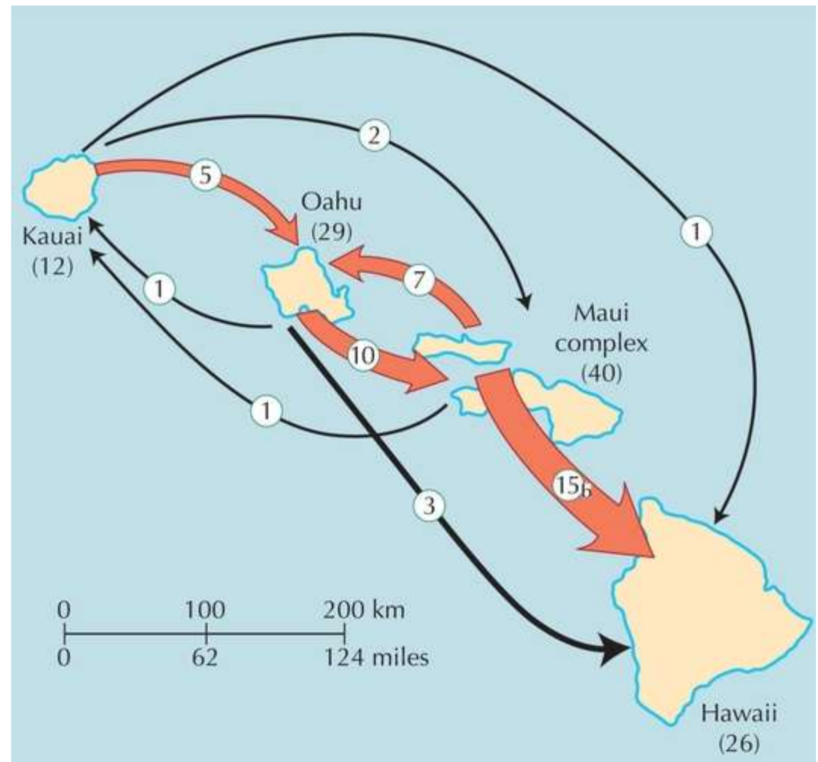
The 6,000-10,000 insects native to Hawaii evolved from 300 - 400 ancestral immigrant species (Hardy 1983; Gagné and Christensen 1985);

Drosophila:
Hawaii 600 spp. all from a single ancestor during 40 mil years;
100 spp. on the youngest Hawaii island evolved during past 1 mil years
Hawaii species represent 40% of world's Drosophila



Drosophila phylogeny shows jumping from older to younger islands

Picture-wing *Drosophila* spp.

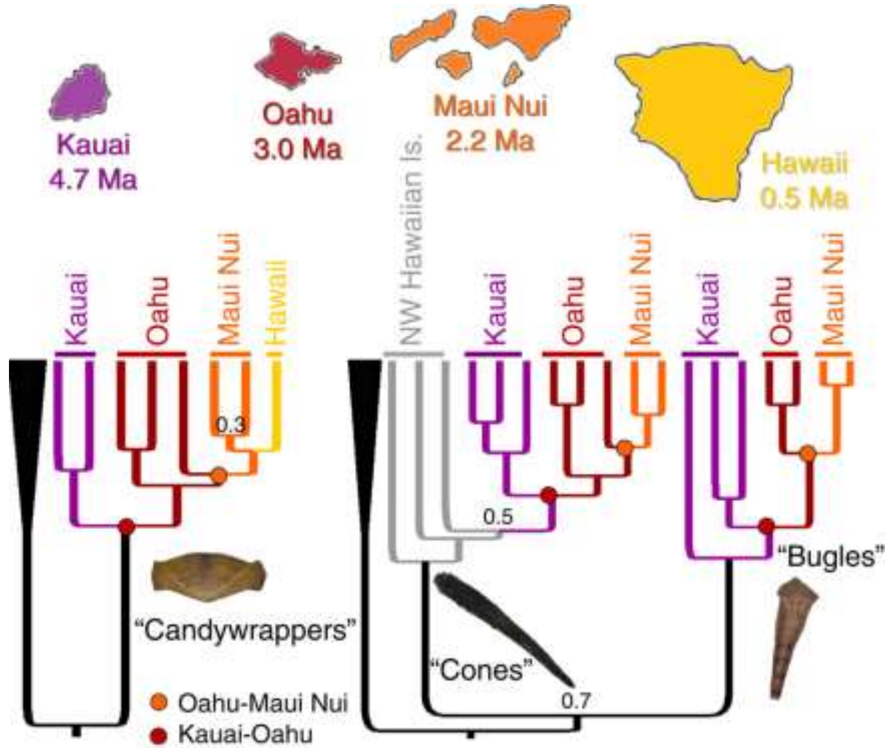


The number of founder events reconstructed for the phylogeny of 103 spp. Of picture-wing Drosophila (No. of spp on each island in brackets_.

Magnacca & Price Molecular Phylogenetics and Evolution 92 (2015) 226–242

Further examples of explosive insect radiation in Hawaii:

Hyposmocoma (Cosmopterigidae): 400 spp., evolved in 15 M years,
Represent >1/3 of all Lepidoptera spp on Hawaii



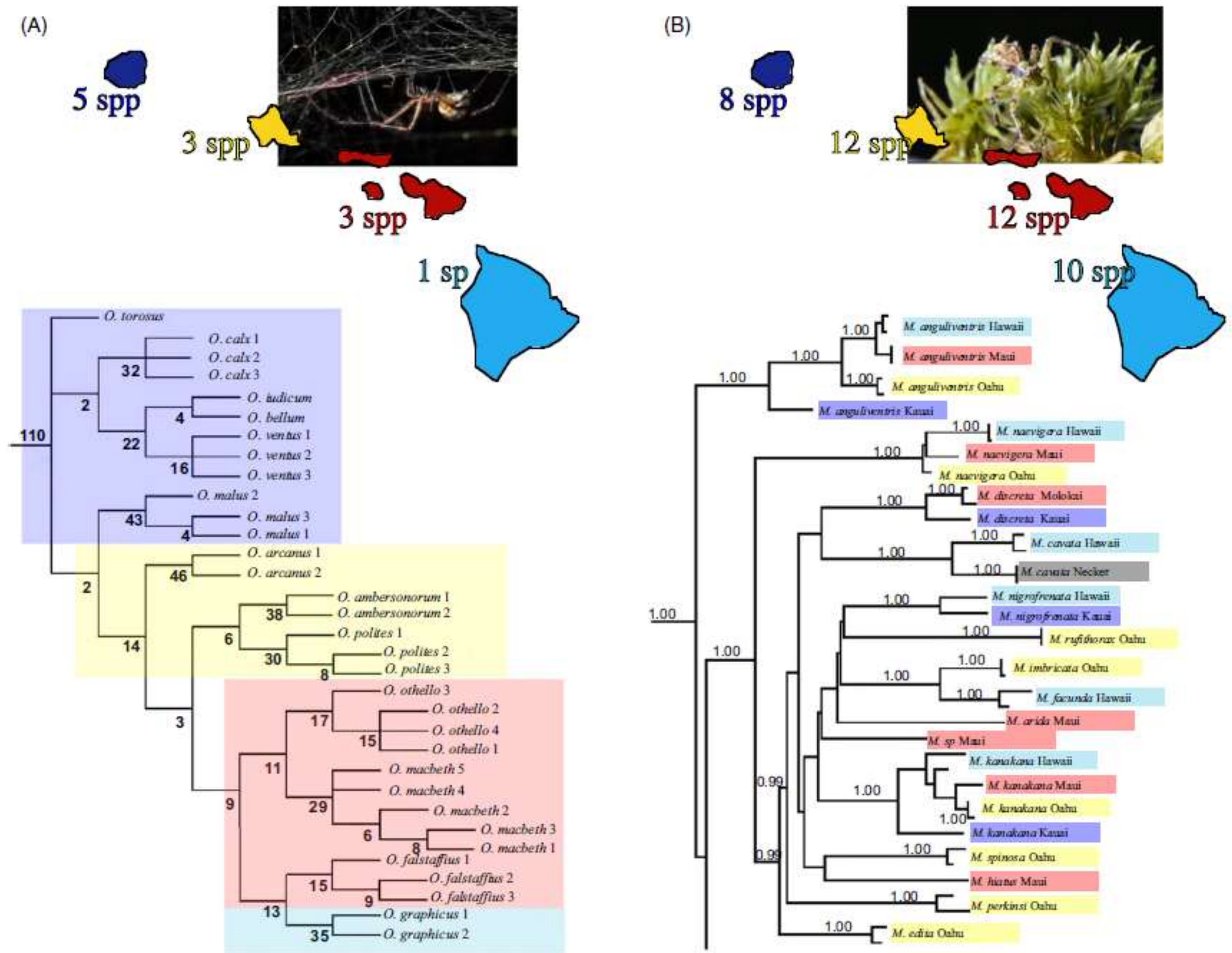
Phylogenies of 3 *Hyposmocoma* case-bearing lineages

Kawahara et al. unpubl 2015 Haines et al. Nature Communications 2014, doi 10.1038/ncomms4502

Plagithmysus (Cerambycidae): 139 spp., other cerambycids: 2 spp.

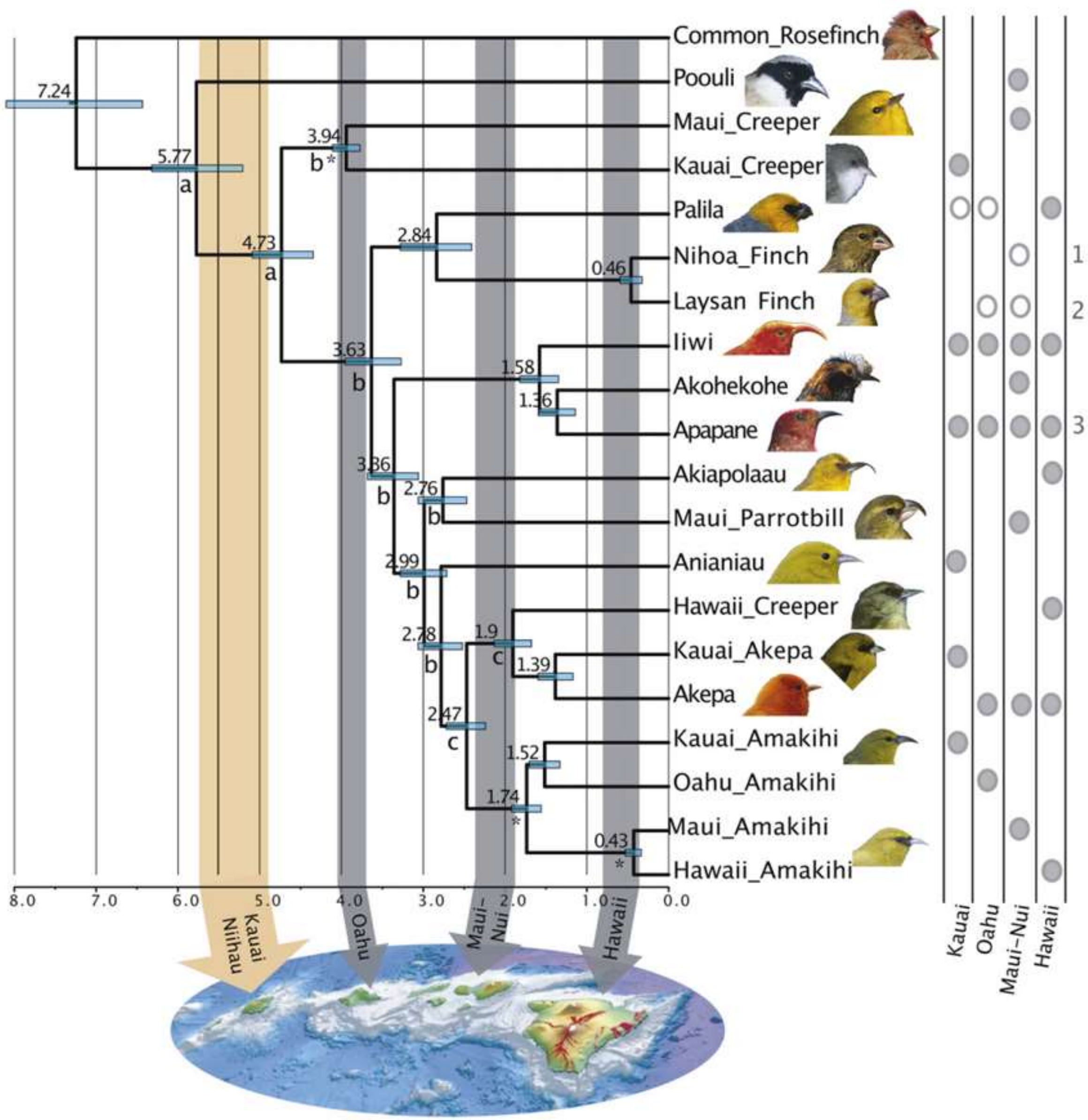
Spiders: speciation between and within islands

(A) *Orsonwelles* spiders, radiation progressed down the island chain
(B) *Mecaphesa* spiders, early diversification into different ecologically defined taxa, subsequent progression down the island chain in each species.



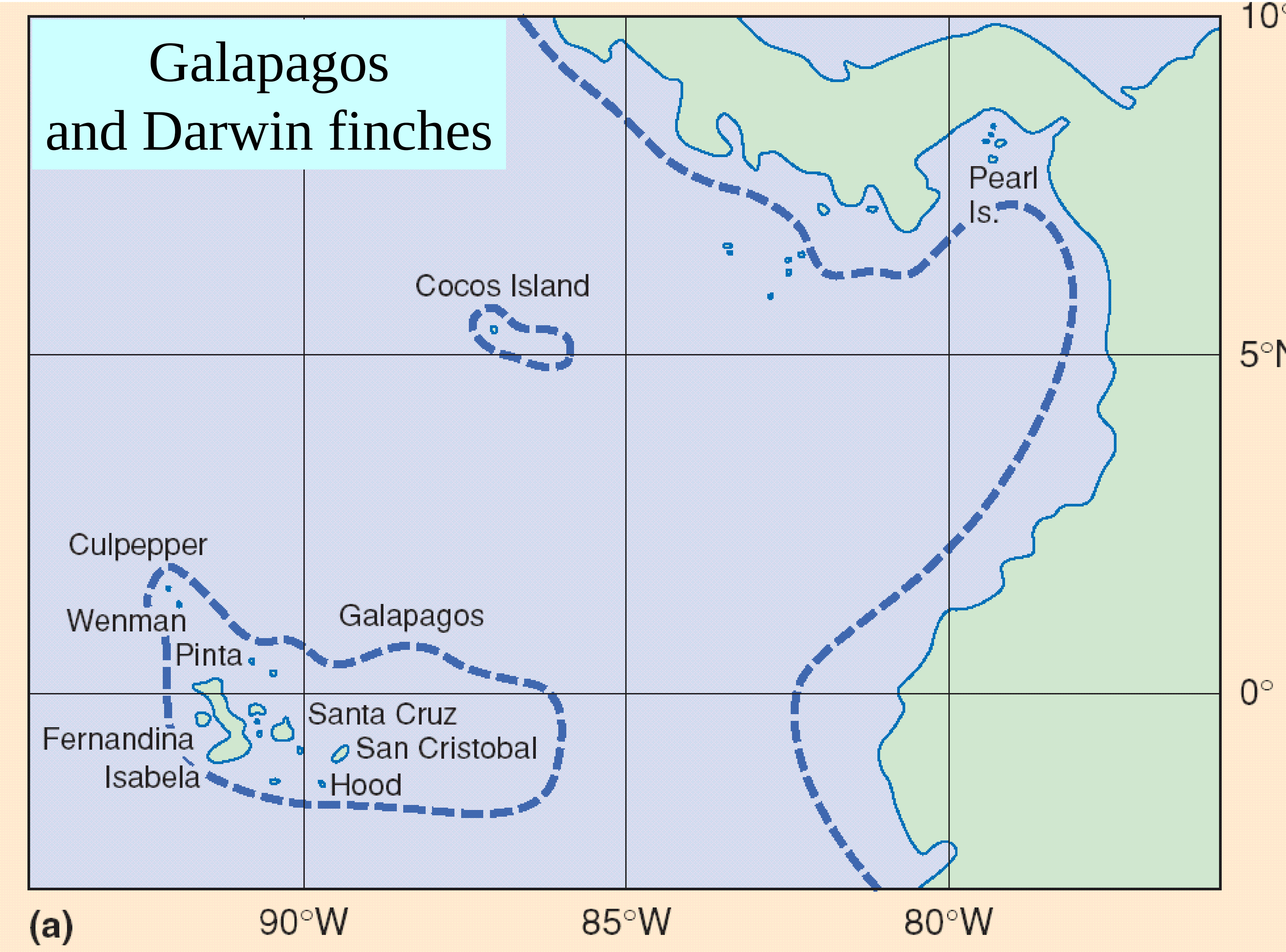
Gillespie, R. 2015. Evolutionary Applications

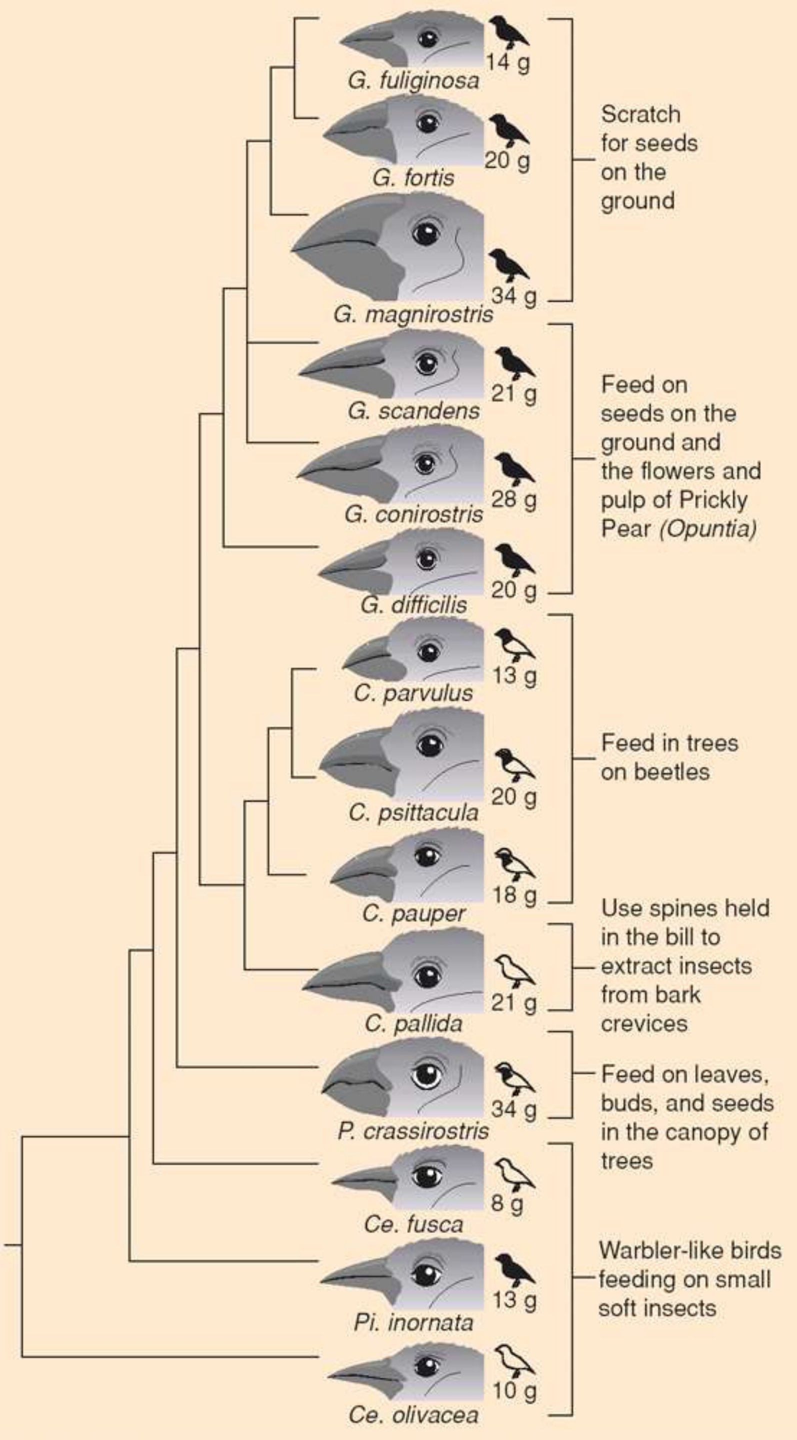
Drepanididae: and endemic Hawaiian family, 52 spp., incl. 18 extinct



Lerner et al. 2011, Current Biology 21, 1838–1844

Galapagos and Darwin finches




G. fuliginosa
14 g
G. fortis
20 g
G. magnirostris
34 g
Scratch for seeds on the ground
G. scandens
21 g
G. conirostris
28 g
G. difficilis
20 g
Feed on seeds on the ground and the flowers and pulp of Prickly Pear (Opuntia)
C. parvulus
13 g
C. psittacula
20 g
C. pauper
18 g
Feed in trees on beetles
C. pallida
21 g
Use spines held in the bill to extract insects from bark crevices
P. crassirostris
34 g
Feed on leaves, buds, and seeds in the canopy of trees
Ce. fusca
8 g
Pi. inornata
13 g
Ce. olivacea
10 g
Warbler-like birds feeding on small soft insects


small ground finch
medium ground finch
large ground finch
sharp-beaked ground finch
cactus finch
large cactus finch
small tree finch
large tree finch?
vegetarian finch
woodpecker finch
warbler finch

Geospiza on Galapagos: coexistence and beak size

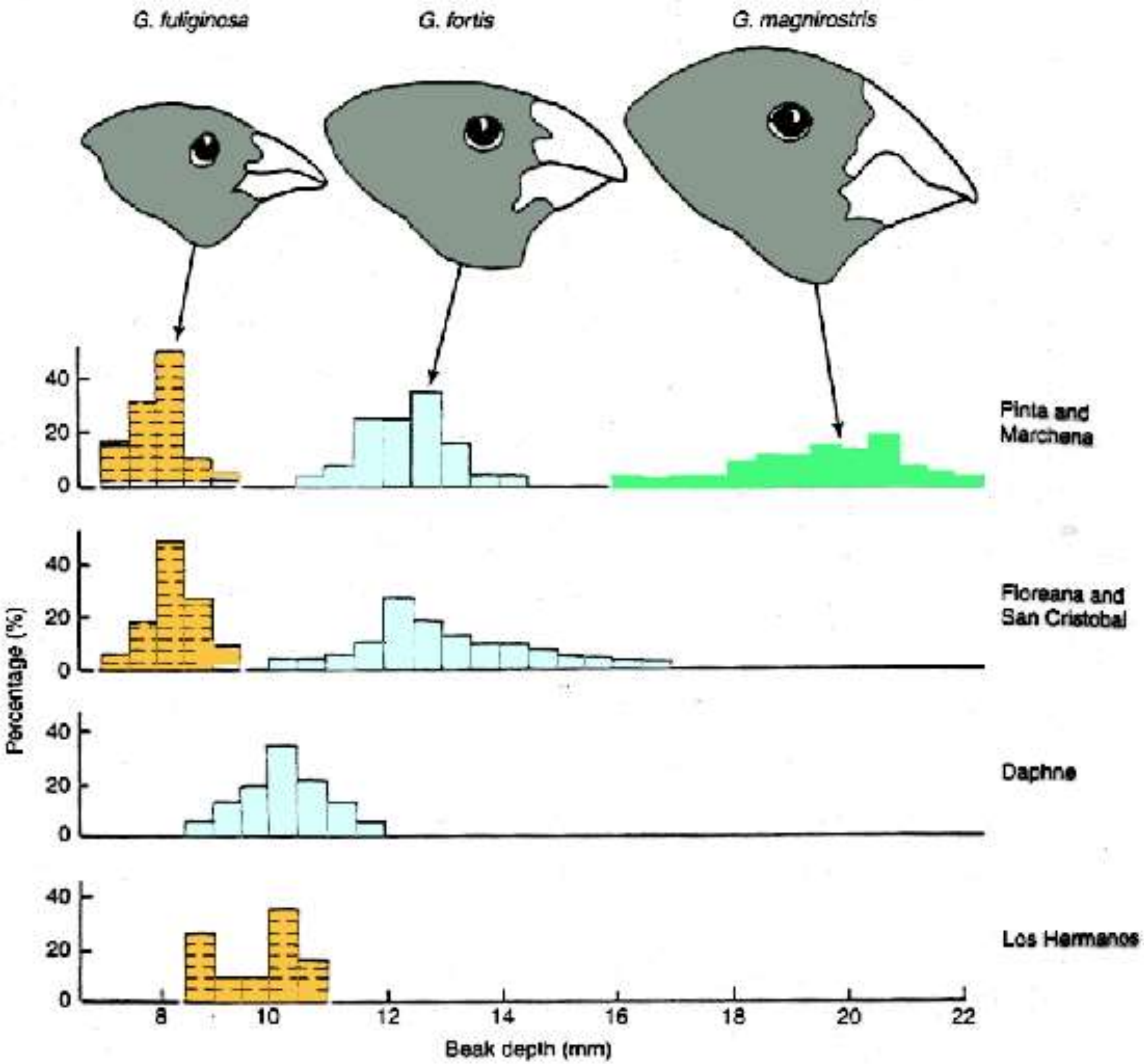
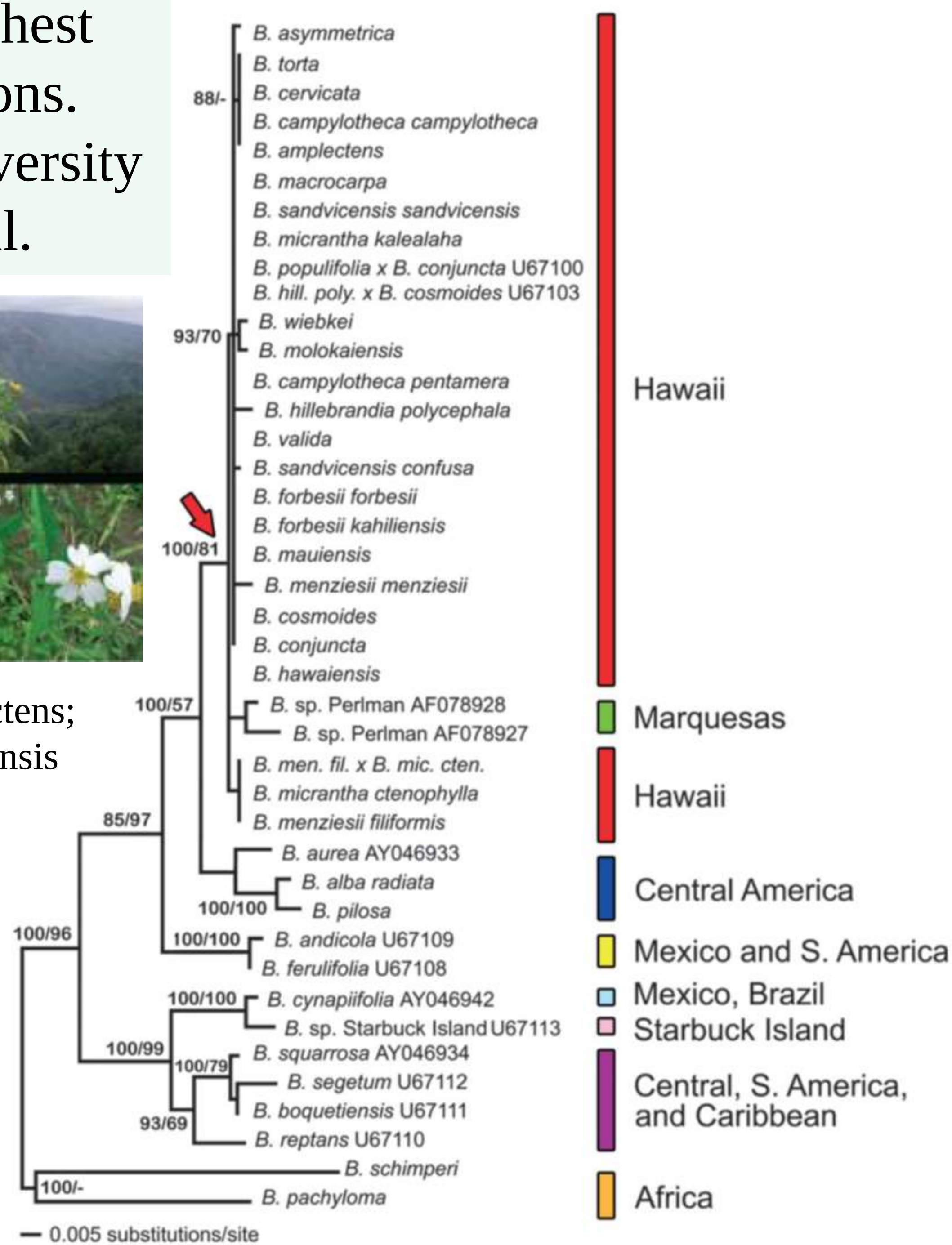


Figure 12.13 Percentages of individuals with beaks of different depths in three species of ground finches (*Geospiza* spp.) on islands in the Galapagos Archipelago. Note the increase in beak depth in *G. fortis* on Floreana and San Cristobal Islands where *G. magnirostris* is absent and the altered beak size distributions of *G. fortis* and *G. fuliginosa* on Daphne and Los Hermanos Islands respectively (after Lack 1947; Ricklefs 1997 with kind permission from Peter Lack and Cambridge University Press).

Bidens in Hawaii: one of the highest speciation rates for plant radiations. Rapid diversification: habitat diversity and the adaptive loss of dispersal.

a: B. hillebrandia; b: B. cosmoides; c: B. amplectens; d: B. sandvicensis; e: B. mauiensis; f: B. hawaiensis



Maximum likelihood phylogram based on ITS sequences for Hawaiian and outgroup Bidens spp.

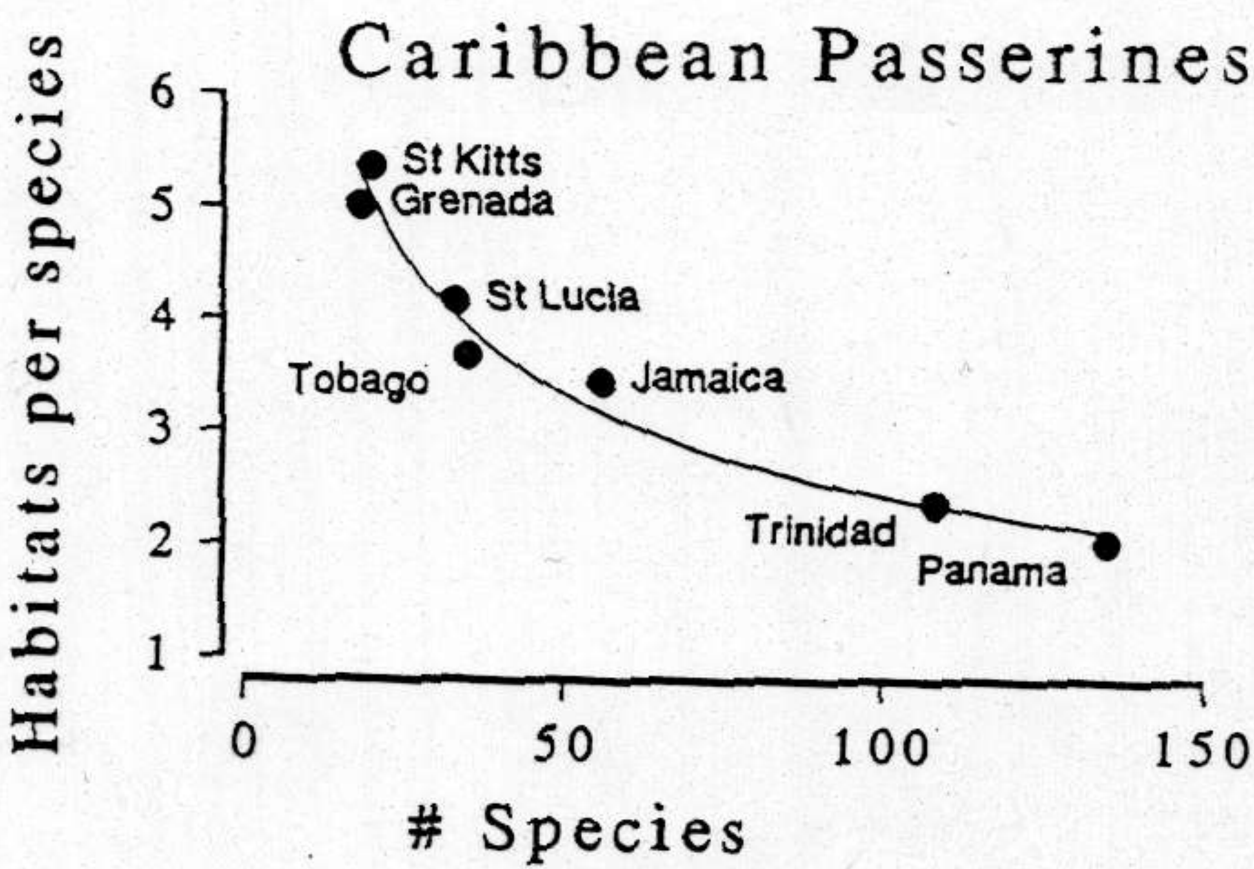
Knope et al. 2012 J. Biogeogr.

• wide niches

Metrosideros polymorpha (Myrtaceae): dominates Hawaiian forests from the sea shore to 2,600 m asl, as a tree or shrub

Hawaii forests: dominated by Metrosideros polymorpha and Acacia koa

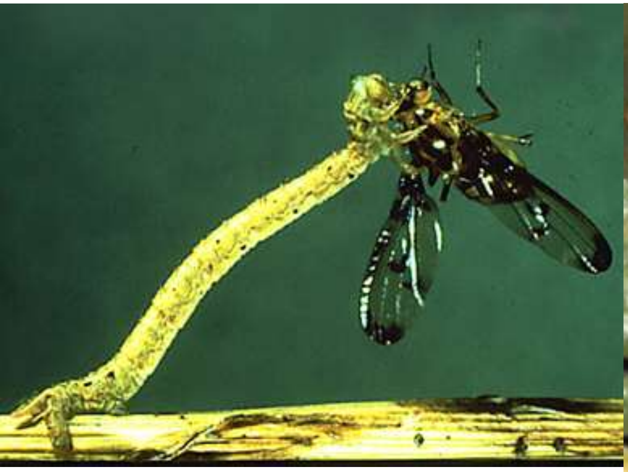
Wider niches: bird species use more habitats on species poor islands



The more species of birds, the fewer habitats used by each species. Data from Cox and Ricklefs (1977) and Wunderle (1985).

• unusual shifts of ecological niches

• *Euphitecia* (Geometridae): 18 spp. are the only known predatory caterpillars



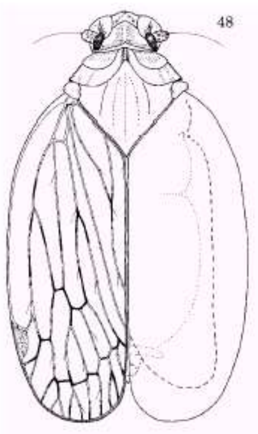
• *Megalagrion oahuense* (Odonata): has terrestrial larvae

• Delphacidae (Hemiptera): ~1,800 spp. feed almost exclusively on monocotyledoneous plants, but all 135 Hawaiian spp. feed on dicotyledoneous hosts

Photos Bill Mull, Dan Polhemus

Oliarus (Cixiidae, Hemiptera): 7 cavernicolous spp. in lava tubes, each by a separate cave colonization

Hoch, H. 2002. Denisia 4:139-146



wing, eye & pigment reduction

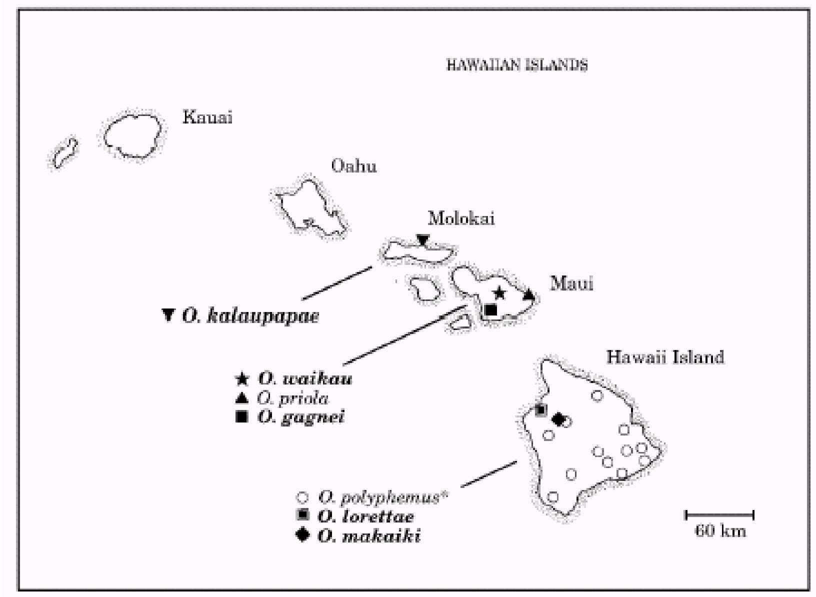


Figure 59. Distribution of cavernicolous *Oliarus* species in the Hawaiian Islands. *Localities after Hoch and Howarth (1993) and Hoch (unpublished data).

Some plants lost their anti-herbivore defence in Hawaii, such as secondary chemicals (*Mentha* spp.) or thorns (*Rubus* spp.)

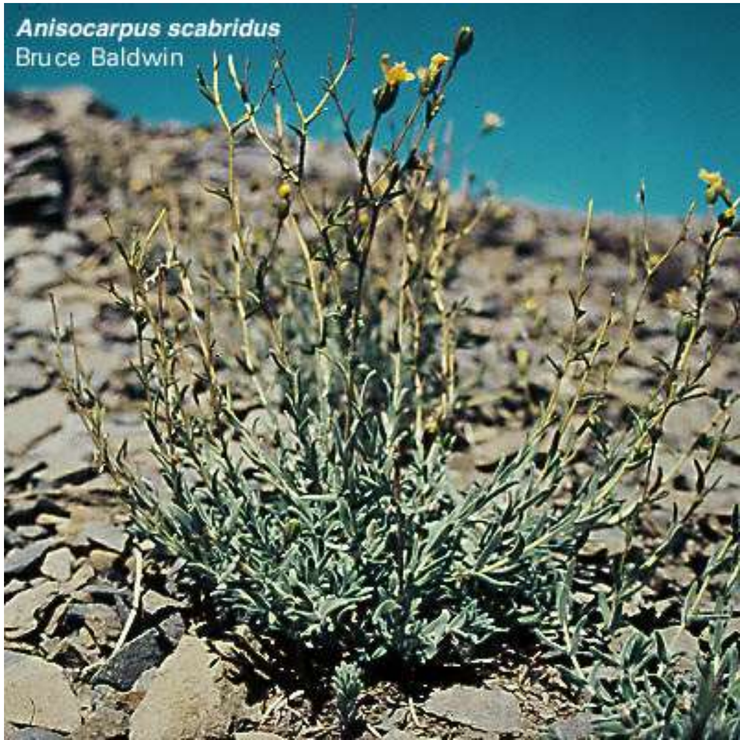
Mentha sp.

Rubus hawaiensis

Sometimes, strange organisms evolve on islands

Agroxiphium sandwicense (silversword) Hawaii

Silverswords evolved after a single colonization by an Asteraceae plant near the extant Anisocarpus:



Radiation of Asteraceae on St. Helena island

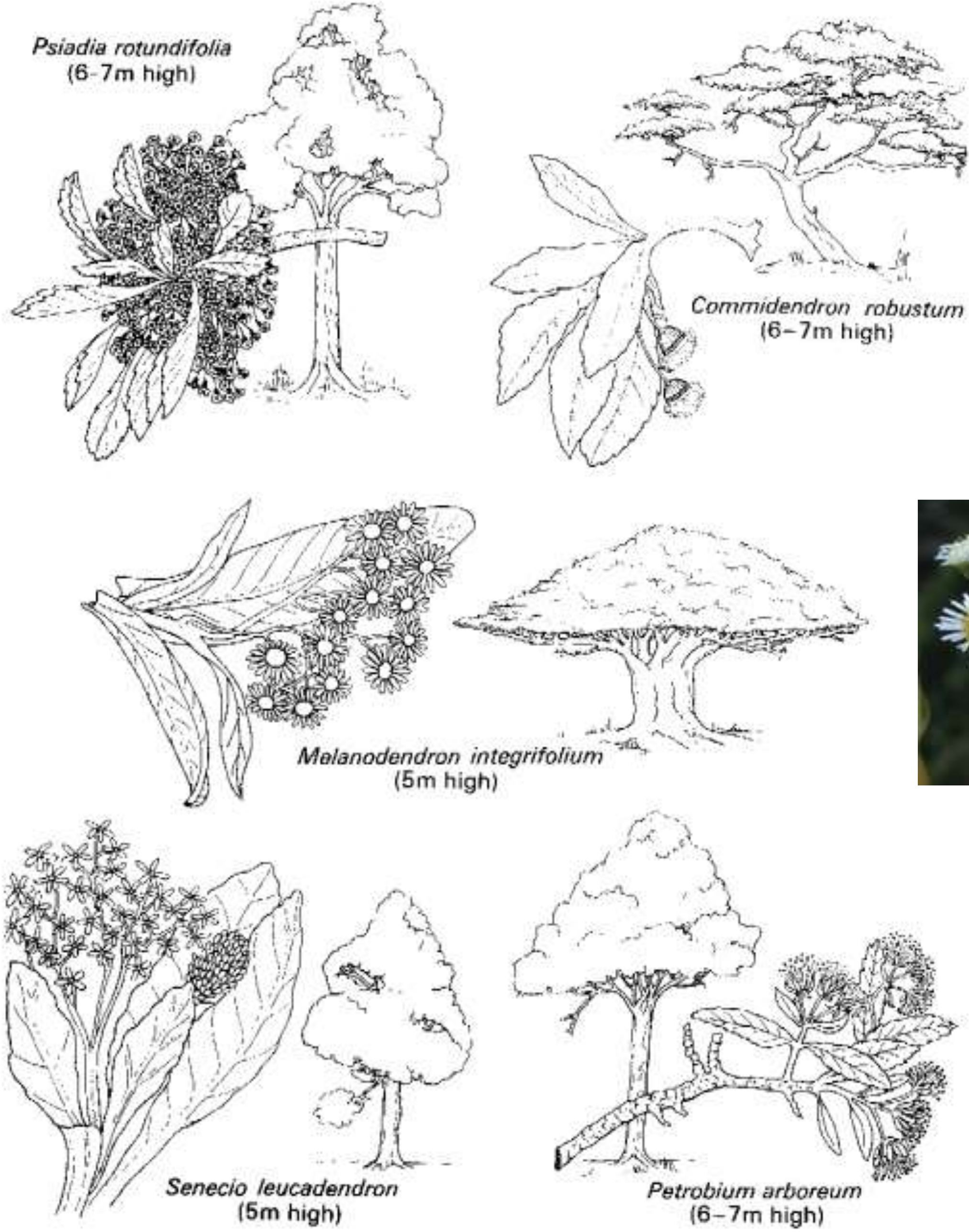
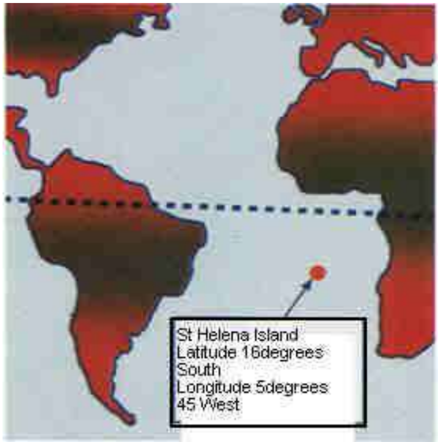
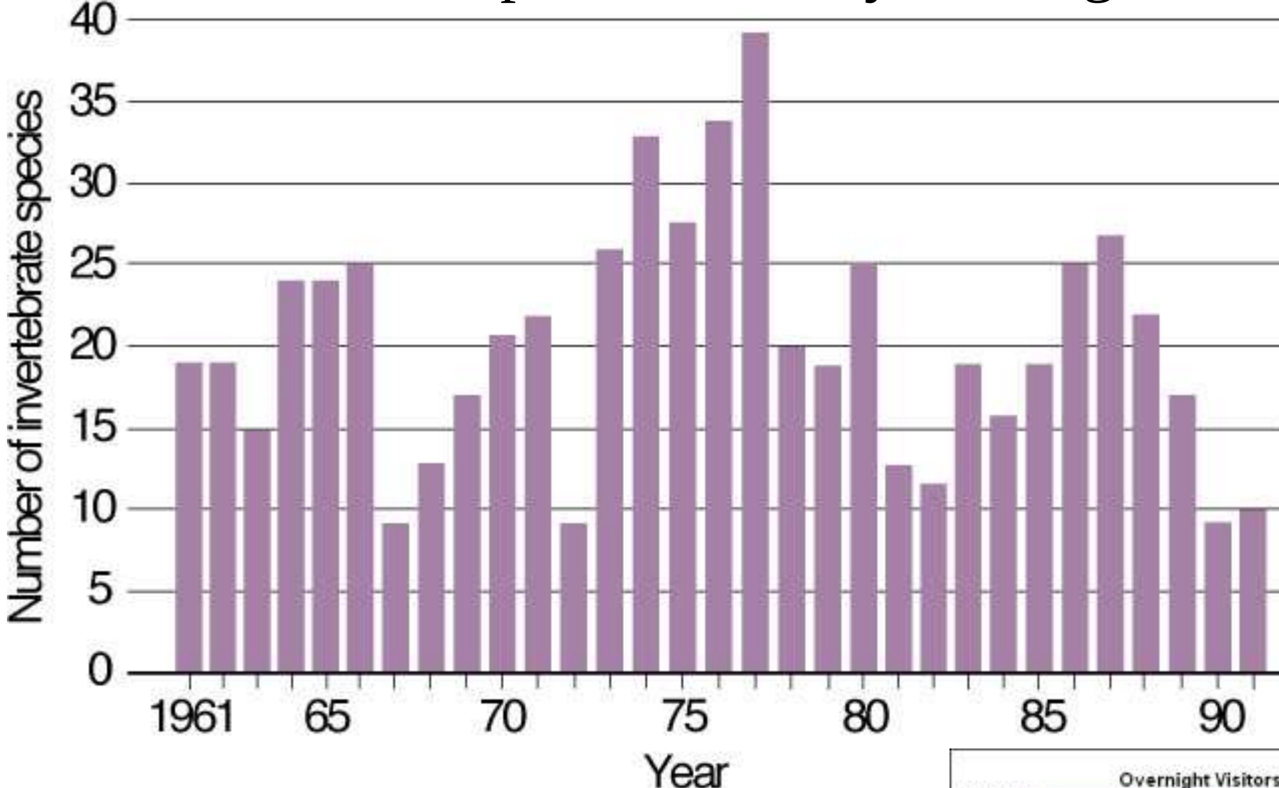


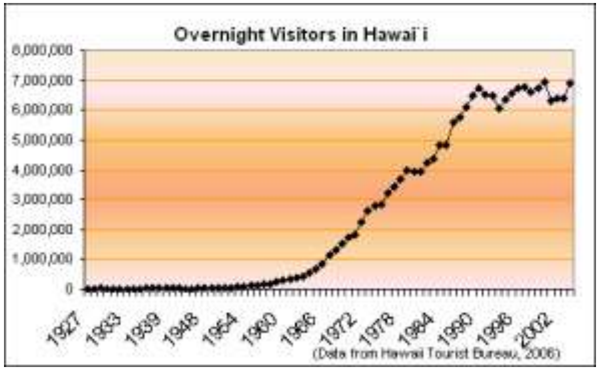
Figure 5.8. The varied trees which have evolved from immigrant sunflowers on St. Helena Island.



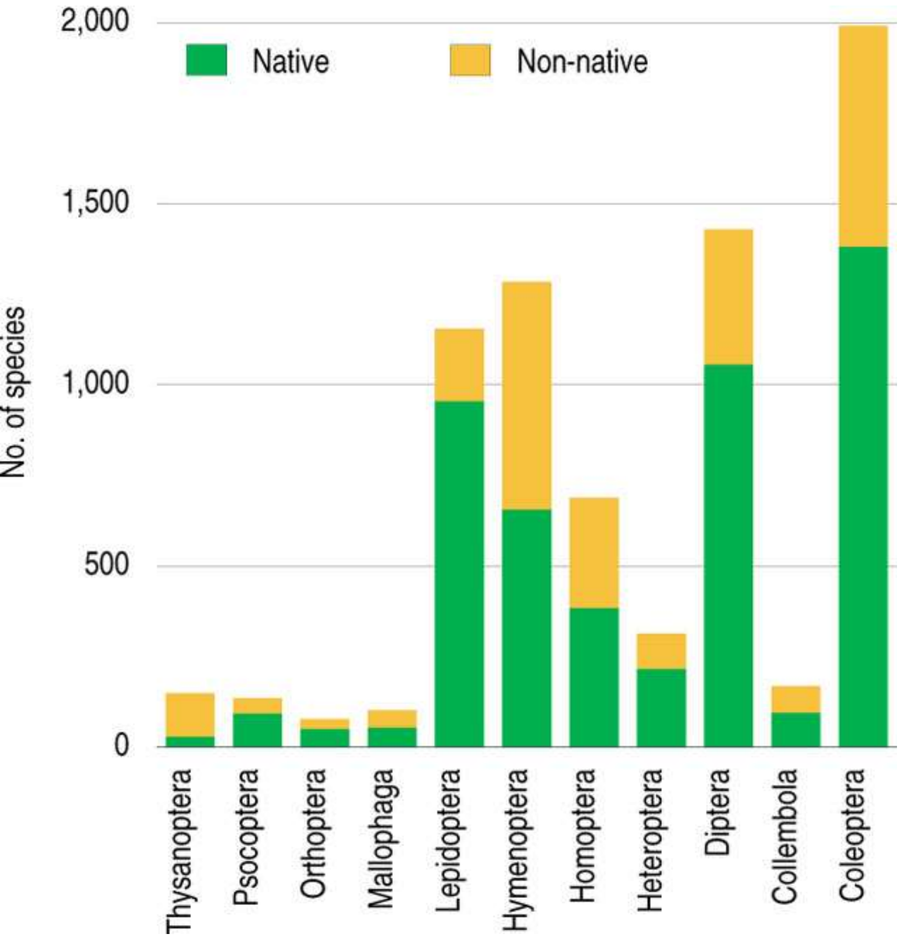
• susceptibility to invasive species

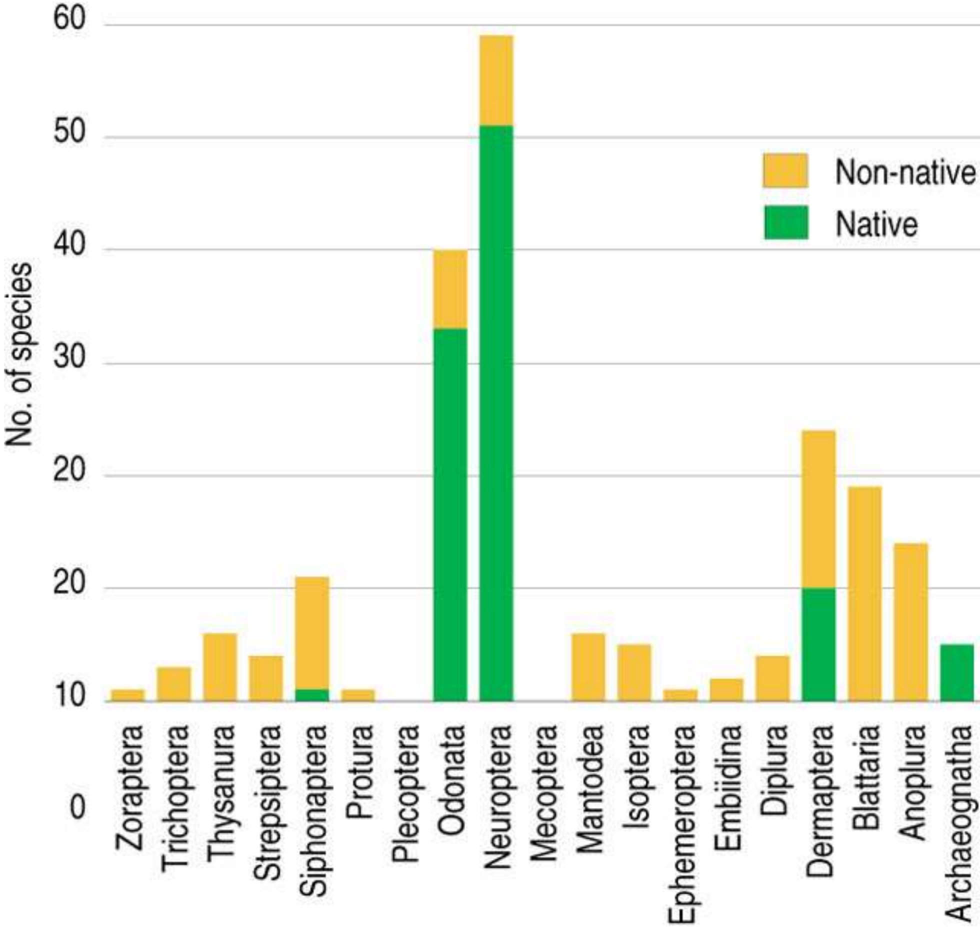
No. of alien invertebrate species annually arriving to Hawaii





Native and alien species of insects in Hawaii





HAWAII ISLES

	endemic	non-endemic	alien
flowering plants	1,100	87	800
ferns	105	37	21
birds	44	12	38
land mammals	0	0	18
insects	5,000 (?10,000)	>100	2,700

Miconia calvescens (Melastomataceae)

Origin in South America, spreading in Hawaii and the Pacific.
In Tahiti invaded native vegetation and now dominates >60% of local forests, often forming monospecific stands..

Monospecific *Miconia* stand in Tahiti

Falcataria moluccana (Fabaceae)

Large, fast growing N-fixing pioneer, colonizes disturbed sites on Pacific islands. In Hawaii on lava flows, its nitrogen input (240 kg N per ha and year - comparable to industrial fertilization levels for crops) was 4-55x greater than from native vegetation, altering successional trends – facilitating alien Psidium cattleianum, suppressing native dominant Metrosideros polymorpha

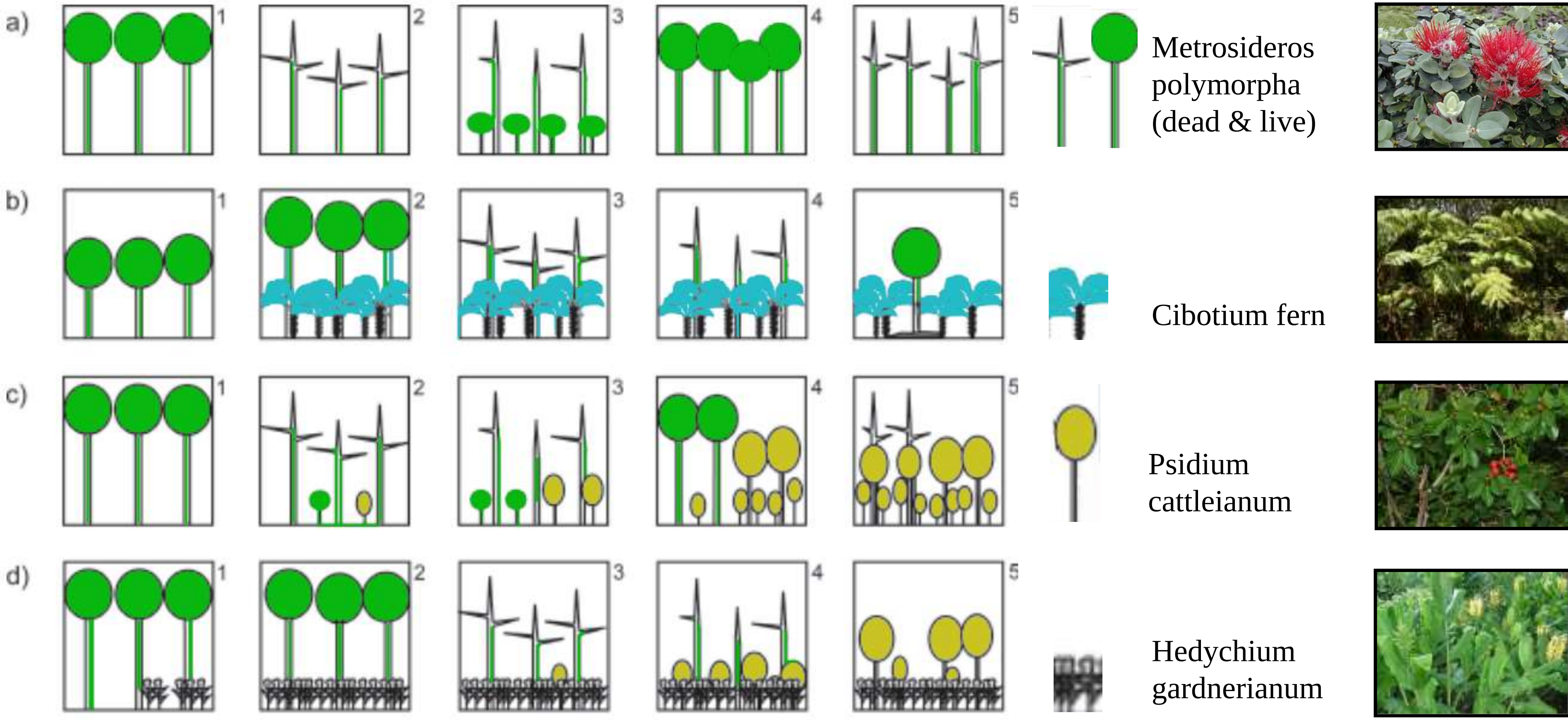
Falcataria moluccana

↓ Metrosideros polymorpha

↑ Psidium cattleianum

Hughes & Denslow Ecological Applications 15:1615–1628.

Invasive spp. changing Hawaii forest dynamics



M. polymorpha forest dynamics – simple replacement of dead trees by conspecific recruits (a) or the replacement is slowed on nutrient rich soils by native tree fern Cibotium (b).

Invasive P. cattleianum colonizes tree gaps and suppresses Metroxylon regeneration producing Psidium forest (c) or dominance in the understorey by invasive ginger Hedychium that suppresses Metroxylon but not Psidium, resulting in Psidium forest with Hedychium understorey..

Keppel et al. PACIFIC CONS. BIOL. 2014

Christmas Island

Invasion of ‘crazy ant’
Anoplolepis gracilipes

↓

Elimination of *Gecarcoidea natalis* crab

↓

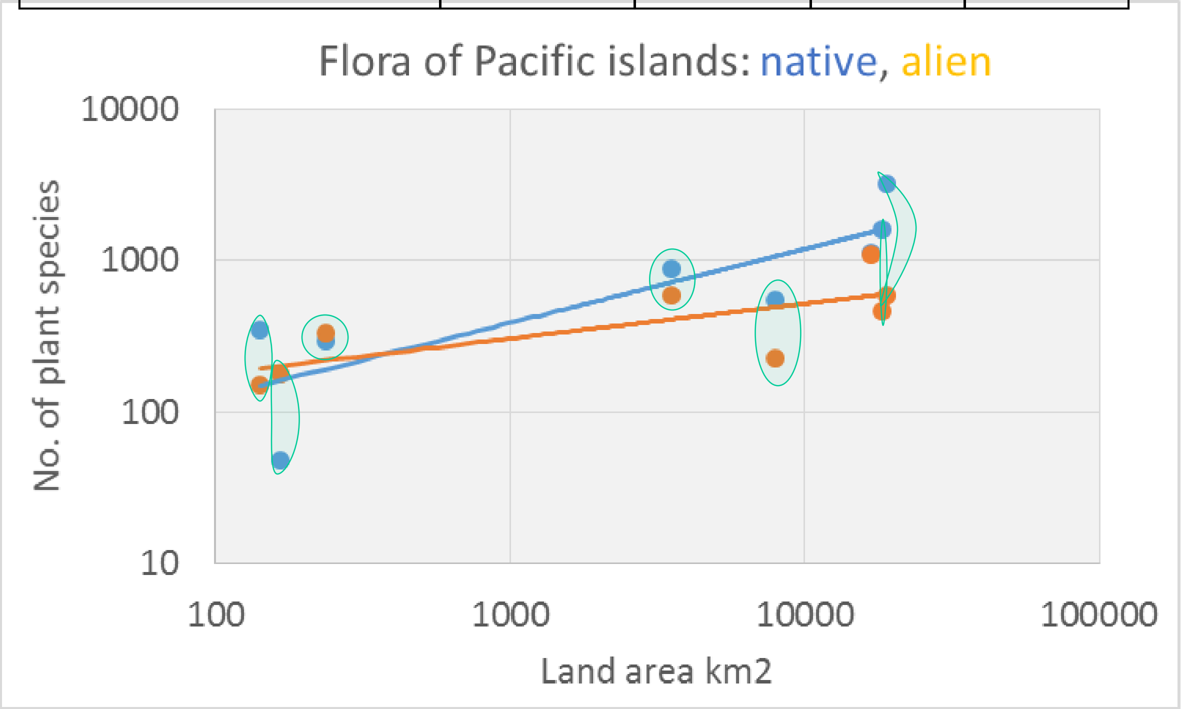
Increase in forest understorey cover

O’Dowd et al. 2003 Ecology Letters, 6: 812–817

Figure 1 Impacts of invasion of island rain forest by the yellow crazy ant, *Anoplolepis gracilipes*. (a) Uninvaded site (Winifred Track) with open understorey maintained largely by the foraging activities of the red land crab, *Gecarcoidea natalis*. (b) Invaded site (Dales) 1–2 years after ant invasion with a dense and diverse seedling cover and thick litter layer. Photographs by Peter Green.

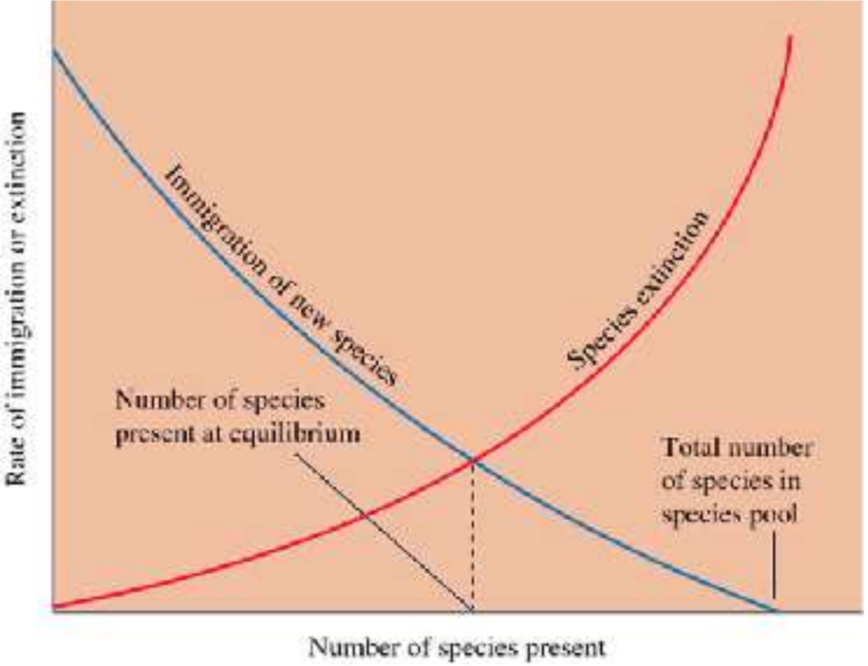
Pacific islands floras: 15-79% alien

	Area km2	Native	Alien	% alien
New Caledonia	19060	3261	595	15
Fiji	18270	1622	461	22
Hawai'i	16880	1138	1104	49
Galápagos	7900	550	229	29
French Polynesia	3519	885	593	40
Cook Is.	238	296	333	53
Rapa Nui (Easter Is.)	166	48	180	79
Wallis et Futuna	142	351	151	30

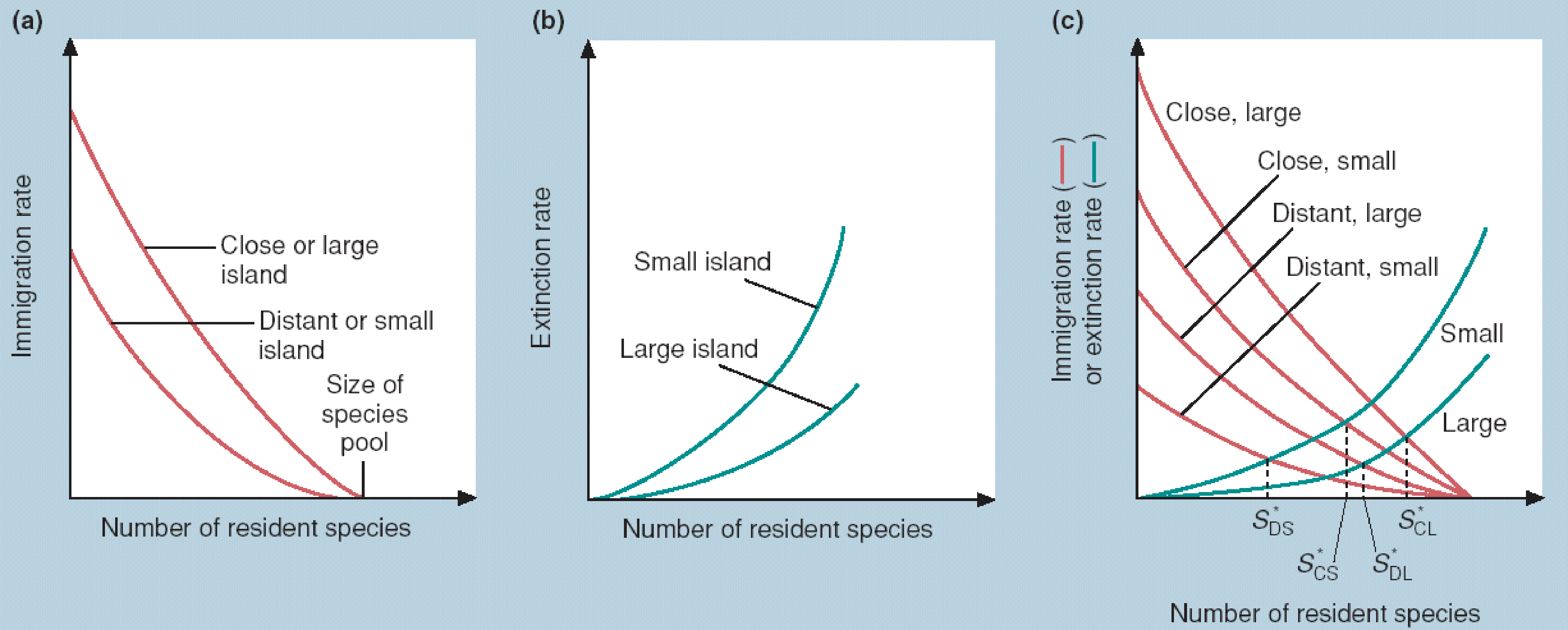


Native and alien data points for each site are connected: At 3 sites, alien flora equals or exceeds native

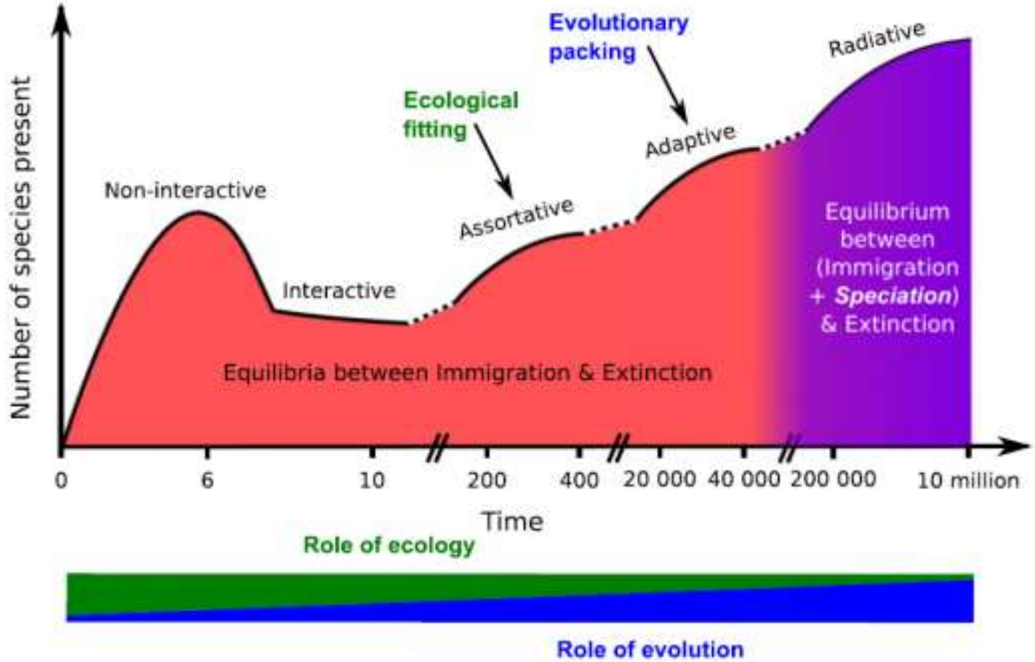
Meyer 2014. PACIFIC CONS. BIOL. 20: 146–164



Island biogeography



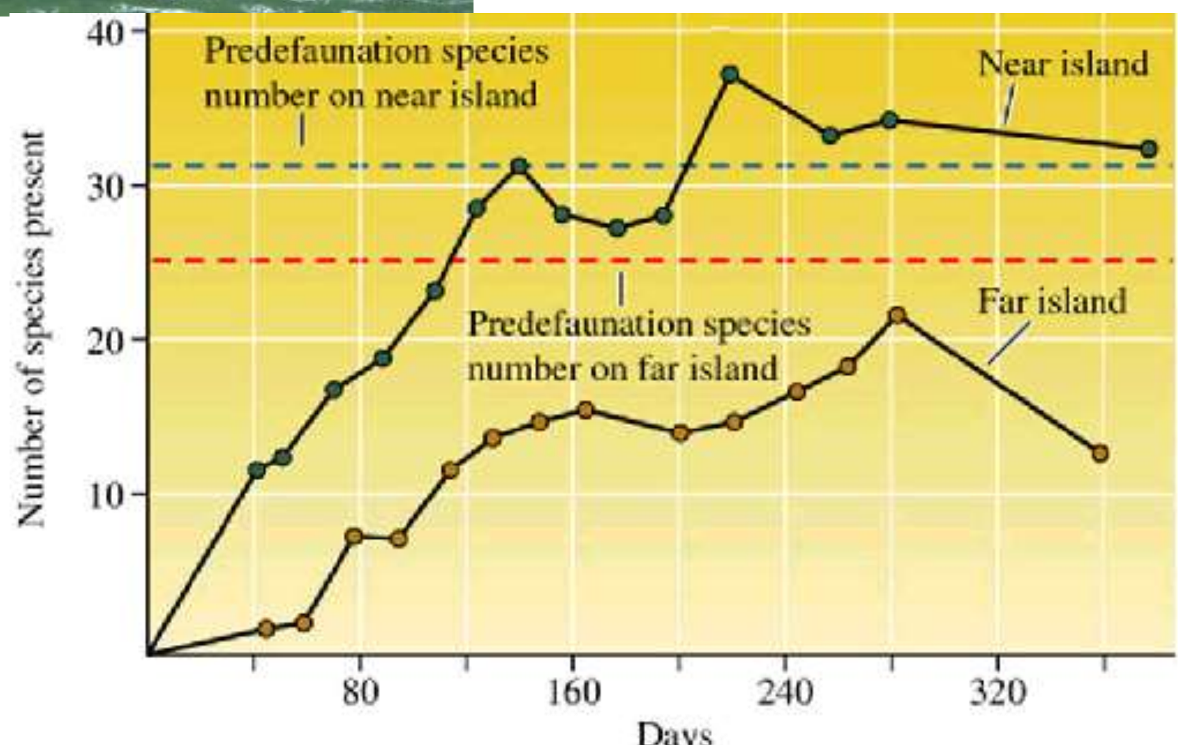
Ecological – evolutionary continuum in equilibrium number of species in communities



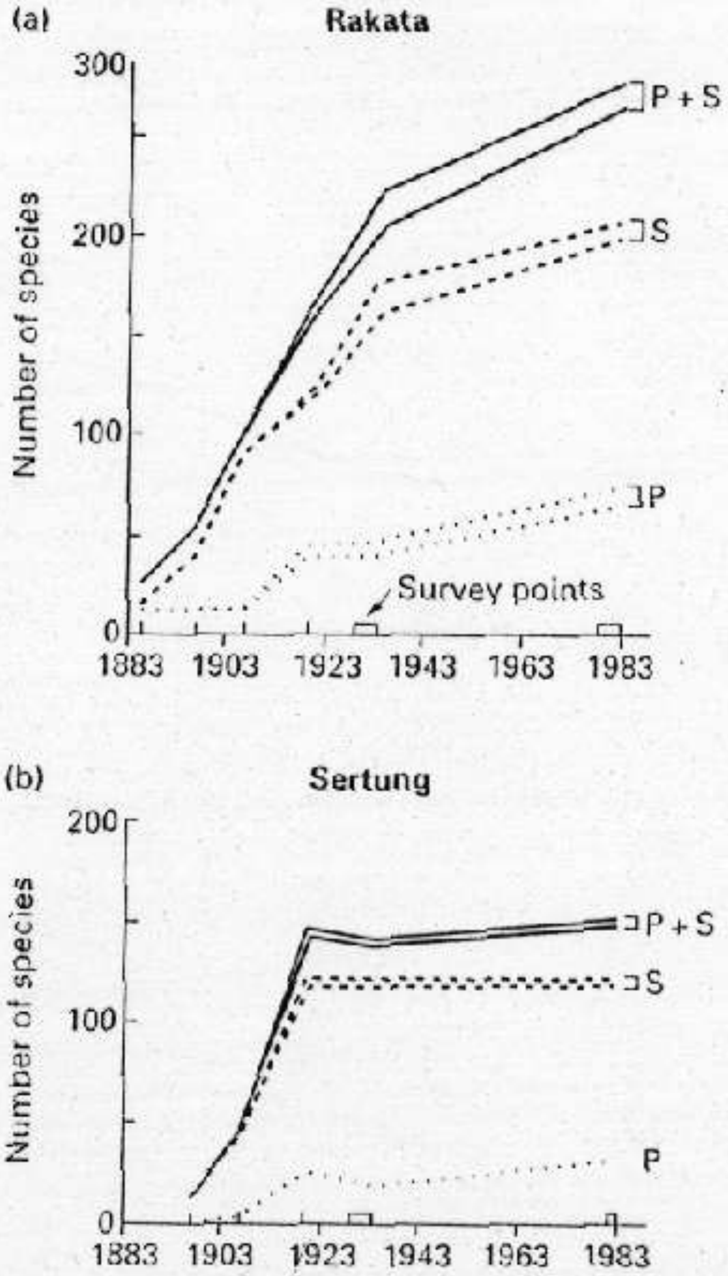
(1) Non-interactive equilibrium: prior to the attainment of high population densities needed to make species competitive exclusion a major factor in extinction,
(2) Interactive equilibrium: species interactions incl. competitive exclusion are a major factor
(3) Assortative equilibrium: in response to environmental filtering, i.e. the conditions of the local environment and interactions with other species over the long term,
(4) Adaptive equilibrium: reached when populations undergo evolutionary adaptive change in response to environmental conditions and other species.

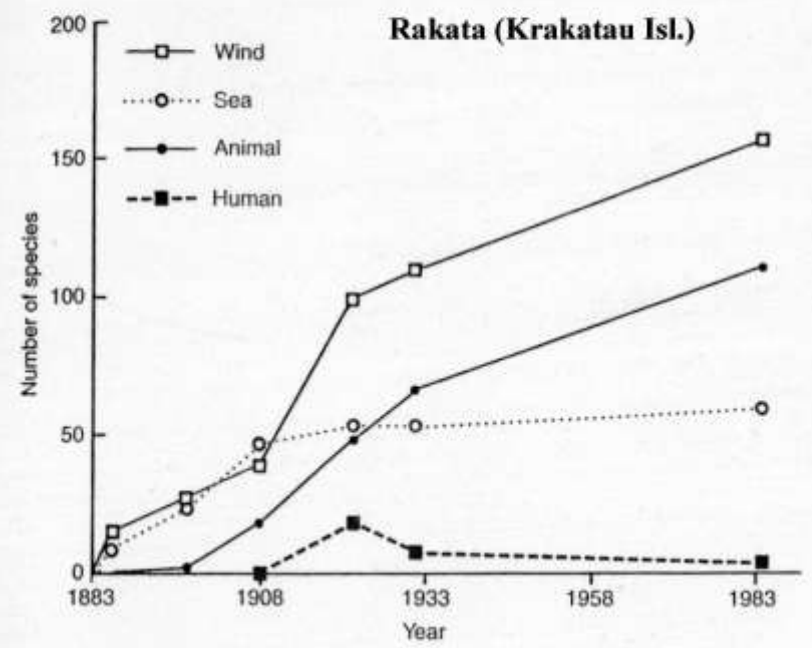
Warren et al. 2014. Ecol. Lett. doi: 10.1111/ele.12398

Wilson and Simberloff (1970): experimental tests of the theory, monitoring arthropod immigration and extinction after complete defaunation of small mangrove islands offshore Florida



SUCCESSION ON KRAKATAU
S spermatophyta P pteridophyta



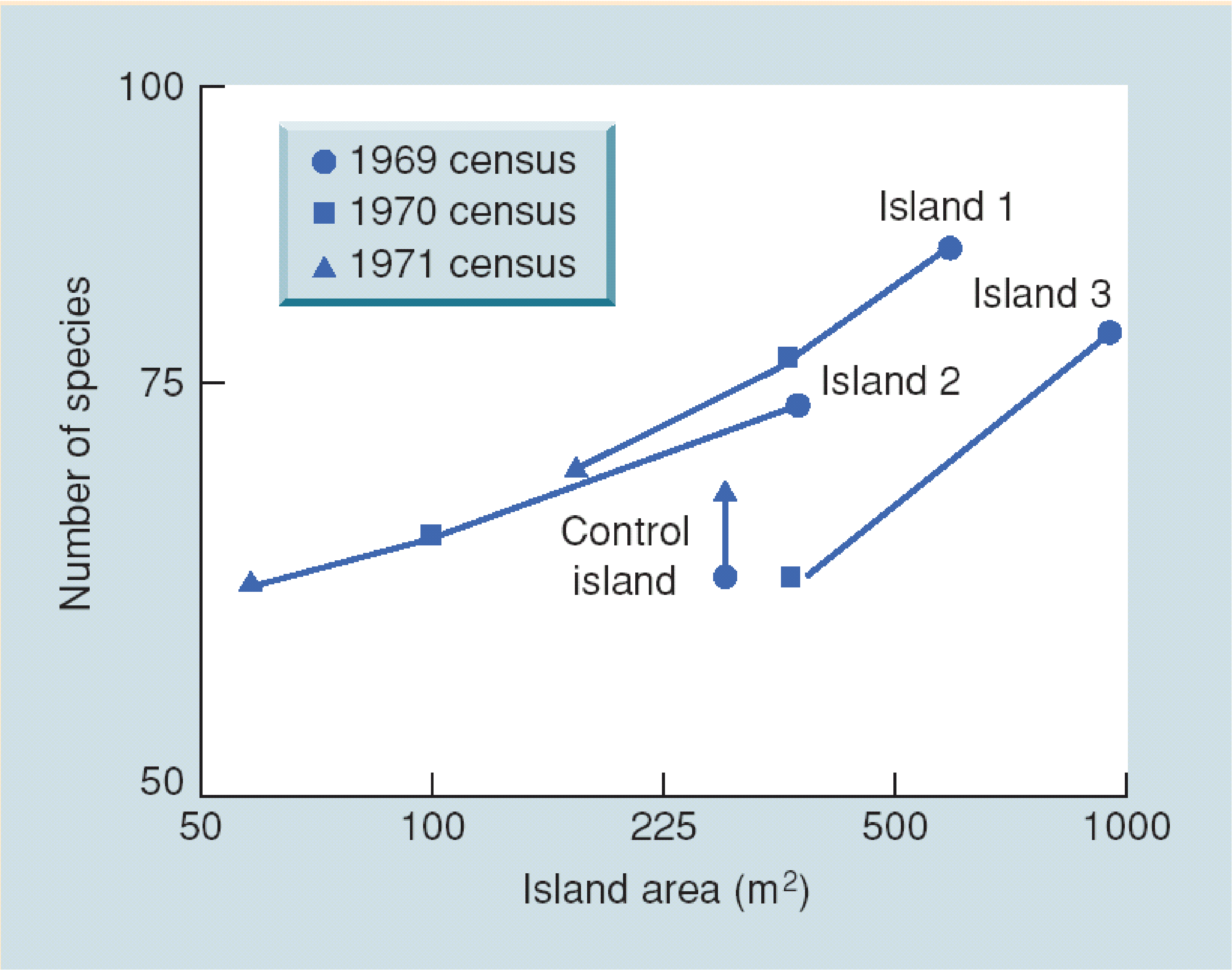


Species accumulation after defaunation of Krakatau

Fig. 4.18 Number of species recorded in particular survey periods for Pteridophyta (P), Spermatophyta (S) and all higher plants (P + S) for the three older Krakatau Islands: (a) Rakata; (b) Sertung; and (c) Rakata Kecil. The ranges take into account the uncertain identification of some taxa. (After Whittaker *et al.* 1989.)

Figure 12.3 Dispersal mode spectra of vascular plants on Rakata at successive survey periods. Surveys made in the periods 1920–24, 1929–34 and 1979–89 are grouped and the data plotted at the mid-point of these periods. Note: (1) how the presence of sea-dispersed plants levelled out after 1924; and (2) the increase in wind-dispersed plants between 1908 and 1924, which was largely due to the arrival and colonisation of species adapted to the more shady conditions provided by the developing forest canopy (adapted from Thornton 1996; Whittaker *et al.* 1992. Reprinted by permission of the publishers from *Krakatau* by Ian Thornton, Cambridge, MA: Harvard University Press, Copyright © 1996

Experimental test of the effect of island area on species richness



The effect on the number of arthropod species of artificially reducing the size of mangrove islands. Islands 1 and 2 were reduced in size after both the 1969 and 1970 censuses. Island 3 was reduced only after the 1969 census. The control island was not reduced, and the change in its species richness was attributable to random fluctuations. (After Simberloff, 1976.)

Reptiles and amphibians in the Caribbean: an example of species-area relationships for islands

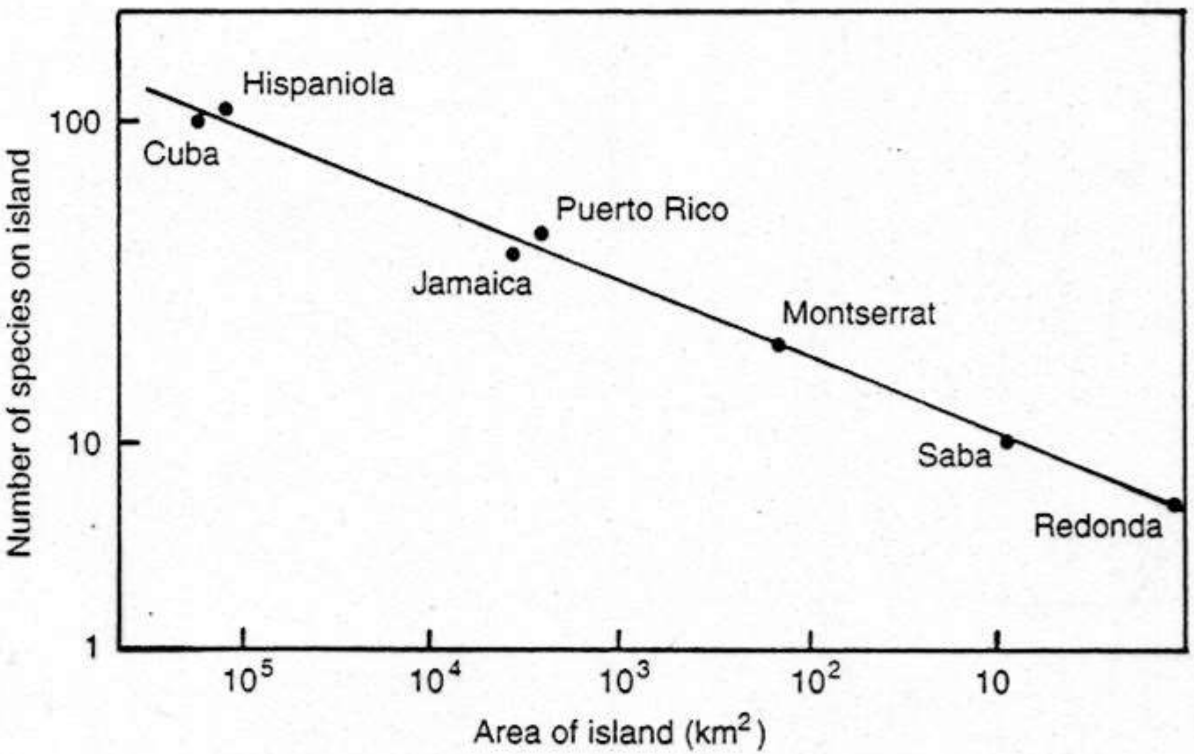
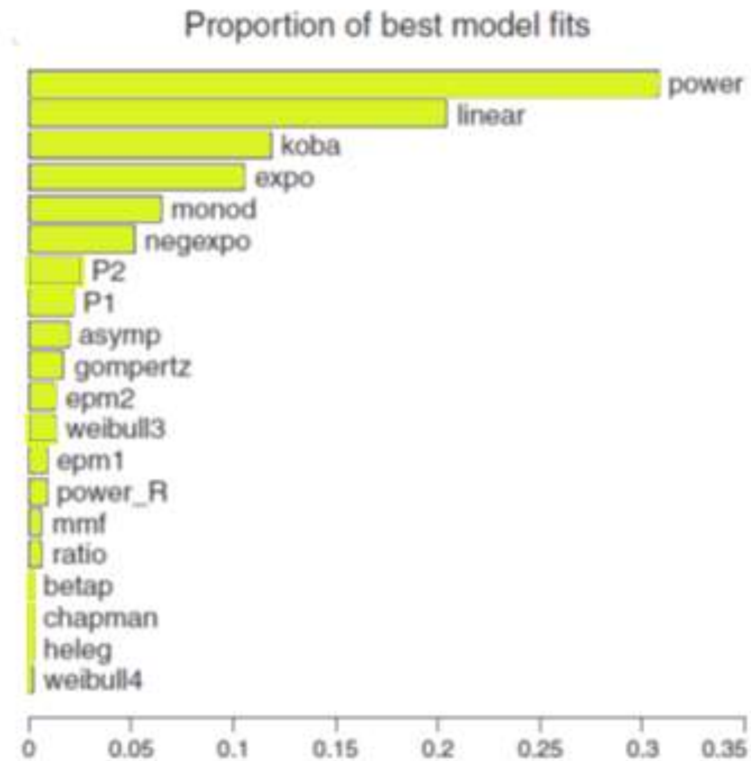


Figure 12.9 The number of species of reptiles and amphibians on seven Caribbean islands plotted against island size (after MacArthur and Wilson 1967; Wilson 1992.

Relationship between island size and number of species: always power?

Function name	Formula	Shape type	Asymptote
Linear	$S = c + zA$	Linear	No
Power	$S = cA^z$	Convex	No
Power Rosenzweig	$S = k + cA^z$	Convex	No
Extended Power 1	$S = cA^{zA-d}$	Both	No
Extended Power 2	$S = cA^{z-(d/A)}$	Sigmoid	No
Persistence Function 1	$S = cA^z \exp(-dA)$	Convex	No
Persistence Function 2	$S = cA^z \exp(-d/A)$	Sigmoid	No
Exponential	$S = c + z \log A$	Convex	No
Kobayashi Logarithmic	$S = c \log(1 + A/z)$	Convex	No
Monod	$S = d/(1 + cA^{-1})$	Convex	Yes (d)
Morgan–Mercer–Flodin	$S = d/(1 + cA^{-z})$	Sigmoid	Yes (d)
Logistic	$S = c/(f + A^{-z})$	Sigmoid	Yes (c/f)
Negative Exponential	$S = d[1 - \exp(-zA)]$	Convex	Yes (d)
Chapman–Richards	$S = d[1 - \exp(-zA)]^c$	Sigmoid	Yes (d)
Weibull-3	$S = d[1 - \exp(-cA^z)]$	Sigmoid	Yes (d)
Weibull-4	$S = d[1 - \exp(-cA^z)]^d$	Sigmoid	Yes (d)
Asymptotic	$S = d - cz^A$	Convex	Yes (d)
Rational	$S = (c + zA)/(1 + dA)$	Convex	Yes (z/d)
Gompertz	$S = d \exp[-\exp(-z(A-c))]$	Sigmoid	Yes (d)
Beta-P	$S = d[1 - (1 + (A/c)^z)^{-f}]$	Sigmoid	Yes (d)

Species-area functions: S = no. of species, A = area, c, d, f, z = fitted parameters; asymptote's value in brackets (last column)



Island species–area relationship models across 465 data sets

Triantis et al. 2012, J. Biogeogr. 39, 215–231

Species-area relationships from SE Asia

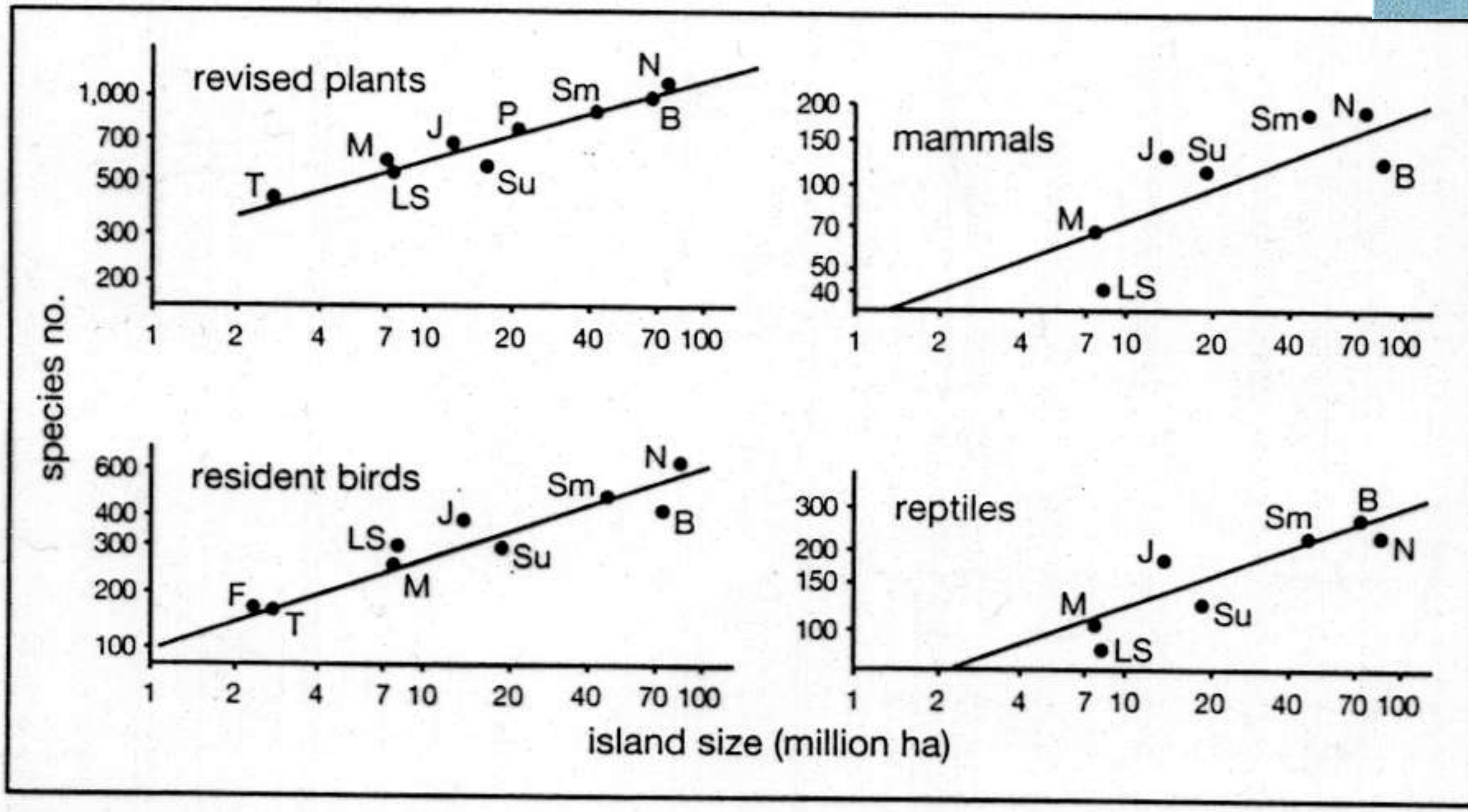
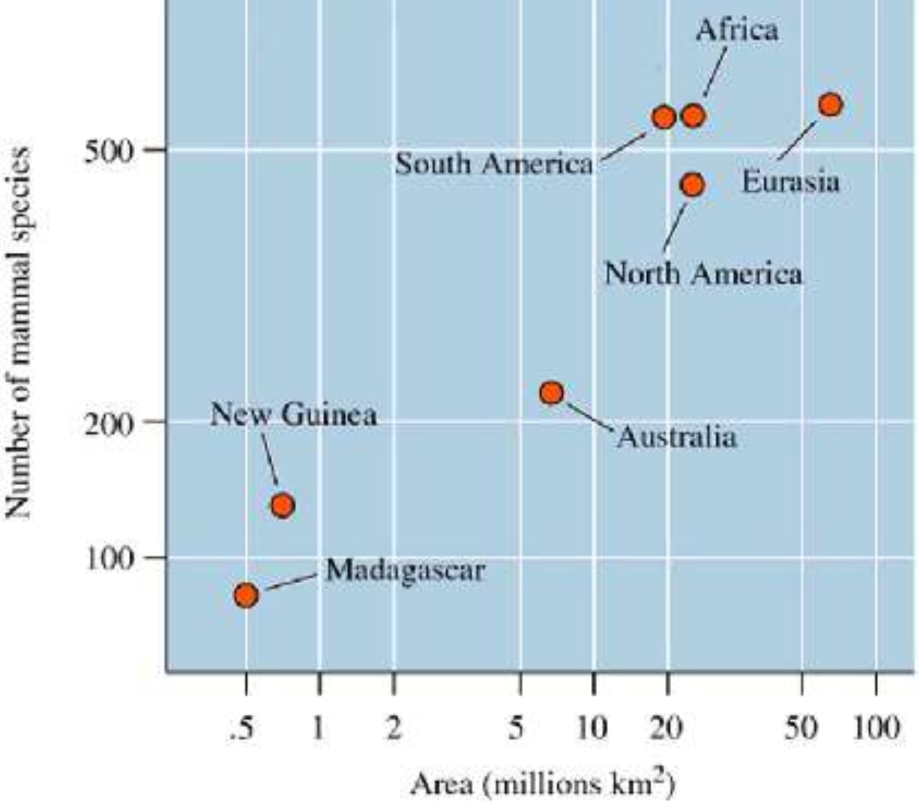
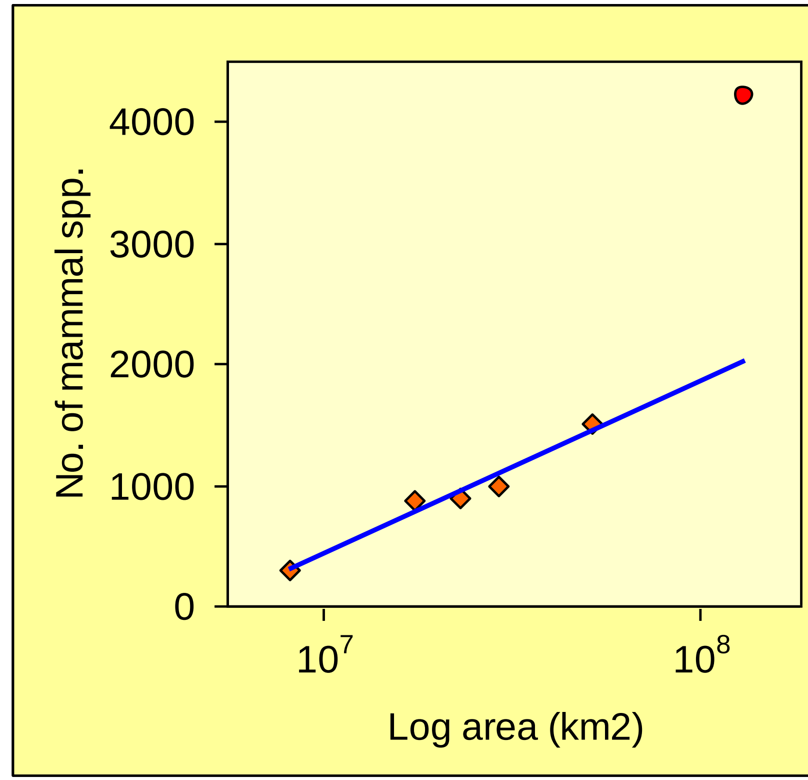


Figure 1.19. Relationship between number of species and island size for revised plants (reviewed in Flora Malesiana), resident birds, mammals and reptiles. B - Borneo, F - Flores, J - Java, LS - Lesser Sundas, M - Moluccas, N - New Guinea, Sm - Sumatra, Su - Sulawesi, T - Timor.



The fragmentation of land to five continents doubled species richness of mammal species in the world



Species-area relationship for large islands and continents

Lovel 1997, Nature 388:627

Species richness on islands tends to be lower than in mainland areas of the same size: ants in New Guinea and smaller islands

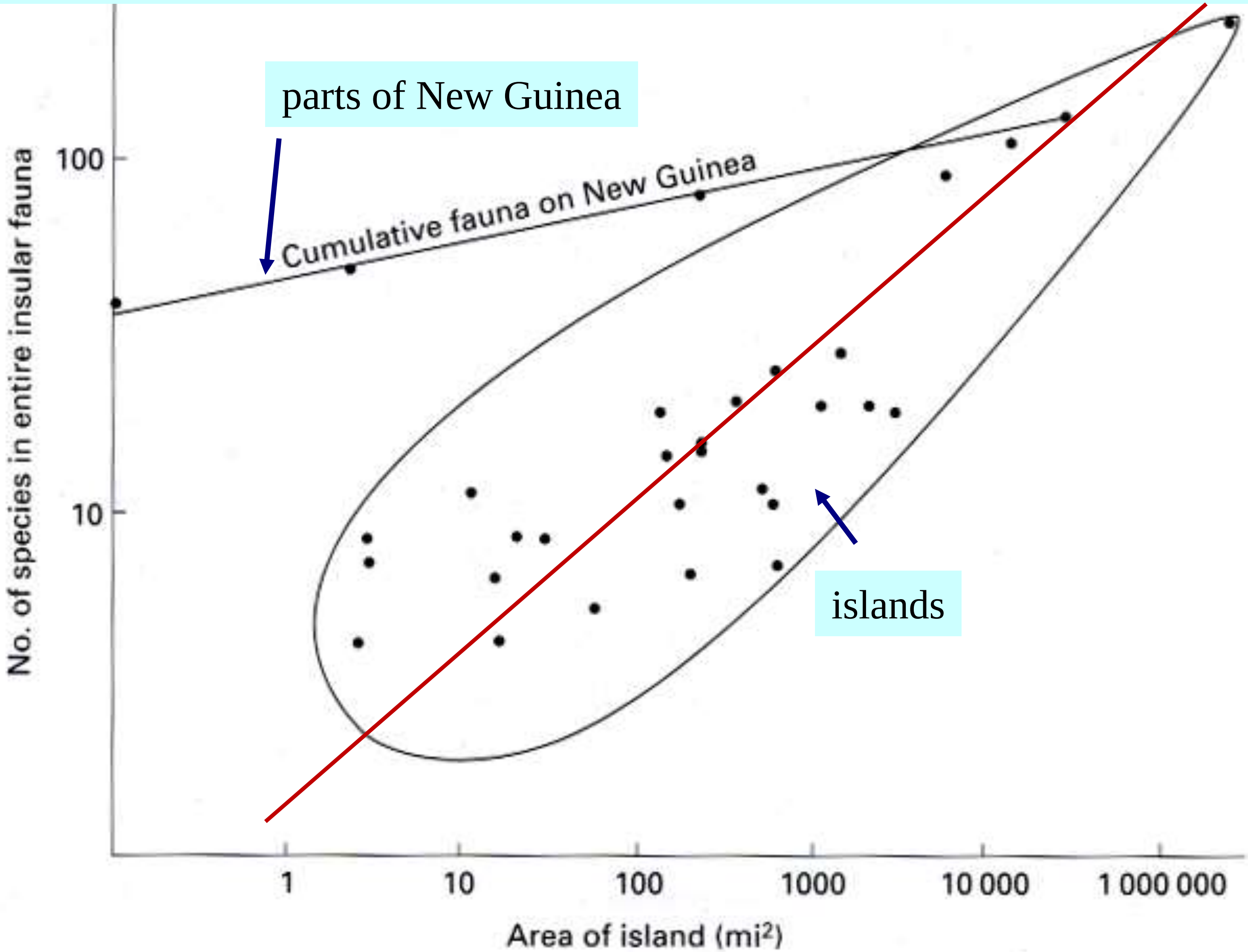
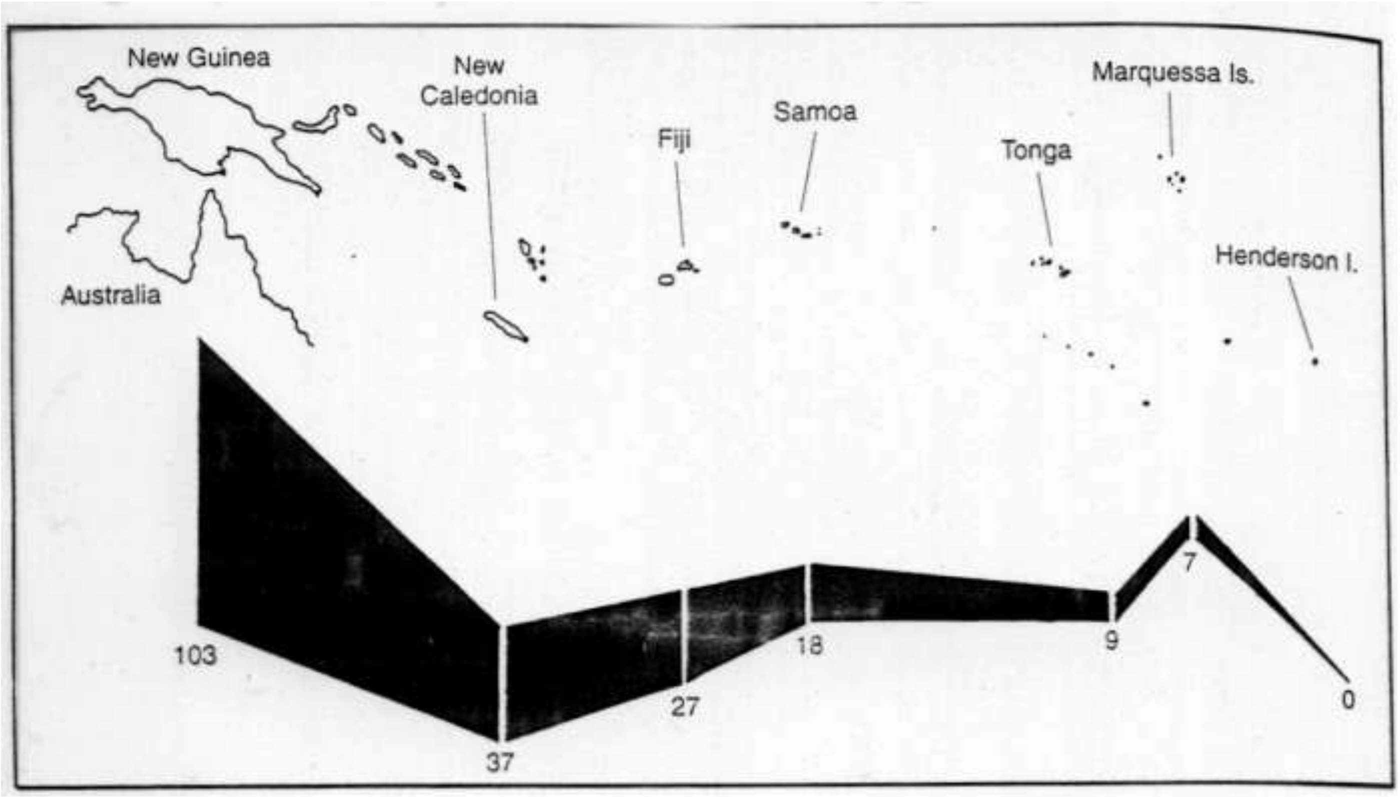


Fig. 8.14 The relationship between the number of (ponerine and cerapachyine) ant species found on different Moluccan and Melanesian islands and the area of these islands. (From Wilson 1961, with permission from The University of Chicago Press.)

Species-area relationship: combined effect of island isolation and size



Species richness of Cryptorhynchidae: declining rapidly as a result of decreasing island size and increasing isolation

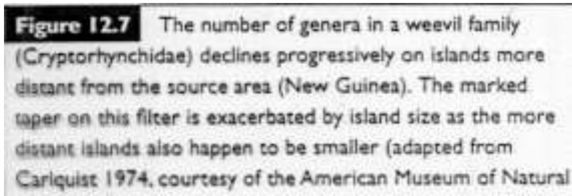
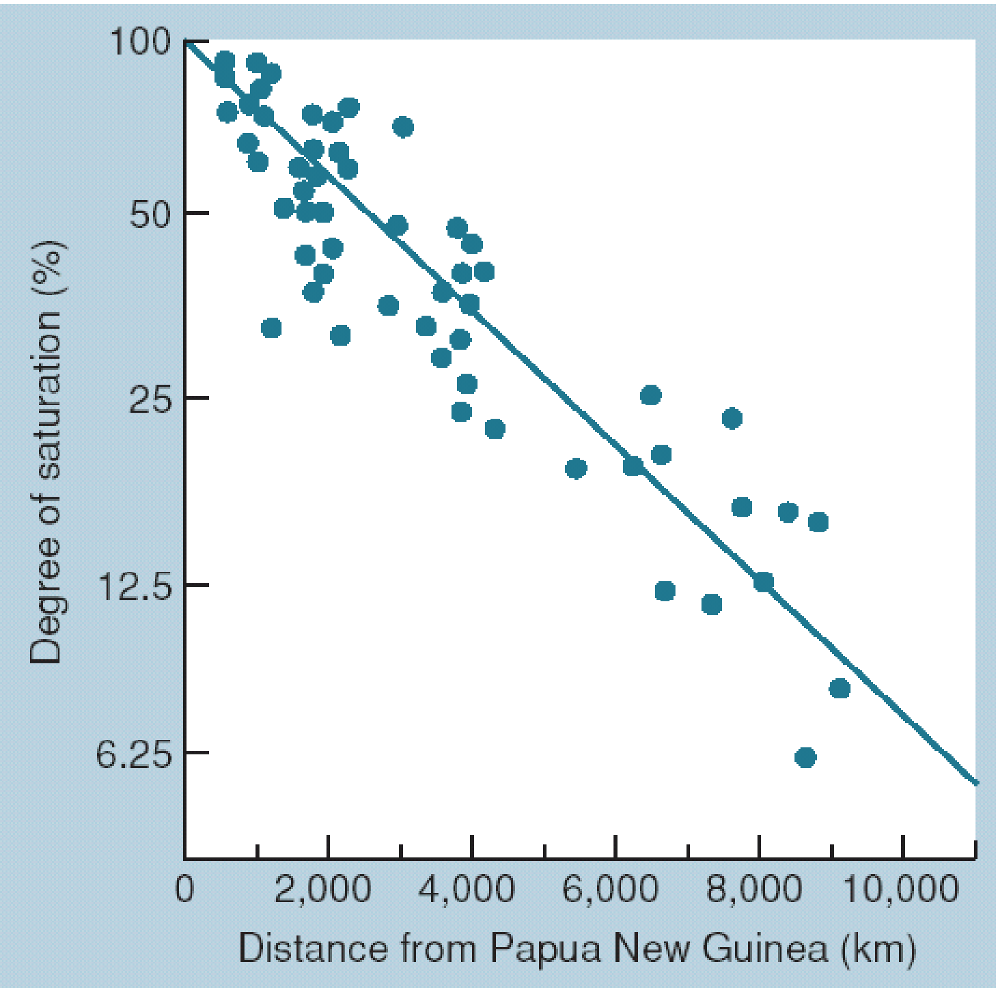
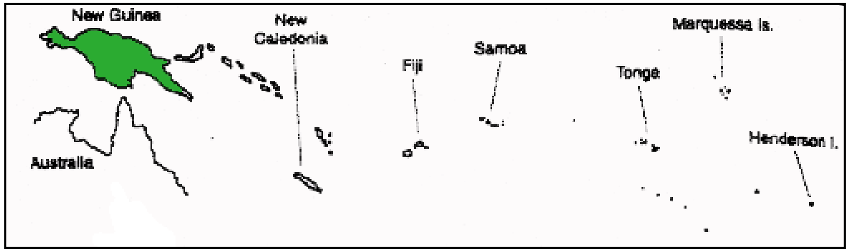


Figure 12.7 The number of genera in a weevil family (Cryptorhynchidae) declines progressively on islands more distant from the source area (New Guinea). The marked taper on this filter is exacerbated by island size as the more distant islands also happen to be smaller (adapted from Carlquist 1974, courtesy of the American Museum of Natural

Species-area relationship: the effect of island isolation

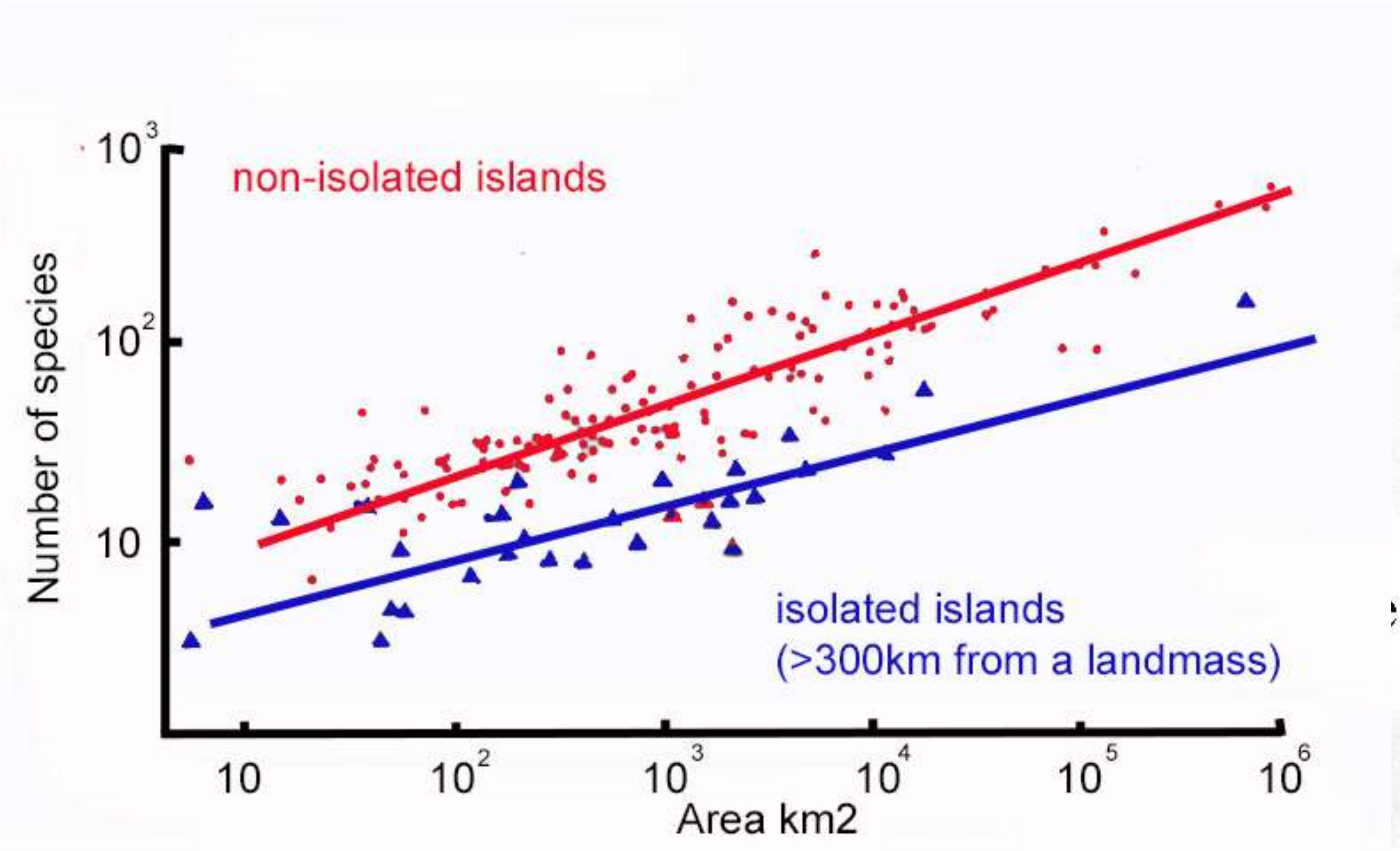
Number of resident lowland bird species on islands far (>500 km) from New Guinea as % of species richness on islands of the same size adjacent to New Guinea





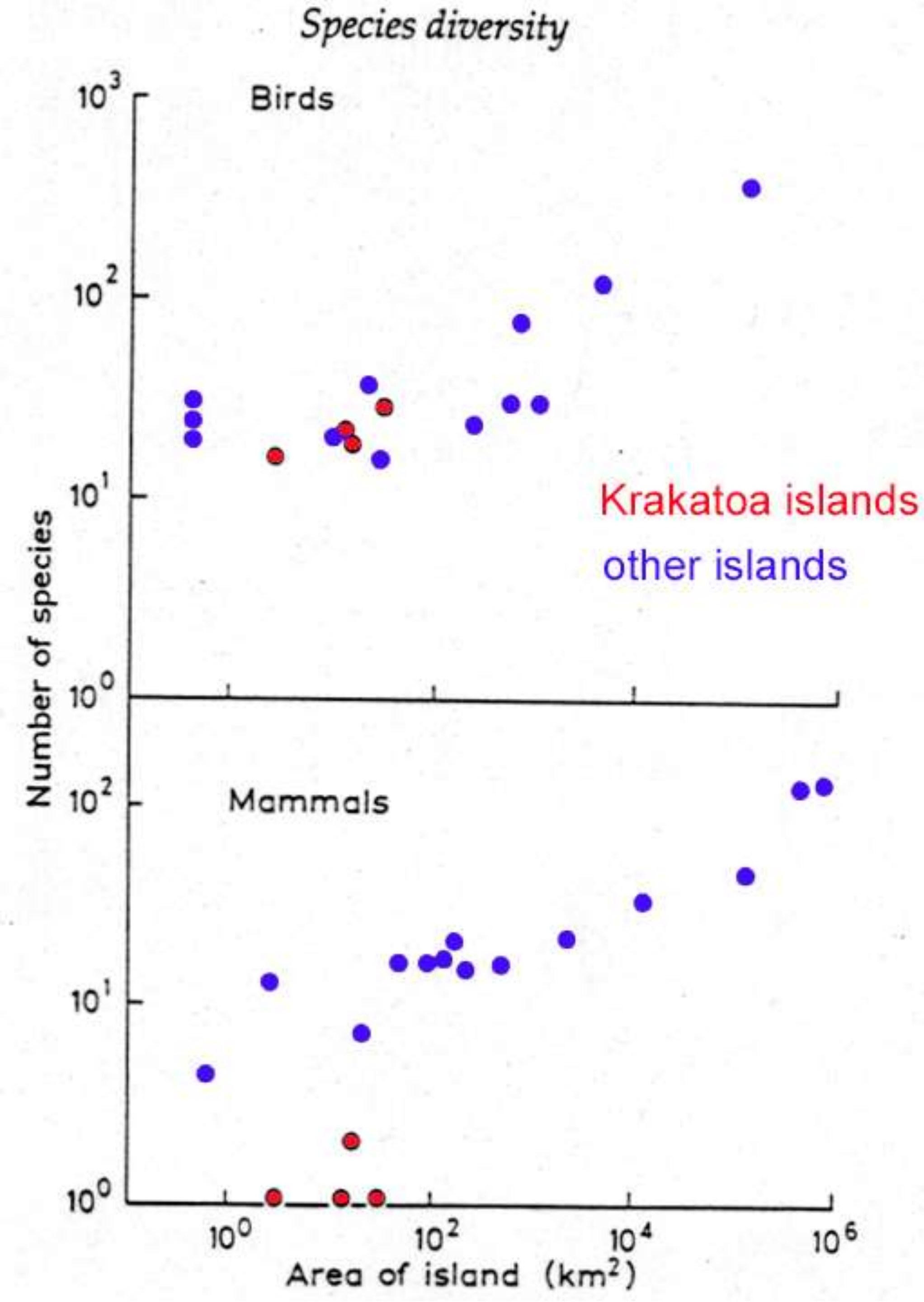
The number of resident, nonmarine, lowland bird species on islands more than 500 km from the larger source island of Papua New Guinea expressed as a proportion of the number of species on an island of equivalent area but close to Papua New Guinea and plotted as a function of island distance from Papua New Guinea. (After Diamond, 1972.)

Species-area relationship: the effect of island isolation



Land birds on tropical islands that are isolated (>300 km from a landmass) are poorer in species than on non-isolated islands

Williamson 1981

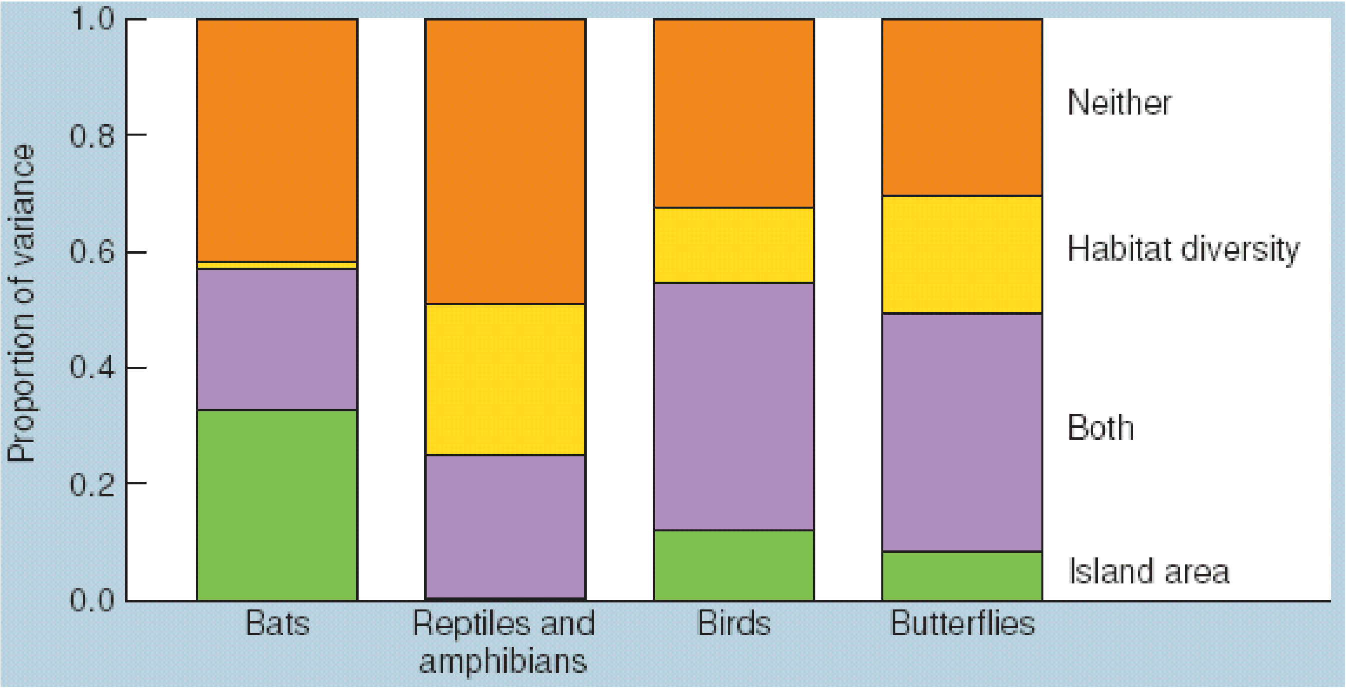


Species-area relationship: the effect of recent disturbance

Bird diversities has recovered since 1883 eruption – unlike that of mammals.

Thornton 1986

Species-area relationship: combined effects of area and habitat diversity

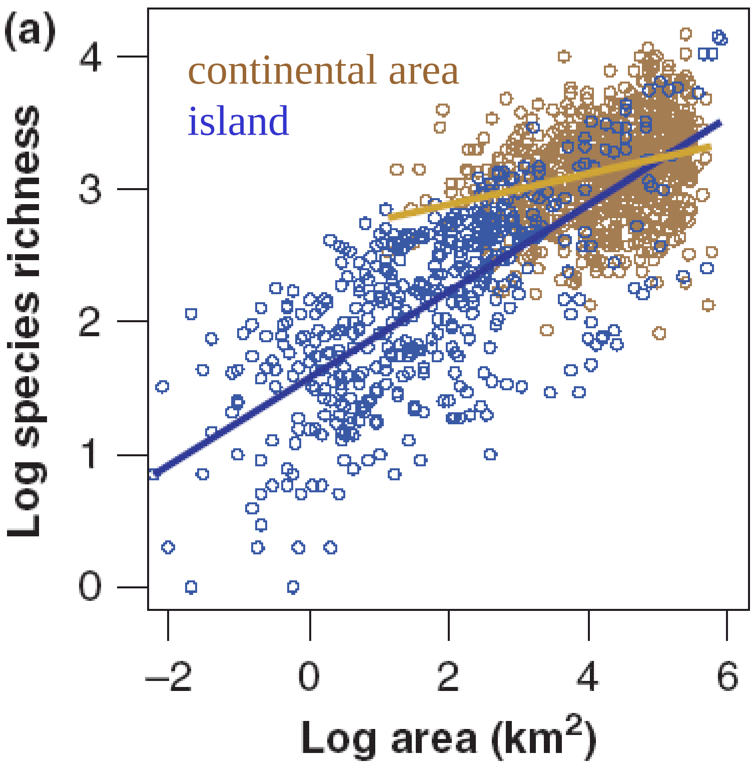


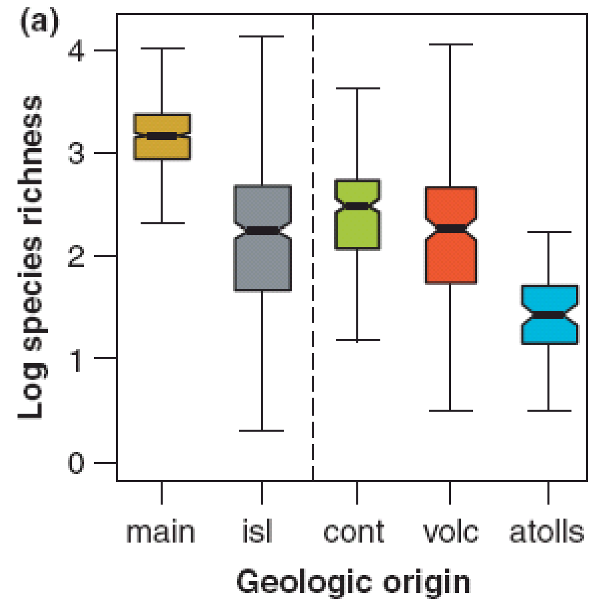
Variance in species richness among islands in Lesser Antilles explained by island area, habitat diversity, their interaction, and other factors

Becker, 1992.) (b) Proportion of variance, for four animal groups, in species richness among islands in the Lesser Antilles related uniquely to island area (green), uniquely to habitat diversity (yellow), to correlated variation between area and habitat diversity (purple), and unexplained by either (orange). (After Ricklefs & Lovette, 1999.)

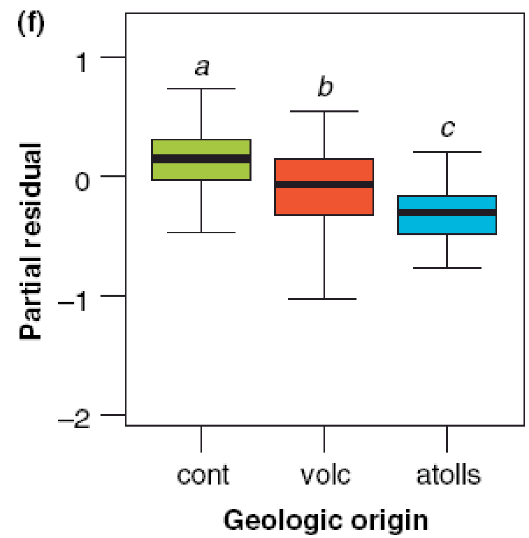
Species-area curves for vascular plants on islands and in continental areas

Species richness for continental and island areas, and islands of various origin



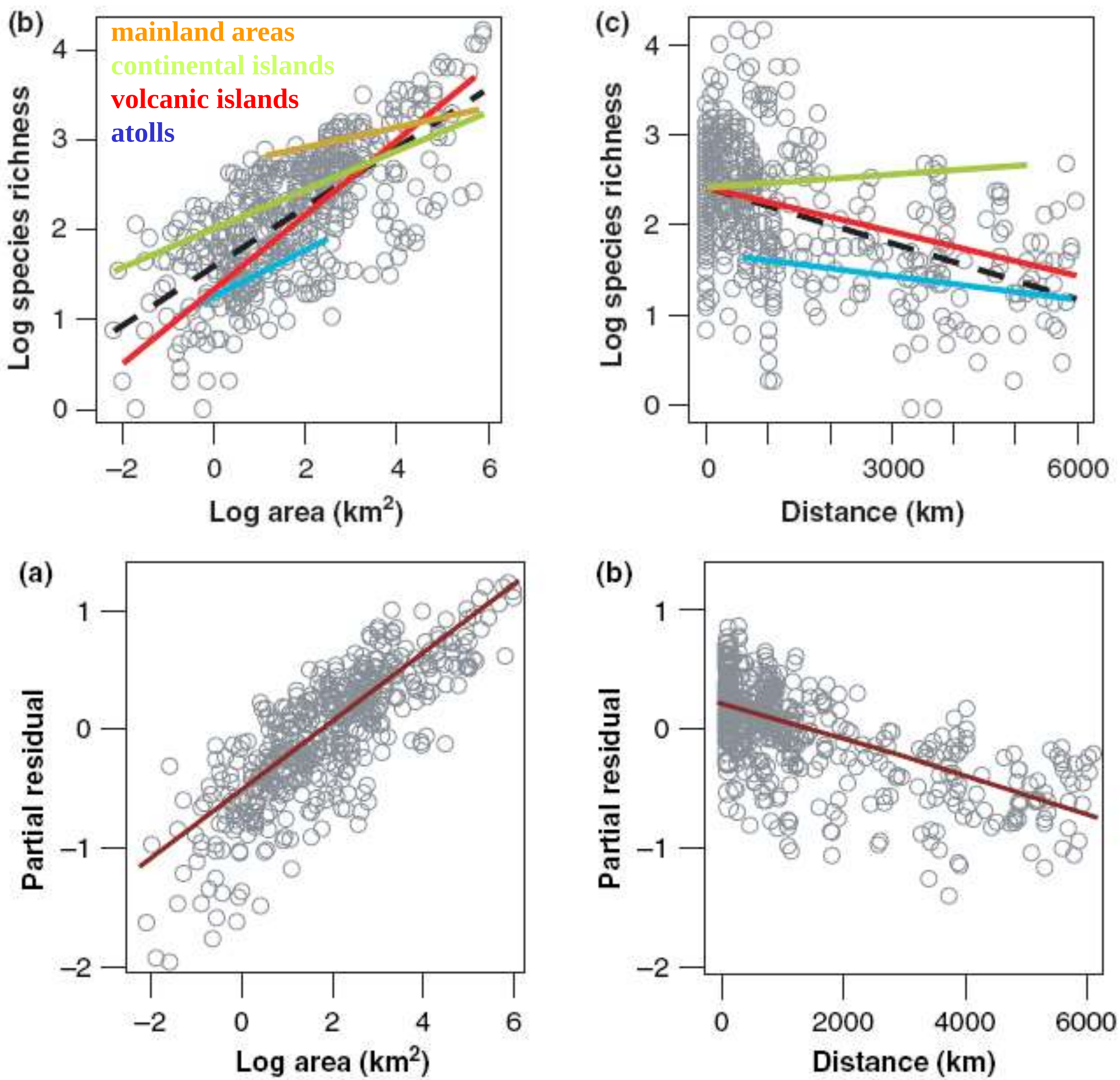


Species richness for islands of various origin
[residuals after regression for size, distance to mainland, elevation range, precipitation and temperature]



Kreft et al., Ecology Letters, (2008) 11: 116–127

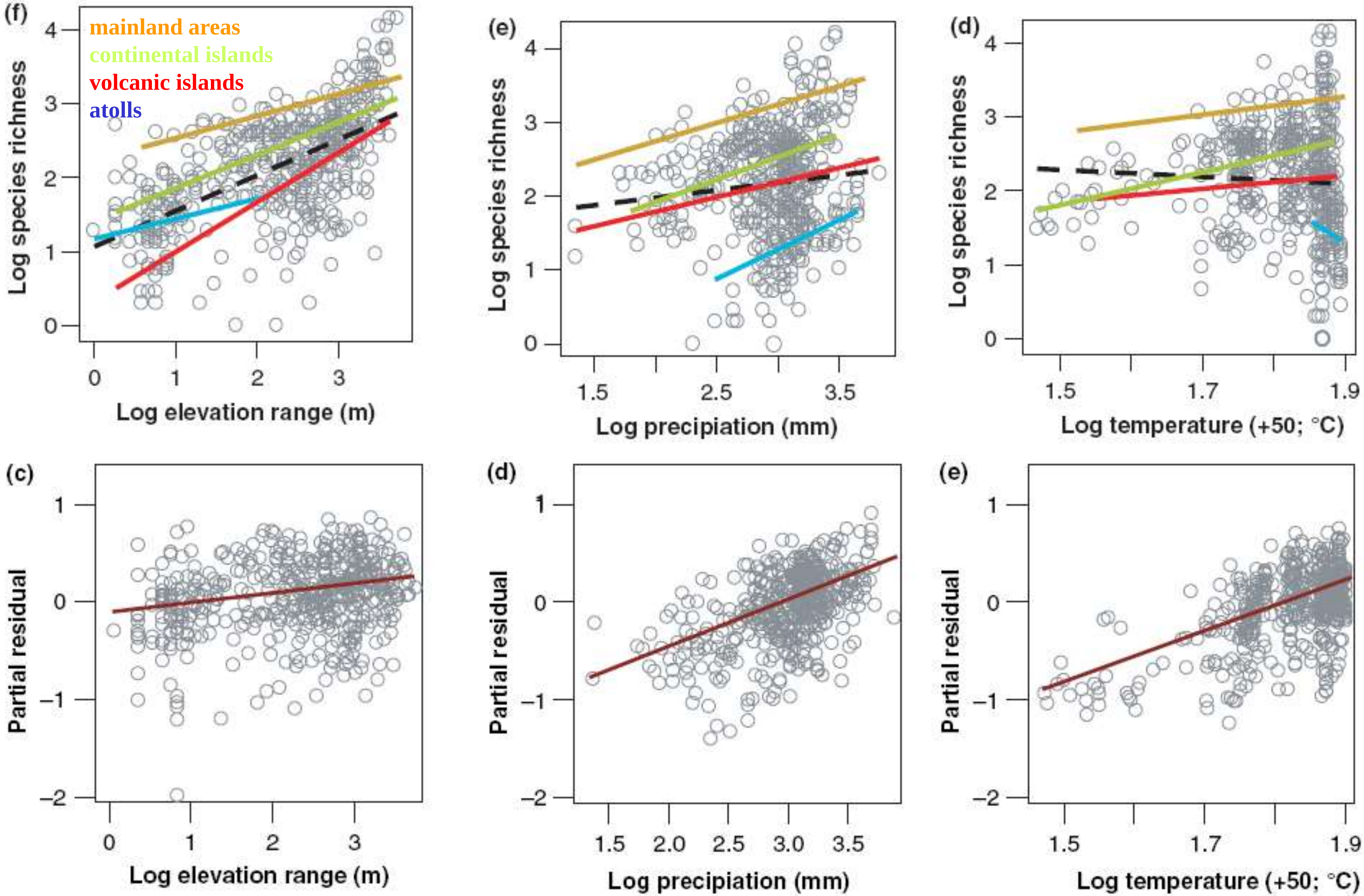
Relationships between plant species richness and (i) island area, and (ii) island distance from the mainland



Raw data (above) and residuals (below) after regression on:

- island size
- distance to mainland
- elevation range
- mean precipitation
- mean temperature

Kreft et al., Ecology Letters, (2008) 11: 116–127



Relationships between plant species richness and elevation range, precipitation and temperature

Raw data (above) and residuals (below) after regression on island size, distance to mainland, elevation range, mean precipitation and mean temperature

Kreft et al., Ecology Letters, (2008) 11: 116–127

Island isolation and endemism

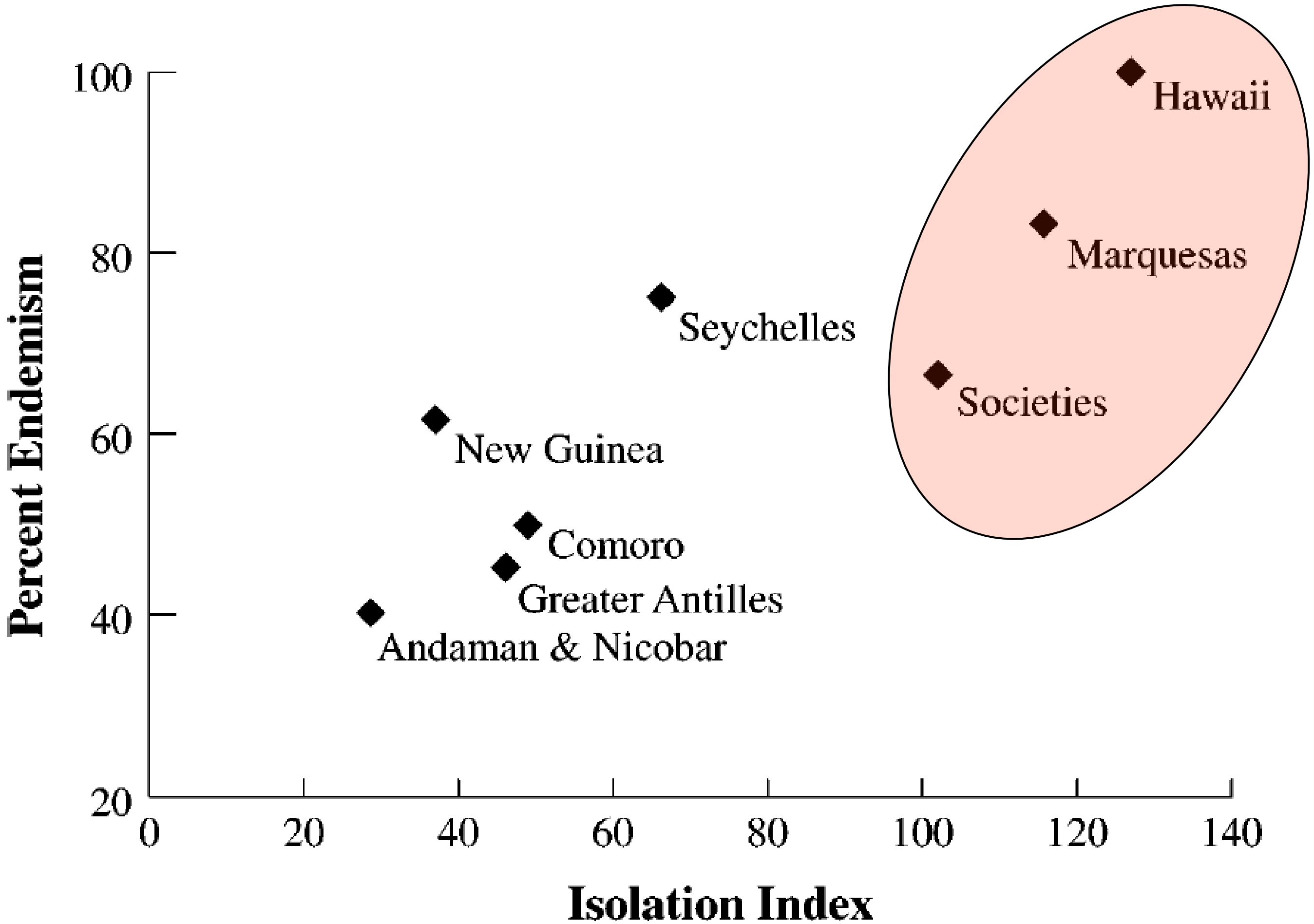
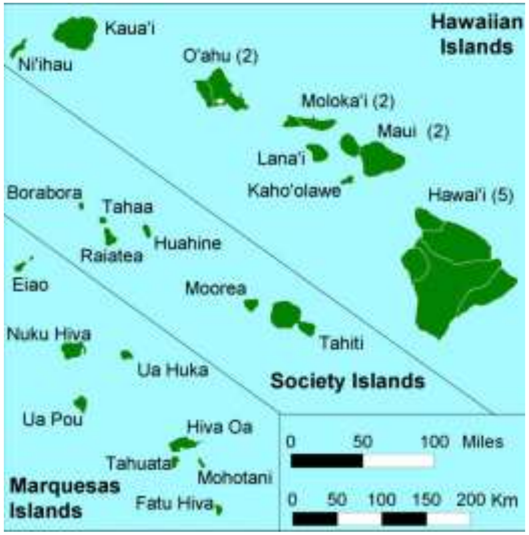


Figure 3 The relationship between isolation and endemism for spiders in the genus *Tetragnatha* (R. Gillespie, unpublished data). Isolation index calculated as above.

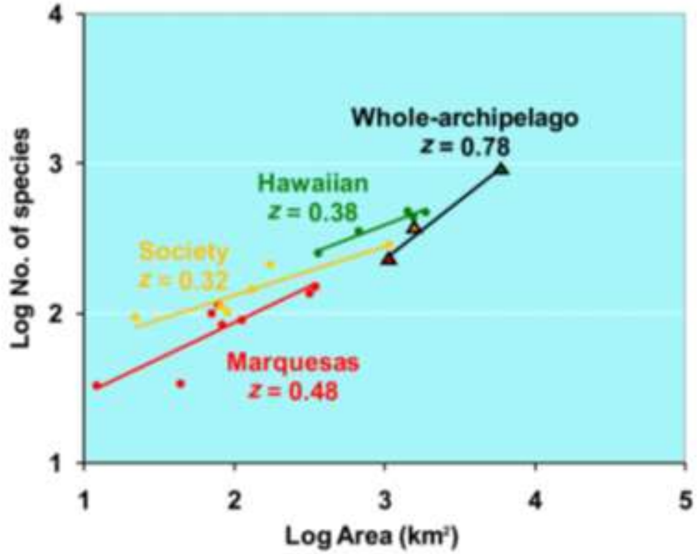
Tetragnatha sp.

Gillespie & Roderick 2002

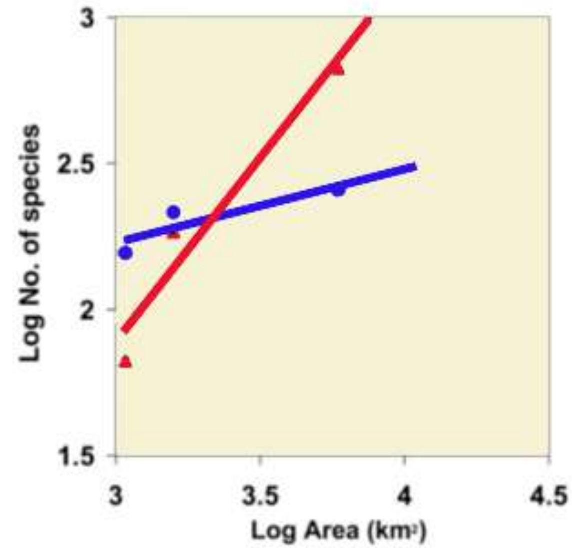
Colonization, anagenesis and cladogenesis on islands



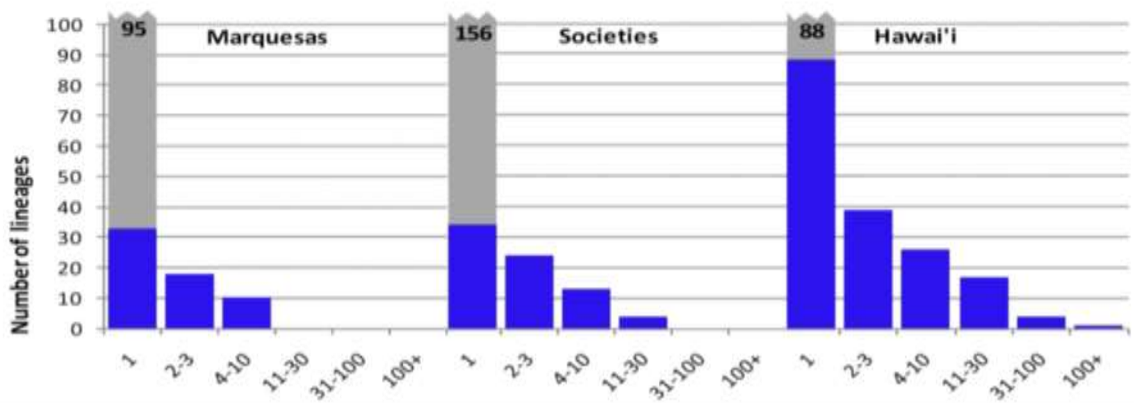
Three Pacific archipelagoes



Species-are curves



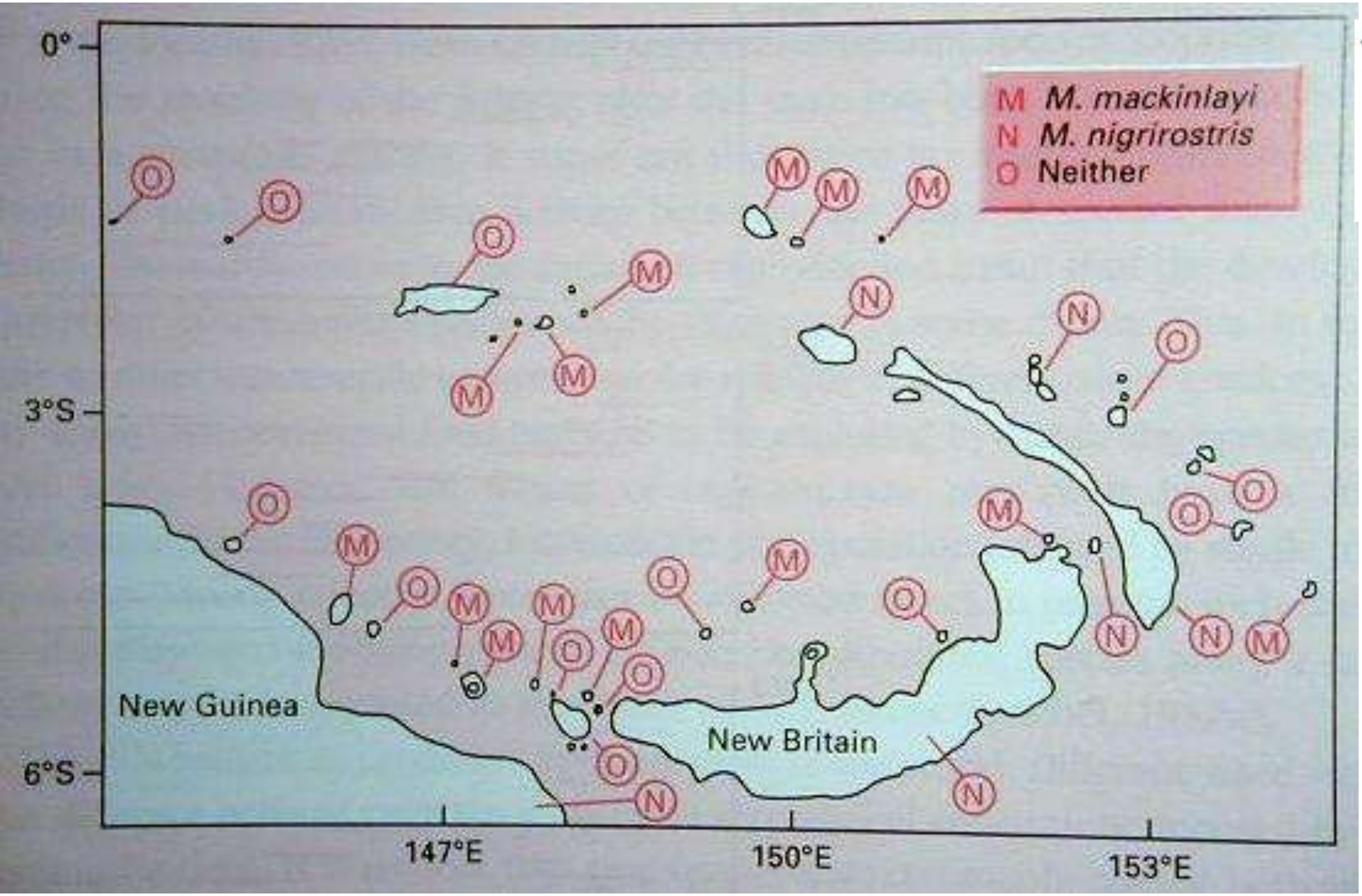
Contribution of colonization (dots) and cladogenesis (triangles) to the species pools of the archipelagoes



Single-species lineages that have differentiated from ancestral species to form an endemic species (anagenetic lineages) and lineages with multiple endemic species (cladogenetic lineages) in blue. Single-species lineages consisting of nonendemic species in gray.

Price & Wagner 2011. Am. J. Bot. 98: 449–459.

“Checkeboard distribution” - not predicted by island biogeography



M. nigrirostris

M. mackinlayi

Cockoo-dove *Macropygia mackinlayi* and *M. nigrirostris*

Diamond, J.M. (1975) Community Ecology

Checkerboard distribution: *Zosterops* birds in New Guinea

Z. atriceps

Z. buruensis

Z. chloris

Z. griseotincta

Z. hypoxantha

Z. kuehni

Z. mysorensis

Z. novaeguineae

Z. uropygialis

Z. atrifrons

Z. meeki

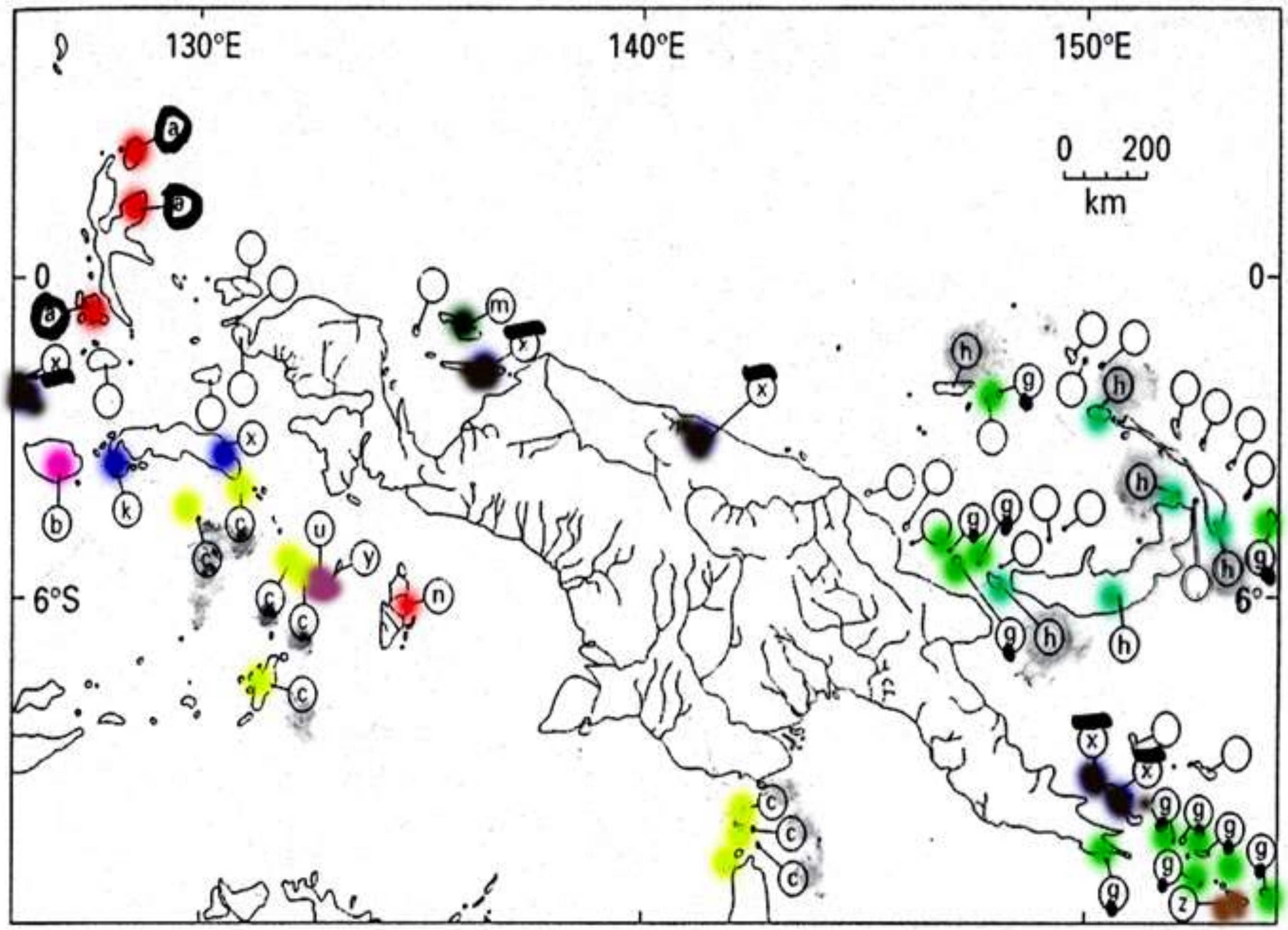
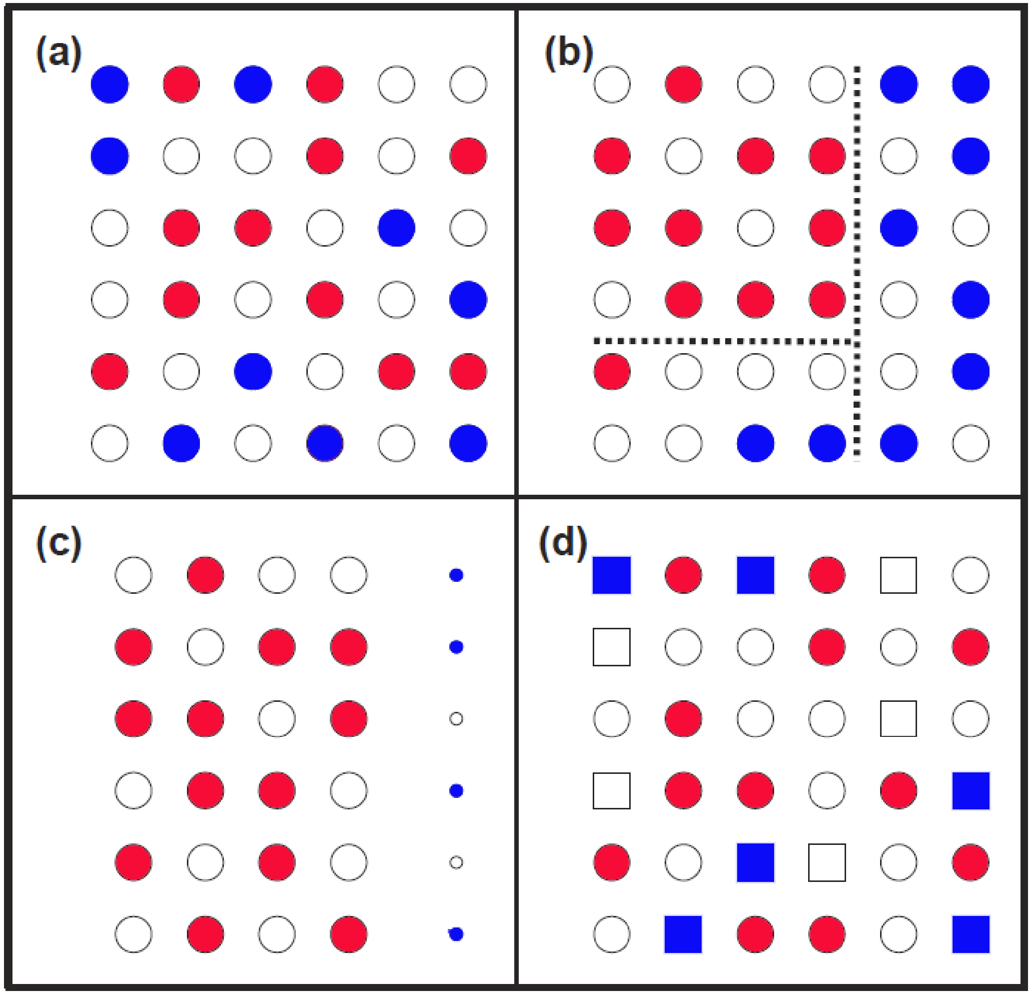


Fig. 6.12 Checkerboard distribution of 12 species of white-eyes (the genus *Zosterops*) on the islands of the New Guinea region. Symbols on the islands are: a, *Z. atriceps*; b, *Z. buruensis*; c, *Z. chloris*; g, *Z. griseotincta*; h, *Z. hypoxantha*; k, *Z. kuehni*; m, *Z. mysorensis*; n, *Z. novaeguineae*; u, *Z. uropygialis*; x, *Z. atrifrons*; y, *Z. grayi*; z, *Z. meeki*. Islands without a symbol in a circle have no *Zosterops* species. (Reprinted by permission of the publisher from *Ecology and Evolution of Communities* by M.L. Cody & J.M. Diamond, Cambridge, MA: Harvard University Press, Copyright ©1975 by the President and Fellows of Harvard College.)

Checkerboard distribution patterns



Checkerboard distribution tests: how much to randomize the original communities?
No. of spp per site?
No of sites per spp?

A representation of (a) checkerboard distribution due to competition, (b) regional allopatry, (c) supertramp distributions, and (d) differences in habitat preference. Supertramp species are restricted to small, isolated or disturbed islands. Circles = islands; squares = islands with a different habitat type. Red and blue represent islands occupied by different species.

Collins et al. 2011. J. Biogeogr. doi:10.1111/j.1365-2699.2011.02506.x

Nestedness: species on species-poor islands represent a subset of species on species-rich islands

Species No. 1-22 from rare (top) to common (bottom)

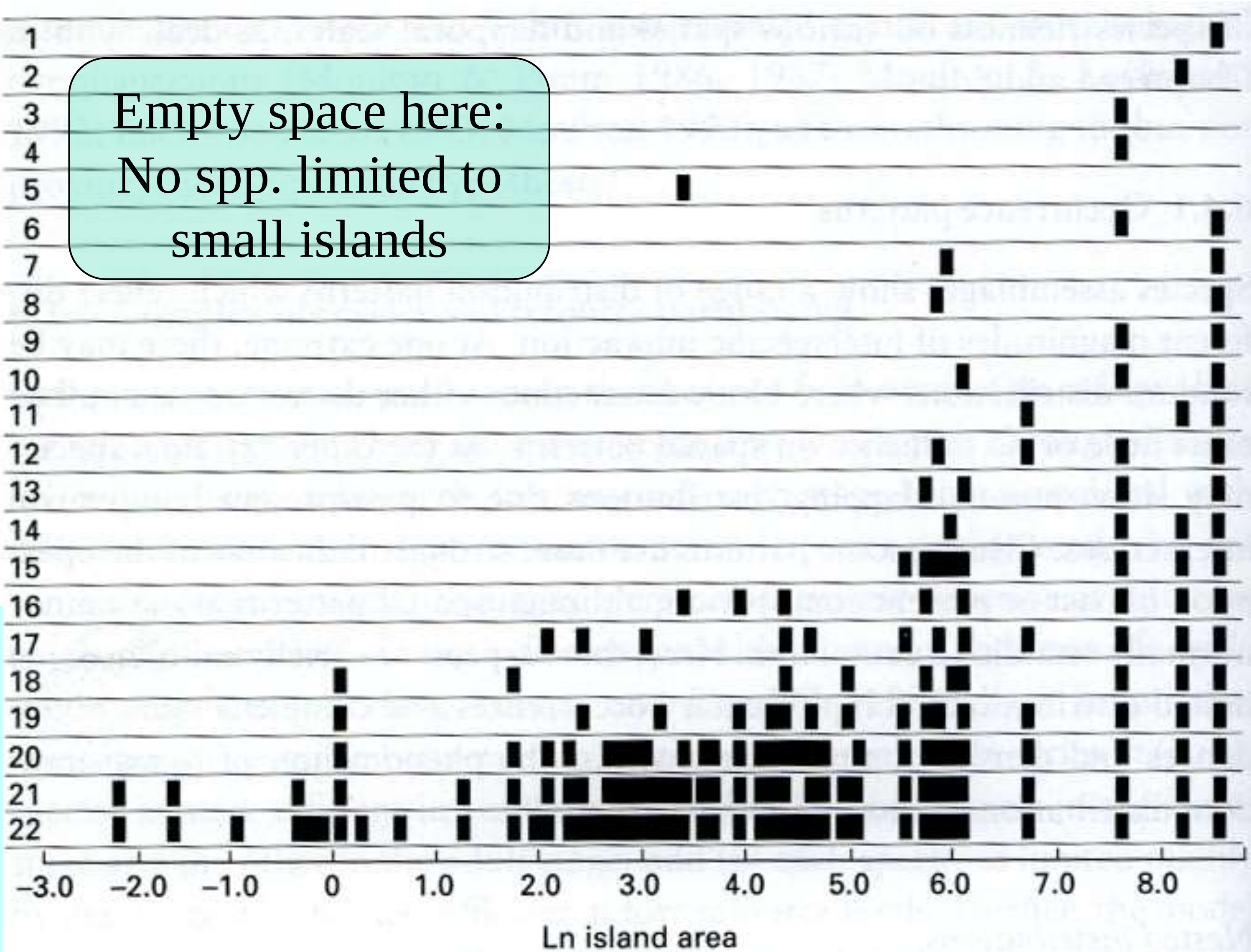
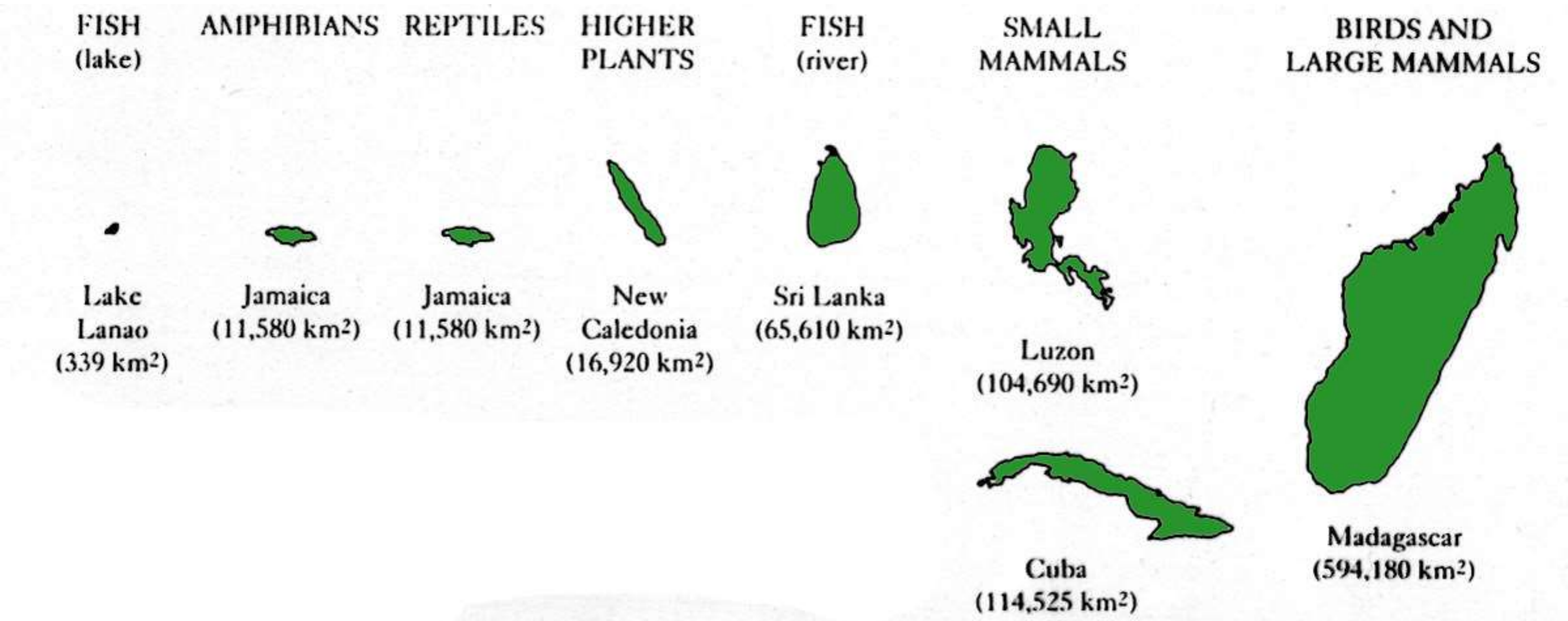
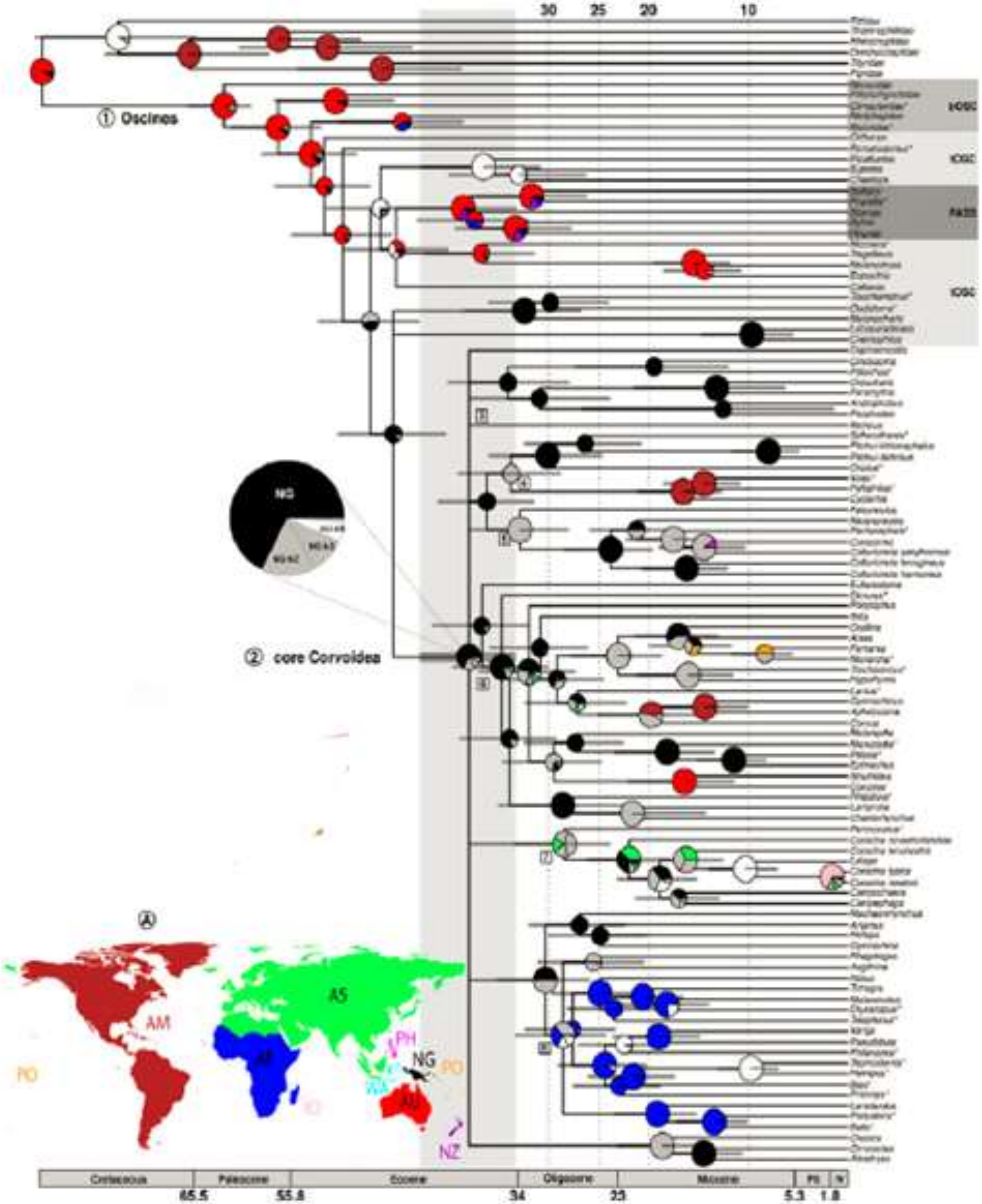


Fig. 6.11 Species occurrence of herpetofauna on the British Virgin Islands. Numbers on the left denote different species. (Data from Lazell 1983; Schoener & Schoener 1983a,b.)

Herpetofauna on British Virgin Islands: a nested pattern of species distribution

Minimum area required for evolutionary radiation by different lineages



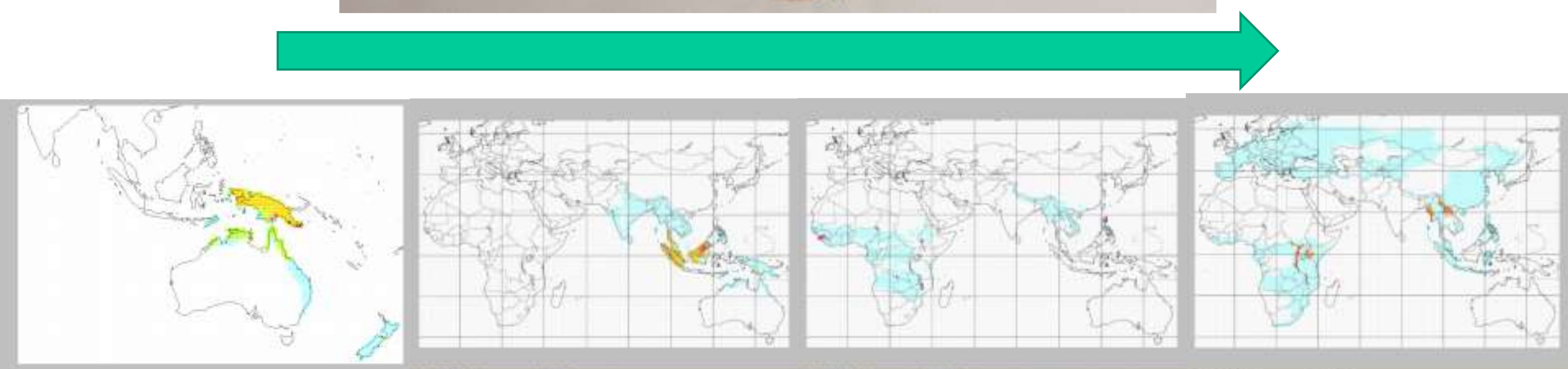


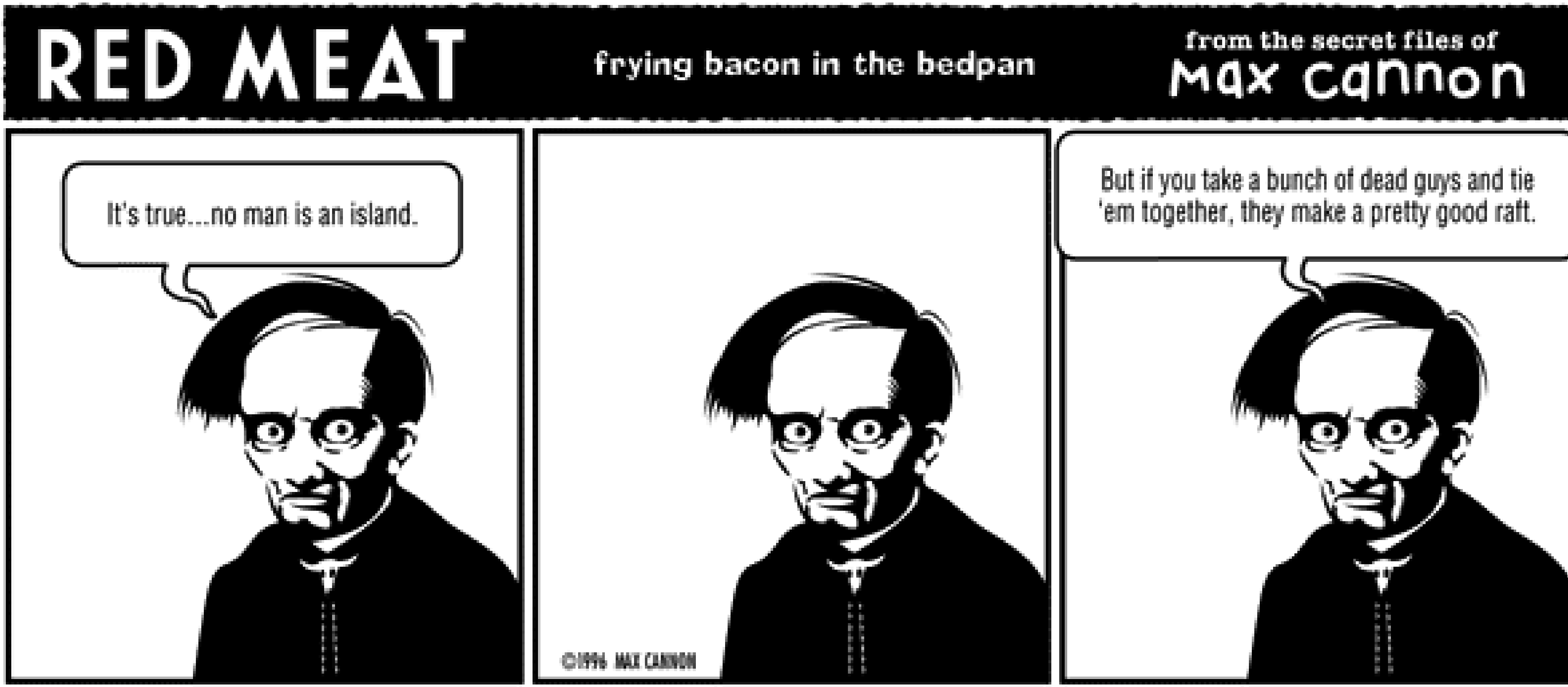
Islands can also serve as cradles for lineages spreading from them to continents

Core Corvoidea (>700 spp) spread from the Papuan archipelago

Jonsson et al. 2011 PNAS 108: 2328

Oriole expansion: phylogenetic root-path quartiles, the deepest branches have Papuan area origin; younger lineages widespread Old World species.




RED MEAT
frying bacon in the bedpan
from the secret files of
Max Cannon
It's true...no man is an island.
©1996 MAX CANNON
But if you take a bunch of dead guys and tie 'em together, they make a pretty good raft.