The Remaining Islands with Primary Rain Forest: A Global Resource

GORDON BRENT INGRAM
Departments of Forest Resources Management
& Plant Science
University of British Columbia
2357 Main Mall
Vancouver, British Columbia V6T 1Z4, Canada

ABSTRACT / Islands with large tracts of primary rain forest constitute a distinct complex of terrestrial and marine ecosystems with global significance because of high levels of biological richness or, in the case of oceanic islands, the evolutionary distinctiveness of the organisms that they support. The myriad of small habitat units makes these settings particularly prone to fragmentation and thus problematic for the conservation of biological diversity. Most of the remaining examples of islands with primary rain forest are in the Pacific Rim, particularly in Indonesia, and there are threats from intensive timber harvesting, mining, tourism, and dismemberment of traditional conservation systems. Prospects for inventorying, monitoring, and protecting the remaining islands with relatively pristine successional mosaics of humid forest and shallow marine habitats within a framework global monitoring are explored. Recommendations are made for a program of expanded use of the biosphere reserve designation for rain forest islands and adjacent marine areas.

Islands with Primary Rain Forest as a Distinct Complex of Ecosystems

Tropical islands with rain forest (Richards 1952) and adjacent coral reefs may well comprise the most biologically rich complexes of ecosystems on the planet. As the interest in conservation of biodiversity (Wilson 1988, Ehrlich 1988) increases, the remaining islands with rain forest will take on greater significance for research and nonconsumptive recreation as well as by the many communities that are struggling to maintain traditional conservation systems (Ingram 1990). Unfortunately, an appreciation of the uniqueness of these island systems, in terms of requirements for the conservation of biological diversity, has often been drowned in more generic discussions of tropical rain forest and shallow marine habitat. Islands with temperate rain forest, if in fact the term can be applied to cooler climes, have similarly been neglected.

Terrestrial species richness on islands tends to be lower than on similar mainland areas. Species–area relationships for shallow marine systems have been more difficult to ascertain, but if we look at island systems as supporting and intensifying the linkages between marine and terrestrial food webs, as in the case of dead wood on the north Pacific coast (Maser and others 1988) and mangrove systems (Figure 1), a distinct setting for inventorying, monitoring (Burley 1988, Hamnett 1990), and conservation becomes apparent.

KEY WORDS: Rain forest; Biological diversity; Tourism; Tropical islands; Pacific rim; Indonesia

Mosaics of tropical forest, with a range of ecosystem structures as related to moisture availability, as well as with a diversity of habitat types and successional phases, are the most species-rich terrestrial ecosystems on Earth. This is as much the result of the combined set of gaps and edges, the level of landscape heterogeneity, as of the habitats and food webs that are afforded by the relative stability and accumulation of biomass. A comparable framework for analyzing habitat mosaics in shallow marine systems has yet to be devised, although it is clear that coral ecosystems comprise some of the most biologically rich sites on the planet.

There is a range of forces that have sustained the spectacular evolution of species that has taken place in the world's humid tropical forests. One hypothesis explaining plant species diversity views the forest environment as particularly heterogeneous (Ricklefs 1977) and relates this to greater biomass, high nutrient levels within vegetation, rapid decomposition and equatorial sunlight.

There are some modest parallels between humid tropical forests and temperate rain forests, such as those found on the north Pacific coast of North America. There is a subset of forest species that are associated with successional mosaics dominated by large living trees and dead trees that are either standing or fallen, along with structures such as tree cavities for nesting (Carey 1989). Even though these species often

Figure 1. Mangrove, Fergusson Island, D'Entrecasteaux Islands, Papua New Guinea.

Figure 2. Small islands of temperate rain forest, South Moresby, Queen Charlotte Islands, Canada.

utilize old-growth (Franklin 1981) habitat attributes, dependence correlations have been poorly confirmed, and the diversity of overall vertebrates and vascular plants in these cool, slow-cycling ecosystems is still relatively low. The similarities between temperate and tropical humid forest ecosystems on islands are more related to (1) high levels of standing biomass; (2) complexity of forest structures, gaps, and edges; (3) relatively small and therefore fragmentation-prone habitat units; and (4) significance of shore areas to virtually all terrestrial and shallow marine food webs.

Marine areas adjacent to islands often rival terrestrial zones in the richness of biological diversity. The structure of marine ecosystems has been less comprehensively categorized (Ray 1988). The marine areas with the greatest species diversity, such as coral reefs, have tended to be relatively stable, and free of dramatic change and stress factors, but with some regular perturbations and clear, warm water.

Productivity involves another set of factors that effect biological richness. Systems that involve deeper waters and upwelling, such as the Kai Islands of Maluku Province, Indonesia, are exceptional in their levels of productivity. Archipelagoes with rich terrestrial and/or marine zones, such as those that have mangroves with considerable vertical complexity, tend to support high levels of both biomass and species richness.

Biogeography of Islands with Rain Forest

Scientific interest in islands and endemism goes back to the beginnings of the modern concepts of evolution, speciation, and biogeography. Charles Darwin acknowledged the role of isolation as early as 1844 (Darwin 1909). Joseph Dalton Hooker (Turril 1964) began his description of island forms of plants in the same decade. Alfred Russell Wallace expanded the discussion of dispersion and dispersal barriers in his *Island Life* of 1880 (Wallace 1911).

The evolutionary factors that combined to make some island populations and communities unique involve: (1) isolation and subsequent low rates of colonization (Carlquist 1974); (2) acute reduction of gene flows as a stimulant for local speciation; (3) the lack of some selection factors involving predation and competition; and (4) adaptive radiation resulting from unique island niches. All four factors are most pronounced on oceanic islands and decline in significance as spatial and temporal isolation diminishes.

There are different types of island ecosystems as related to age and isolation. The simple dichotomy of oceanic (Menard 1986) and continental islands, originally outlined by Wallace, has been expanded. There are at least three general types of island system types in the Pacific Rim and these categories can be broken down by formation processes, age and climate.

Continental

These islands share plates with continental land masses. There has been intermittent disconnection and reconnection through land bridges. Periods of isolation have intensified fragmentation processes, have subsequently lowered species richness, and sometimes have fostered endemism. Bali, linked to Southeast Asia, and the Queen Charlotte Islands (Figure 2) (Foster 1984), linked to North America, are examples of such mildly pronounced island ecosystems.

Transitional and/or Microcontinental

These islands are associated with mountain building and isolated land masses that were formerly part of continents. Long-isolated remnants of continental biotas have given rise to divergent evolutionary lines. The relative size of these areas and the relatively long periods of isolation have allowed for the survival of numerous relict and endemic species as well as highly distinct ecosystems, as in the case of New Zealand, New Caledonia, and the re-emergent Seram.

Oceanic

Because of extreme isolation, there are barriers to entire groups of organisms, such as amphibians. Because of the limited pool of terrestrial species, ecosystem structures are usually simpler than in continental ecosystems. Relatively open niches can lead to rapid speciation (Berry 1983), as suggested by Darwin's observations on the Galapagos Islands, which laid the basis for the modern theory of evolution. The Hawaiian Islands are one of the most pronounced oceanic archipelagoes, although there are additional factors that isolate less spatially distant groups, such as the Banda Islands of eastern Indonesia.

Island endemics often occur away from shore areas. Since the post-Pleistocene fluctuations in sea level (Menard 1986), there may not have been sufficient time for recolonization back into previously inundated areas, especially for highly localized species associated with stable types of forest habitat. Biota of mountainous islands are vulnerable through climatic change, which often causes populations to be particularly marginal, unstable, and therefore under particularly active selection pressures.

The concept of disharmonious biota has been employed with respect to the terrestrial zones of island ecosystems. This derives from the earliest formulations of the equilibrium theory of island biogeography (MacArthur and Wilson 1967, Connor and McCoy 1979). Rates of colonization and extinction might eventually balance as a function of the total area of land mass and of isolation (Diamond 1971, Faeth and Connor 1979). Where colonization is particularly slow, there are lags in attaining any intrinsic saturation points. On islands, this can be complicated by the continued speciation of the organisms that have already become successfully established.

The ecological boundaries of islands are not limited to shores and shallow marine areas. Rather than simply a barrier, a shoreline is a zone of overlap between terrestrial and marine food webs, and it involves a distinct and added set of habitat types. The shape of these habitat units is usually long and narrow and therefore prone to breakup in times of environmental change (Figure 3).

Within these island forest settings, there is often a tremendous diversity of vegetation types, both of humid and drier types. Drier, seasonal forests (Janzen 1988) are often more vulnerable to deforestation and fragmentation because of the attractiveness of associated sites to clearing for agriculture, which leads to slower rates of forest regrowth.

Alteration and Loss of Primary Rain Forest on Islands

"Tropical islands are microcosms of the variety of coastal ecosystems on continents with more limited resources. These limitations render the resources more vulnerable to outside perturbations, including development. Human activities on islands and beaches usually adversely affect natural communities" (Maragos and others 1983).

There is currently a tremendous economic incentive to log most lowland rain forest. Because of relatively high human population densities in many coastal areas, lowland forests near the sea and along waterways have largely been cleared or severely altered. Remaining forests in areas close to water access, such as on the smaller islands, are attractive for commercial timber harvesting because less road construction is necessary. Nearly all of the primary forests on accessible islands, which are outside of nature re-

Figure 3. Lowland primary rain forest with culturally modified strips, Fergusson Island, D'Entrecasteaux Island, Papua New Guinea.

Figure 4. Lowland primary rain forest, Nade, Fergusson Island, D'Entrecasteaux Islands, Papua New Guinea.

serves (Shafer 1990), will be liquidated through logging concessions or agricultural clearing in the coming decade. This is already the case across large areas, such as much of the Philippines.

The capital necessary to establish logging activities in such remote areas usually requires that extractive operations be intensive. This severe pressure for high rates of profit has tended to inhibit the conservation of primary forest habitat and the establishment of management areas with high values for aboriginal land use and wilderness recreation.

Impacts of Loss of Habitat through Fragmentation

Portions of moist forest biota have some dependence on mature successional stages and relatively undisturbed sites, although these relationships are clearer for tropical areas (Johns 1983, Ingram 1989). Modern alterations of island forests are producing changes that are often not comparable to those of natural processes or impacts from traditional societies. The scales (Noss and Harris 1986, Meentemeyer and Box 1987) and rates of modern change are often much greater. The tracts of primary forest that remain are often degraded on an indefinite basis due to expansion of edges and decreasing size of habitat units.

The availability of technologies such as chainsaws, the almost ubiquitous intrusion of the global economy with reduction of peripheral economies due to resource extraction, and increased human populations have all exacerbated more natural extirpation and extinction processes. Solutions have not always been clear. On small islands, the twentieth century dichotomies of preservationism and multiple-use conservationism are often problematic (Dahl 1985b), as there are shortages of land for a range of consumptive and nonconsumptive needs (Hein 1990).

It should be possible to predict the vulnerability to fragmentation (Temple and Wilcox 1985, Wilcox and Murphy 1985, Harris 1985, Lovejoy and others 1984) of particular islands and archipelagoes in terms of:

- sizes of islands (MacArthur and Wilson 1967, Diamond 1972, Cole 1981);
- ecosystem and community types and "spatial pattern" (Turner 1989);
- landform types (Swanson and others 1988);
- frequencies and sizes of natural patches and gaps as related to regimens of disturbance (Brady and Hanley 1984);
- typologies of the vulnerability of communities and species as related to current or past response to change (Hunter and others 1988);
- "spatial landscape models" of the responses of particular populations and subareas of communities (Baker 1989) to change such as forest clearing.

The size, shapes, and formation patterns of patches and gaps (Brokaw 1985, Denslow 1980) within successional mosaics (Forman 1982, Ewel 1983) is particularly central in determining the fragmentation sensitivity of a particular archipelago. Similarly, there are variable regimens of disturbance and ecotones (Raney and others 1981, Schonewald-Cox and Bayless 1986, Hansen and others 1988, Wiens and others 1985), which enter into the equation of "intrinsic vulnerability" through loss of species due to fragmentation. Cultural factors that exacerbate sensitivity to fragmentation (Balser and others 1981) can then be analyzed in terms of:

- the extent of traditional modification of ecosystems;
- prospects for the use of technologies and respective intensities and sites across landscape units and regions (Giacomini and Romani 1978, Janzen 1983);
- prospective species introductions (Carlquist 1974, Vitousek 1988); and
- long-term demands for tourism and recreation.

A long-term threat to the continuing evolution and the prospects for successful management of island biotas is that of the disruption of patterns of colonization across entire archipelagoes. There is a similarity, here, with networks of protected habitat. As natural habitats and their respective populations on mainlands and adjacent islands decline, the functional distance–time factor increases for potential recolonization. Maintenance of connectivity (Shafer 1990), no matter how tenuous are the colonization pathways, should therefore be a major criterion in planning protected areas within archipelagoes.

Insularization (Shafer 1990) is compounded by inevitable catastrophes and stochastic losses, including problems of environmental regulation and the implementation of conservation planning, which destabilize already unstable systems. Human beings are making virtually all islands more "oceanic" and oceanic islands are relatively depauperate yet derive much of their global significance, in terms of biodiversity, from the organisms that have persisted and evolved over long periods of relative stability, a stability that has not been afforded by human beings even where there are well-protected reserves.

Structure of Synergistic Impacts of Land Use on Islands

The history of the impacts of human beings on the organisms found on islands, particularly species that are terrestrial, is one of ecological disaster and, more specifically, "extreme increases in instability and entropy" (Murdock 1961). More than 80% of the vertebrates, which have become extinct since 1600 AD, have been island endemics.

In their paleoecological research on an oceanic island in the South Pacific, Steadman and Olson (1985) correlated early human intrusion with substantial losses of vertebrate species. There have been a number of popularized accounts of the second wave of losses that occurred with the coming of the first Europeans (Crosby 1986). The structure of many island ecosystems tends to be especially vulnerable to displacement by invasions of alien species (Vitousek 1988). Island forms are often predisposed to extinction.

Island vegetation is susceptible through loss of species, from mechanical interference (cutting and bulldozing), and when grazing animals and plants are introduced (Moore 1983). On oceanic islands, such as Hawaii, native plants are particularly prone to displacement by invasive aliens when disturbance is also induced by land use (Mueller-Dombois and others 1981).

The responses of shore zones (Figure 5) to land use vary with a wide range of practices and biophysical settings and, in the case of sediment transport, im-

Figure 5. Shoreline, Burnaby Island, Queen Charlotte Islands, Canada.

pacts diverge between temperate and tropical ecosystems (Johannes 1986). There are a number of types of ecological degradation, where tropical biota are more sensitive, such as with the lowering of concentrations of oxygen in marine areas and loss of atmospheric ozone.

There are a number of key pathways for the synergistic transmission of disturbances from terrestrial areas to adjacent marine zones, and a more modest set exists for the transfer of source perturbations in marine areas onto land. Terrestrially derived disturbances often involve the soil mantle, alterations of freshwater regimens and the deposition of suspended sediment in the sea. Even for the many small streams that usually carry the bulk of freshwater on small islands, such extended watershed pathways may have a central influence on entire island ecosystems.

The impacts of terrestrial activities on adjacent and downstream marine ecosystems can be devastating. Coral reefs are particularly sensitive to erosion from on-shore activities including road building and timber removal (Hodgson 1988, Hodgson and Dixon 1988), as well as to pollution. Because of the pressures of logging, coral reefs adjacent to islands with high timber values will be particularly vulnerable in the coming decade.

Marine islands with pressures for exploitation of extensive tracts of rain forest deserve some of the greatest attention for habitat conservation in the coming decade due to (1) high species diversity spanning a range of forest and shallow marine communities; (2) the high levels of endemism and disjunct species associated with island ecosystems; (3) low or negligible rates of recolonization; and (4) the rapid destruction of the remaining island ecosystems without modern intrusion (Crosby 1986).

Islands with Primary Rain Forest as a Threatened Global Resource

Most of the world's islands that were dominated by mosaics of primary rain forest have been radically altered in the nineteenth and twentieth centuries. There are virtually no truly oceanic islands where the majority of the lowland forests were not largely altered or converted within a century of European intrusion. Similarly, nearly all of the lowland forests of the world's transitional islands, with the notable exception of Seram and Halmahera in eastern Indonesia, have been altered.

There are more primary rain forest and relatively pristine shallow marine areas on continental islands, because adjacent mainland areas have been more attractive for extractive activities. The prospects for conservation are more promising and most of the remaining large islands with primary rain forest are in this category. The off-shore islands of New Guinea, the Solomon Islands to the east, and the Moluccas to the west have the largest remaining pristine areas of island–forest–shallow marine configurations (Figure 6).

Four sets of human impacts comprise the most severe threats to the biological diversity of the remaining islands dominated by primary rain forest:

- conversion and alteration of primary rain forest;
- fragmentation of natural habitats, particularly in forested areas;
- the impacts of terrestrial land use on marine areas; and
- generalized degradation of the marine environment.

All four categories of impacts work synergistically and can produce cumulative impacts (Dickert and Tuttle 1985), which can be rapid, devastating, and largely irreversible.

Both islands and moist forest on islands are underrepresented in internationally recognized networks of protected areas (IUCN/UNEP 1986), although such areas could provide relatively secure sites for long-term monitoring and control of disturbance. Unfortunately, this promise has been jeopardized in recent years by global warming and possible sea level rise.

In his review of the status on the biota on South Pacific islands, Dahl (1984) stated that "there are probably more endangered species per capita in the South Pacific islands than anywhere else in the world." He attributed this to: (1) the naturally low numbers of certain species and small areas of habitat types; (2) the introduction of predators and weedy and aggressive species that overexploit or displace island species; and (3) the relative ease with which land-use expansion can destroy unique habitat types. In the most extensive review of conservation needs in the South Pacific, focused on the roughly 50 islands in Oceania, that have significant tracts of natural habitat, Dahl (IUCN/UNEP 1986) noted that less than 25 have island-wide habitat protection, and these are very small in size, with the remainder having less than 1% of the total protected areas. Most of the protected forest habitat on islands is situated on high islands, and there is still little conservation on atolls.

There are major constraints on implementing boundaries for shallow marine protected areas (Salm 1984). Methods for the identification of priority areas for conservation in marine zones, particularly coral reefs (Bakus 1982–1983), and sensitivity analysis are less developed than those for terrestrial areas, but they could lay the basis for integrated, terrestrial–marine zoning.

Conservation of the biological diversity of marine areas in the face of a myriad of inevitable and often subtle forms of environmental degradation, is problematic. Baseline areas are difficult to establish and maintain. The present knowledge of nearly all reef ecosystems, especially with respect to the South Pacific, is inadequate in terms of the information requirements for management (Dahl 1985b).

The Task Ahead: Protection of Islands with Primary Rain Forest for Refuges and Baselines

Islands that are relatively pristine with complex forest mosaics may well become the central metaphor in humanity's conception of "nature" and ecosystems in coming decades: archipelagoes that are almost saturated with biological richness and linked by highly permeable membranes (marine areas) and yet, paradoxically, which are perpetually vulnerable to isolation. The probability that additional activities in these areas, no matter how careful, will not produce negative impacts on some elements of local biodiversity is slim, but even if pressures for logging and mining are removed, as in the case of the establishment of national parks, programs of inventorying and monitoring must be initiated quickly (Ingram 1989).

If an expanded international program of island conservation goes ahead, it will need to take place in the next decade and exist within the imperfect contexts of national and provincial frameworks of plan-

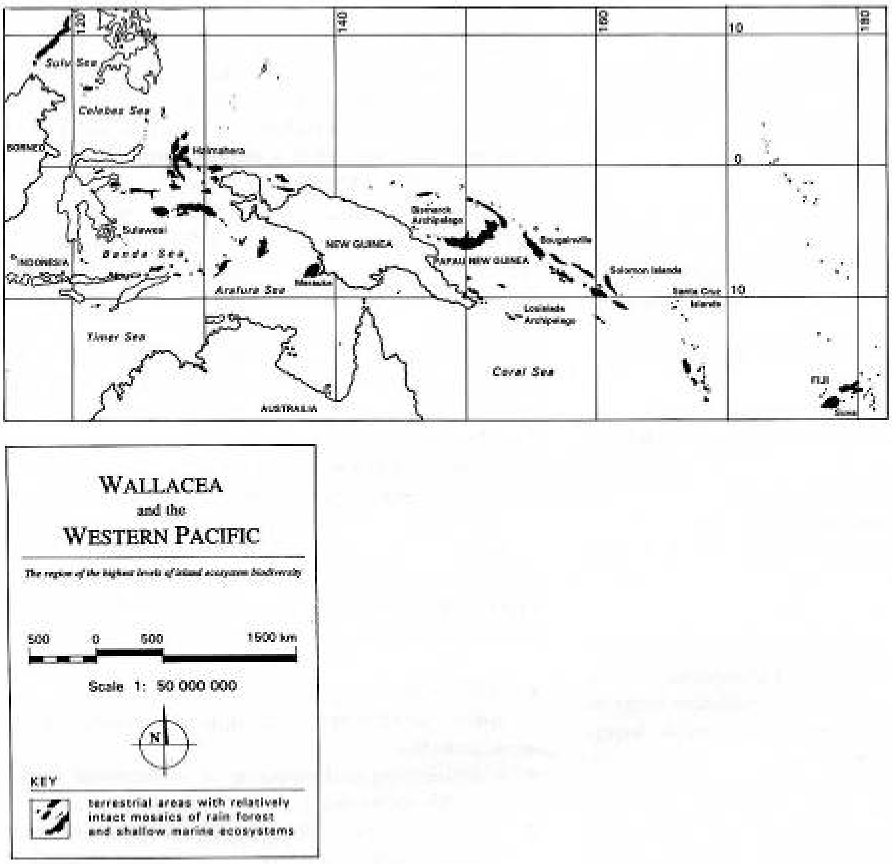

Figure 6. Map of the coastlines of the islands of eastern Indonesia, Papua New Guinea, and the Solomon Islands extending north to the Philippines and south to the coast of Northern Australia.

ning and land management. Given the traditional communities that currently occupy many areas and pressures for settlement or tourism on most of these islands, it is highly unlikely that many wilderness preserves will be possible. Even on remote islands such as Siberut, Mentawai Islands, Indonesia, which still are largely covered by more mature phases of forest (Figure 7), the impacts of logging and tourism suggest that large, multiple-use management units with small, pristine cores are inevitable (Ingram 1989, Mitchell and Tilson 1986). Priority sites for habitat conservation on islands with large tracts of primary forest can be evaluated through matrices with one axis that includes the following parameters (Ingram 1989):

- ecosystems;
- shore zones;
- shallow marine ecosystems requiring clean water;

Figure 7. Lowland primary rain forest, Siberut Island, Mentawai Island, Indonesia.

- terrestrial–marine pathways such as estuaries and mangroves;
- relatively stable terrestrial mosaics with relatively small gaps such as ever-wet forest (Whitten 1982);
- marginal habitats with more extreme seasonal and diurnal fluctuations;
- successional mosaics;
- edges between habitat types and life zones;
- habitat isolates that are smaller in comparison to similar types in adjacent mainland areas;
- long and narrow habitat units such as long shore lines and foothill areas;
- representative ecosystems and complexes of species;
- sites that are vulnerable to fragmentation;
- sites that are vulnerable to aspects of land use practices;
- sites that are traditionally exploited;
- sites that are harvested for export; and
- sites that have holding species that are genetic resources.

Another axis in the matrix could include prospective change factors that are related to logging, mining, agriculture, tourism, and more cumulative impacts. Such matrices would be linked to site-specific inventory data to allow for impact assessment, mitigation formulation, and incremental conservation planning on an on-going basis, if there is the political will to make conservation, both ecological and cultural, the overriding priority for "eco-development" (McElroy and de Albuquerque 1990). Mapping and decision-making will be increasingly finely scaled at 1:10,000 to 1:1,000.

Goals for a Network of Biosphere Reserves for the World's Remaining Islands Dominated by Primary Rain Forest

Biosphere reserves (Batisse 1982, Robertson Vernhes 1989) offer the most promise for an effective network of conservation and monitoring of biological diversity on the least altered islands. This international designation, administered through the Man and the Biosphere Program, allows for a range of preservation and conservation options to be adopted across a district, through highly protected cores and carefully managed buffers, transition areas, and corridors. Such zonation schemes are sufficiently flexible to allow for adaptive management of the terrestrial–marine interface if the cores, as habitat islands, are sufficiently pristine.

The greatest advantage of the biosphere reserves system is the potential for sharing information in terms of particular ecosystems and environmental settings, such as islands with rain forest. The global monitoring potential of biosphere reserves has barely been explored, although it is a major component of the program (UNESCO 1984).

There are major gaps in the theory and methodology of conservation of biological diversity on islands, on the marine areas that surround them, and in rain forest. All protected areas and management regimens that have or are currently being proposed may be inadequate for the conservation of local biological diversity as international standards coalesce over the coming decade. The linking of initial and revised criteria for conservation and reserve design with data on the continuing responses of protected populations is crucial to effective maintenance of the more sensitive elements of local biological diversity.

Monitoring frameworks could be standardized within matrices of ecological and land use typologies to test hypotheses for island conservation biology. Research priorities for islands with rain forest include:

- verification of species–area curves between and within archipelagoes through more complete inventorying;
- identification and mapping of successional mosaics, with respective gaps and isolates, over time;
- verification of causal linkages between natural and cultural disturbance factors and mosaic dynamics;
- verification of the representativeness of species for complexes of species, particularly for terrestrial–marine areas and relatively unique ecosystems;
- verification of the vulnerability of species to fragmentation and human-induced change and descriptions of the structure of the causal linkages;
- tracking of cumulative impacts for particular species and across complexes of terrestrial and marine ecosystems;
- tracking the impacts of human activities in relatively closed systems; and
- tracking the roles of traditional conservation practices in such relatively closed systems.

We live on a planet that has become painfully finite in its life-support systems and its ability to evolve, given the havoc that human beings can wreak. These islands confirm the limitations of all ecosystems when overwhelmed, but perhaps island boundaries, no matter how permeable and problematic, can also provide some clues on how to maintain and rebuild regional ecosystems. These islands require an international response not only for their uniqueness but also for the opportunities that they provide for linkages across great distances, no matter how tenuous they are at the present time.

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