

3.

INDICATORS OF BIODIVERSITY

A minimum set of 22 indicators providing information useful for national and international policy makers is presented in Table 1 and discussed below. The table presents a matrix combining the major conservation concerns with a working set of indicators that can be used to assess long-term trends in the conservation of biodiversity. Thirteen of the indicators deal with wild species' and genetic diversity, four with community diversity, and five with domesticated species. Together, they comprise a basic set of indicators that can be used to understand better how well the goals of biodiversity conservation are being met, whether at local, national, regional, or global levels.

Indicators of Wild Species and Genetic Diversity

This section identifies and describes the thirteen indicators that have been developed to assess wild species' and genetic diversity.

1. *Species richness (number of species, number of species per unit area, and number of species per habitat type)*

Species richness is only a partial measure of species diversity, but it remains one of the most useful indicators of status and trends. Peru, for

example, has approximately 1,705 species of birds, whereas the United States, a country seven times larger, has about 650 species (WCMC, 1992). Even so, measurements of species richness are hindered by the lack of data in much of the world: less than one out of five species—possibly as few as one out of a hundred—has been identified and named by scientists. As a result, species richness measurements generally focus on better-known taxa, particularly plants and vertebrates. Although this has the effect of weighting the indicators of diversity toward these groups, such weighting is sometimes appropriate because:

- plants and vertebrates tend to be of considerable direct importance to humanity
- areas with high species richness in these groups tend to have high species richness in other groups
- data on these taxa within a country are often available (estimates of population size have been made for some taxa)
- the diversity of plants in a region does not fluctuate significantly over short time intervals.

Table 1. Indicators of Biodiversity Conservation

| Indicator | Biodiversity Conservation Concerns | | |
|---|------------------------------------|-------------------|---------------------|
| | Genetic Diversity | Species Diversity | Community Diversity |
| Wild Species' and Genetic Diversity | | | |
| 1. Species richness (number, number per unit area, number per habitat type) | X | X | |
| 2. Species threatened with extinction (number or percent) | X | X | |
| 3. Species threatened with extirpation (number or percent) | X | X | |
| 4. Endemic species (number or percent) | X | X | |
| 5. Endemic species threatened with extinction (number or percent) | X | X | |
| 6. Species risk index | X | X | |
| 7. Species with stable or increasing populations (number or percent) | X | X | |
| 8. Species with decreasing populations (number or percent) | X | X | |
| 9. Threatened species in protected areas (number or percent) | X | X | |
| 10. Endemic species in protected areas (number or percent) | X | X | |
| 11. Threatened species in ex situ collections (number or percent) | X | X | |
| 12. Threatened species with viable ex situ populations (number or percent) | X | X | |
| 13. Species used by local residents (number or percent) | X | X | |
| Community Diversity | | | |
| 14. Percentage of area dominated by nondomesticated species | | X | X |
| 15. Rate of change from dominance of nondomesticated species to domesticated species | | X | X |
| 16. Percentage of area dominated by nondomesticated species occurring in patches greater than 1,000 sq km | | X | X |
| 17. Percentage of area in strictly protected status | | X | X |
| Domesticated Species Diversity | | | |
| 18. Accessions of crops and livestock in ex-situ storage (number or percent) | X | | |
| 19. Accessions of crops regenerated in the past decade (percent) | X | | |
| 20. Crops (livestock) grown as a percentage of number 30 years before | X | | |
| 21. Varieties of crops/livestock grown as a percentage of number 30 years before | X | | |
| 22. Coefficient of kinship or parentage of crops | X | | |

Other methods for weighting species prior to measuring species richness may be useful in certain circumstances. For example, one indicator suggested by Duke (unpublished manuscript) scores the economic importance of biodiversity in given regions by tallying the genera present that are known to include economically important species. (See Table 1.) These "econgeners" of plants important for medicine, fiber, fodder, food,

and chemicals are among the most likely to provide economically important products in the near future. For example, 22 percent of the genera of plants present at the Rio Palenque Science Center in Ecuador contain economically useful species (Duke, unpublished manuscript).

The number of species found in an area is, of course, related to the size of the area chosen for

measurement. Larger areas may encompass many more community types and thus more species, even though the number of species per unit area may be the same or smaller. Therefore, for measurements of species richness to be useful in decision-making, sometimes they must be converted to standard areas of measurement (Reid and Miller, 1989). For example, the United States has a higher species richness of mammals (346) than Costa Rica (197). However, Costa Rica has far more mammal species per unit area than the United States (127 per 10,000 sq km, compared to 55 per 10,000 sq km). (The conversion of values to a common area should not be done with a simple (linear) scaling because of the exponential shape of the species area curve: see Reid and Miller, 1989). All else being equal, the protection of 100 sq km in Costa Rica likely would conserve more mammal species than in the United States, even though the United States has a greater number of mammal species overall.

Measurements of species richness also can be given for specific types of habitats (wetlands, savanna/grasslands, tropical forest, temperate forest, etc.). When used in conjunction with national maps of vegetation distribution, data on species per habitat type highlight areas of high diversity within countries. It should be noted that the sum of the number of species for all habitat types will exceed the total number of known species because of the double counting of species that use or are found in more than one habitat type.

2. *Species (populations) threatened with extinction (number or percent)*

3. *Species (populations) threatened with extirpation (number or percent)*

The number of species threatened with extinction is one of the most common indicators of the status of biodiversity, although in most developing countries such data are unavailable even for the best-known taxa. The threat of extinction, however, may be less important than

the threat of local or national extirpation of a species from the standpoint of national or subnational policy-makers. For example, even though the bald eagle was not threatened with extinction globally, its near loss from the contiguous United States led to considerable political support for work to save and restore the species. As discussed earlier, for many purposes the *number* of species threatened with extinction or extirpation also must be supplemented by the *percentage* threatened. Representative data for the numbers of species known, endemic species, and globally threatened species are presented in Table 2.

Each of these indicators also can bear on genetic diversity if patterns of richness, extinction, and extirpation are examined at the level of genetically distinct populations. For example, 159 distinct populations of salmon in the Pacific Northwest of the United States are thought to be in danger of extirpation, but they comprise only 4 species, none of which is threatened with worldwide extinction (Knickerbocker, 1991).

4. *Endemic species (number or percent)*

5. *Endemic species threatened with extinction (number or percent)*

All species are endemic to a region, be that region a small island, a continent, or most of the world. Thus, information on levels of endemism can be somewhat misleading. For example, Cameroon, with only 156 of its 8,000 plant species (2 percent) endemic, has a much smaller proportion of endemic species than Zaire, with 3,200 out of 11,000 plant species (29 percent) endemic. But because the countries are very different in size (Zaire is five times larger), the difference in the percentage of endemism does not mean necessarily that species in Zaire are much more local in occurrence than those in Cameroon.

Table 2. Species Threatened With Extinction

| | Mammals | | | Birds | | | Reptiles | | | Amphibians | | |
|---------------------|-------------------------|--------------------------|---|-------------------------|--------------------------|---|-------------------------|--------------------------|---|-------------------------|--------------------------|---|
| | Number of Species Known | Number of Endemics Known | Number of Globally Threatened Species (a) | Number of Species Known | Number of Endemics Known | Number of Globally Threatened Species (a) | Number of Species Known | Number of Endemics Known | Number of Globally Threatened Species (a) | Number of Species Known | Number of Endemics Known | Number of Globally Threatened Species (a) |
| | | | | | | | | | | | | |
| <i>Africa</i> | | | | | | | | | | | | |
| Algeria | 92 | 1 | 12 | 192 | 1 | 15 | X | 3 | 0 | X | 0 | 0 |
| Botswana | 154 | 0 | 9 | 569 | 0 | 6 | 143 | 2 | 1 | 36 | 1 | 0 |
| Kenya | 309 | 10 | 17 | 1,067 | 7 | 18 | 187 | 15 | 2 | 88 | 10 | 0 |
| Mali | 137 | 0 | 16 | 647 | 0 | 4 | 16 | 2 | 2 | X | 1 | 0 |
| Rwanda | 151 | 0 | 11 | 669 | 0 | 7 | X | 1 | 2 | X | 0 | 0 |
| Zaire | 415 | 25 | 31 | 1,086 | 23 | 27 | X | 33 | 2 | X | 53 | 0 |
| <i>Americas</i> | | | | | | | | | | | | |
| Brazil | 394 | 68 | 40 | 1,573 | 191 | 123 | 468 | 172 | 11 | 502 | 294 | 0 |
| Chile | 91 | 11 | 9 | 432 | 15 | 18 | 78 | 33 | 0 | 39 | 25 | 0 |
| Costa Rica | 205 | 8 | 10 | 848 | 6 | 14 | 214 | 17 | 2 | 162 | 34 | 0 |
| Jamaica | 22 | 3 | 5 | 159 | 25 | 2 | X | 25 | 3 | X | 18 | 0 |
| Mexico | 439 | 136 | 25 | 961 | 88 | 35 | 717 | 368 | 16 | 284 | 169 | 4 |
| United States | 346 | 93 | 27 | 650 | 69 | 43 | X | X | 25 | X | 122 | 22 |
| <i>Asia/Oceania</i> | | | | | | | | | | | | |
| Australia | 282 | 210 | 38 | 571 | 351 | 39 | 700 | 616 | 9 | 180 | 169 | 3 |
| China | 394 | 62 | 40 | 1,100 | 63 | 83 | 282 | X | 7 | 190 | 131 | 1 |
| India | 317 | 38 | 39 | 969 | 69 | 72 | 389 | 156 | 17 | 206 | 110 | 3 |
| Iraq | 81 | 1 | 9 | 145 | 1 | 17 | 81 | X | 0 | 6 | 0 | 0 |
| Papua New Guinea | 242 | 49 | 5 | 578 | 54 | 25 | 249 | X | 1 | 183 | 100 | 0 |
| Philippines | 166 | 90 | 12 | 395 | 172 | 39 | 193 | 131 | 6 | 63 | 44 | 0 |
| <i>Europe</i> | | | | | | | | | | | | |
| France | 93 | 0 | 6 | 267 | 9 | 21 | 32 | 0 | 2 | 32 | 3 | 1 |
| Greece | 95 | 2 | 4 | 244 | 0 | 19 | 51 | 4 | 3 | 15 | 1 | 0 |
| Netherlands | 55 | 0 | 2 | 187 | 0 | 13 | 7 | 0 | 0 | 16 | 0 | 0 |
| Poland | 85 | 0 | 4 | 224 | 0 | 16 | 9 | 0 | 0 | 18 | 0 | 0 |
| U.S.S.R. | 276 | 55 | 20 | X | 13 | 38 | 168 | X | 3 | 37 | 2 | 0 |

Source: World Conservation Monitoring Centre, 1992.

Notes: Countries were chosen to be generally representative of the world's major ecosystems. Globally threatened species numbers do not include species that are threatened only in certain countries of their ranges. a. Includes naturally rare species. X = Not available. For additional information, see the Appendix - Sources and Technical Notes for Tables.

This pattern still would result even if all of the species in the two countries had ranges of identical size because proportionately fewer of the ranges of the species in the larger country would extend past its border (giving it a higher ratio of endemics to nonendemics). Nonetheless, levels of endemism are useful statistics because they reveal nations, ecosystems, or communities that are particularly distinctive biologically. As with species richness, however, it is often more appropriate to express levels of endemism on a per unit area basis. Myers (1988, 1990) uses such a measure in his analysis of potential biodiversity "hot spots" by examining the percentage of endemic species in relation to the percentage of land area involved. Conservation actions in sites with a high number of endemic species relative to the land area are likely to be most efficient in conserving species diversity. Vane-Wright *et al.* (1991) note that measures of taxonomic richness can provide an even more efficient means of making conservation decisions, but measurements of endemism are more readily available today.

6. Species Risk Index

A Species Risk Index combines information on endemic species within a community and on the status of that community in order to provide insights into the status of species, even in the absence of detailed threatened species lists. The index is calculated by multiplying the number of endemic species (per unit area) in a community by the percentage of the natural community that has been lost. Thus, an ecological community with many endemics and with a high proportion of its area lost would be ranked at high risk, while a community with few endemics or one that has experienced little conversion would be ranked at low risk.

The application of this index is demonstrated for seven biogeographic units for which MacKinnon and MacKinnon (1986a) provide data on the endemism of plants, birds, and mammals (see Table 3). To calculate the index, the number of endemic species was converted to a per-unit-

area basis, using a species-area curve. The slope of the species-area curve, determined by the exponent z , varies from region to region because of differences in the number of habitats present. Empirical studies of the species-area relationship have found that the z value typically varies from 0.15 to 0.35. Therefore, a midpoint of 0.25 was chosen for calculations for the Species Risk Index (Connor and McCoy, 1979; Simberloff, 1986). The species-area curve is expressed as:

$$S = cA^z$$

where S is the number of endemic species as listed in MacKinnon and MacKinnon (1986a), A is the area of the biogeographic unit, c is a constant, and z is the exponent. Solving for c and then substituting this value into the same equation (but using a standard area) gives:

$$S_s = (S_1 A_s^z)/A^z$$

where S_s is the number expected per standard area, and A_s is the standard area (100,000 sq km). Multiplying this by the percentage of the biogeographic unit that has been converted yields the Species Risk Index values shown in Table 3. The Philippines, because of its large number of endemic species and relatively high fraction of community lost, is at the highest risk. Borneo and Sulawesi also rank high because of their large number of endemics, even though they have lost less habitat than most of the other regions.

7. Species (populations) with stable or increasing populations (number or percent)

8. Species (populations) with decreasing populations (number or percent)

Some countries have developed "Red Lists of Threatened Species," documenting native species at risk of extirpation or extinction. Diamond (1988) has proposed the establishment of "Green Lists" to document species for which adequate information is available to know that populations are *not* in jeopardy. Such lists could be extremely

Table 3. Species Risk Index

| Biogeographic Unit | Country Containing the Unit | Original Natural Area (sq km) | Percent of Original Area Lost | Number of Endemic Species in Original Area | Endemics per 100,000 sq km (a) | Species Risk Index |
|--------------------|-----------------------------|-------------------------------|-------------------------------|--|--------------------------------|--------------------|
| Philippines | Philippines | 293,194 | 79 | 416 | 318 | 251 |
| Borneo | Indonesia | 735,148 | 31 | 392 | 238 | 74 |
| Sulawesi | Indonesia | 187,882 | 41 | 191 | 163 | 67 |
| Lesser Sunda | Indonesia | 84,092 | 77 | 83 | 87 | 67 |
| Malay Peninsula | Malaysia | 198,482 | 56 | 134 | 113 | 63 |
| Java/Bali | Indonesia | 127,152 | 91 | 73 | 69 | 63 |
| Sumatra | Indonesia | 470,941 | 59 | 126 | 86 | 50 |

Sources: MacKinnon and MacKinnon, 1986 and World Resources Institute, 1990.

Note: The Species Risk Index is calculated from percent community loss and the number of plant, mammal, and bird endemics per unit area (see the text for details).

a. Calculated using a species-area curve to determine the expected number of species in a given area (for details see the Appendix - Sources and Technical Notes for Tables).

valuable as an indicator of the status of species diversity. In addition, a timely "National Green List of Monitored Species" would indicate the state of knowledge of particular species and the need for expanded ecological research. (See Table 3.) Several industrialized countries have begun to report on the percentage of species (mammals, birds, reptiles, amphibians, fish, invertebrates, and vascular and other plants) with decreasing populations (OECD, 1991).

Population trends provide one means for analyzing the status of a species well before it is threatened with extinction. Unfortunately, the costs of obtaining population information on a large number of species are generally prohibitive, although exceptions do exist. For example, the U.S. Fish and Wildlife Service assembles population trends of many breeding bird species in the United States based on yearly sample surveys (Droege and Sauer, 1989). A similar program is under way in the United Kingdom. The existence of such data sets allowed the discovery of significant declines in populations of temperate migratory songbirds wintering in tropical forests, apparently due in part to the loss of habitat in their winter range (Robbins et al., 1989; Terborgh, 1990). Such data sets also can provide

information on rapidly increasing populations and expanding ranges of exotic species, such as the African cattle egret (CEQ, 1981; 1990).

Population monitoring is more affordable when only a few indicator species are tracked. Candidates may include keystone species, those of particular importance to ecosystem function; species with large range requirements, whose survival assures that the habitat requirements of smaller-ranging species are protected; and species particularly sensitive to ecological change. Because of differences between ecosystems, a good indicator species for one region is not necessarily suitable for another. Therefore, data on the population trends of indicator species generally are not comparable between ecoregions or countries.

9. *Threatened species in protected areas (number or percent)*
10. *Endemic species in protected areas (number or percent)*
11. *Threatened species maintained in ex-situ collections (number or percent)*

12. *Threatened species with viable (reproducing) ex-situ populations (number or percent)*

Protected areas and *ex-situ* conservation centers are key tools used in the conservation of biodiversity. The coverage of known threatened or endemic species in protected areas is a useful baseline indicator of the potential conservation role of these areas. Particularly for locally endemic species that are restricted naturally to small areas, their presence in a protected area may ensure their conservation, barring significant environmental changes. However, the presence of threatened species in a protected area does not indicate that they are safe from extinction.

Biodiversity conservation involves the close linkage of *ex-situ* and *in-situ* conservation. Ideally, species threatened with extinction in the wild would be maintained *ex-situ* as insurance until the wild population stabilized. For example, a breeding population of the golden lion tamarin, threatened in its native habitat in the Atlantic forest of Brazil, is being maintained in zoos, and offspring from the captive population are being reintroduced to supplement the wild population. This demonstrates how indicators of the coverage of *ex-situ* conservation are important complements to indicators bearing on *in-situ* conservation.

These few management indicators provide only the minimum set needed for monitoring the effectiveness of specific conservation tools. In particular, information on the status of the management of protected areas, zoos, and botanic gardens would be essential, as would be information on pollution, harvest, and species introductions. In addition, for those indicators of the status of species in protected areas (indicators 9 and 10), estimates of whether these populations are viable are also extremely valuable. However, such information is available at present for very few species only and is costly to obtain. Except for individual species of special concern, the acquisition of such data on a broad scale is unlikely.

13. *Species used by local residents (number or percent)*

The dependence of local residents on biodiversity is an important factor influencing opportunities for its conservation. Where people continue to utilize a variety of wild species for food, medicine, and building materials, the local benefits to be derived from maintaining that diversity are likely to be high. Where such use is low, both local knowledge of biodiversity and the incentive for its conservation will be low as well. An example of data on the percentage of tree species used locally in various regions of the Amazon basin is presented in Table 4. Such an indicator also could be used to compare dependence on biodiversity among gender or age groups.

Indicators of Community Diversity

Indicators of community diversity that can be used at international and global levels are fewer in number and in general are less developed than species indicators.

14. *Percentage (extent) of area (province/nation/ecoregion) dominated structurally by nondomesticated species*

15. *Rate of change from structural dominance of nondomesticated species to domesticated species*

16. *Percentage (extent) of area (province/nation/ecoregion) dominated by nondomesticated species occurring in patches greater than 1,000 sq km*

Traditionally, the status of communities or habitats has been evaluated by a measurement of the remaining natural area. Rarely, however, is "natural" defined. A natural community generally is assumed to be one undisturbed by humans. Arguably, however, all communities have been altered substantially by human activity over the past several thousand years, so the range of human

Table 4. Tree Species Used by Local Amazonian Residents

| Country | Life Zone | Forest Type | Amazonian Community Name | Average Number of Tree Species per Hectare | Average Number of Tree Species Used per Hectare | Percent of Tree Species Used | Source |
|-----------|-----------------------------------|-------------|-----------------------------|--|---|------------------------------|------------------------------|
| Brazil | Tropical dry forest | Managed | Kayapo | 120 (a) | 118 (a) | 98 | Anderson and Posey, 1989. |
| Brazil | Tropical moist forest | Managed | Ribereno Isla das Oncas (b) | 28 | 25 | 89 | Anderson and Posey, 1989. |
| Bolivia | Premountain tropical moist forest | Unmanaged | Chacobo | 94 | 74 | 79 | Prance et al., 1987. |
| Brazil | Tropical moist forest | Unmanaged | Ribereno Isla das Oncas (b) | 53 | 42 | 79 | Anderson and Posey, 1989. |
| Brazil | Tropical moist forest | Unmanaged | Ka'apor | 99 | 76 | 77 | Prance et al., 1987. |
| Brazil | Tropical moist forest | Managed | Tembe | 119 | 73 | 61 | Prance et al., 1987. |
| Peru | Tropical moist forest | Managed | Ribereno San Rafael (b) | 158 (c) | 95 (c) | 60 | Pinedo-Vasquez et al., 1990. |
| Venezuela | Tropical moist forest | Unmanaged | Panare | 70 | 34 | 49 | Prance et al., 1987. |
| Peru | Tropical moist forest | Unmanaged | Ribereno Mishana (b) | 250 | 72 | 26 | Peters et al., 1989. |

Source: Manuel Winograd, World Resources Institute.

Notes: Average number of tree species and tree species used are based on surveys of trees over 10 cm diameter at breast height.

a. Includes shrubs, vines, and tree species under 10 cm diameter at breast height.

b. Heterogenous population of detribalized Indians and mestizos.

c. Data are for a 7.5 hectare parcel.

impacts on ecosystems prevents a clear distinction between "natural" and "disturbed" systems. For this reason, this traditional dichotomy is avoided herein. Instead, distinguishing land dominated structurally by domesticated species from that dominated by nondomesticated species is recommended. For example, if land is divided evenly into categories of agricultural land, timber plantations, secondary forest, and primary forest, the indicator would show that 50 percent of the region is dominated by nondomesticated species. For terrestrial ecosystems, the use of domesticated versus nondomesticated categories (croplands, improved pasture and range, forest plantations, and aquaculture) also lends itself to analysis from remote sensing. However, the categories would be of less use in either marine or freshwater environments. Representative community indicators based on the extent and loss of nondomesticated habitats, are presented in Table 5.

Appropriate baselines for such measurements differ, depending on the scale of analysis. For evaluating the status of community diversity at subnational levels, detailed community classification schemes are generally most useful. Such classifications allow the incorporation of ecologically relevant attributes into the classification of the community (such as the distinction between an old-growth redwood forest community and a second-growth community). But, as discussed earlier, in order to develop indicators relevant at national and international levels, it usually is more convenient to use coarse-grained but comprehensive systems such as ecoregions (or, less desirably, biogeographic provinces). Ideally, rates of change, rather than merely percentage of change should be analyzed over a long period of time. Only with this kind of indicator, which requires periodic monitoring, will it be possible to assess the effectiveness and efficiency of conservation practices and policies.

The fragmentation of a biological community has a significant influence on the numbers and types of species that can be supported. While the

exact relationship between the number and size of natural areas and the number of species conserved depends strongly on local habitat and species distribution patterns, in general, larger areas are likely to contain viable populations of more species. But even extremely large nature reserves (10,000 sq km, for example) are thought to be too small to maintain populations of large mammals indefinitely (Frankel and Soulé, 1981; Shaffer, 1987). In the absence of a clear scientific understanding of the effects of patterns of fragmentation on species persistence, a relatively simple indicator of fragmentation based on the fraction of the remaining habitat dominated by nondomesticated species in "large" tracts (greater than 1,000 sq km) is proposed. Although this area is less than sufficient for the long-term survival of all of the species, the choice of a larger area would provide relatively little more information since few areas of such size remain. For example, only 10 percent of the protected areas in the Indo-Pacific region exceed 1,000 sq km in size (Dinerstein and Wikramanayake, 1993).

*17. Percentage (extent) of area
(province/nation/ecoregion/community type) in
strictly protected status*

A traditional objective of the establishment of protected areas has been to maintain representative samples of biological communities (McNeely and Miller, 1984). This goal has always been problematic, given both the subjectivity in defining communities and their ephemeral nature. Nevertheless, since communities can be defined and monitored meaningfully over periods of decades or even centuries, the conservation of representative samples of biologically defined communities is a reasonable target of conservation efforts. For longer-term conservation considerations, the representative sample approach might be better described as maintaining a representative arena of biological activity.

In either case, the coverage of protected areas is a useful indicator of the status of community conservation efforts. (See Table 6.) Protected areas

Table 6. Protected Areas

| | National Protection Systems | | | | | | International Protection Systems | | | | | | | |
|---------------------|--|-----------------|--------------------------------|---|-----------------|---------------------|----------------------------------|---------------------|--------------------------------------|---------------------|------------------------------------|---------------------|--------------------------------------|----------------------|
| | Strictly Protected Areas (IUCN Categories I-III) | | | Partially Protected Areas (IUCN Categories IV, V) | | | Biosphere Reserves | | Wetlands of International Importance | | Marine and Coastal Protected Areas | | Number of Natural and Heritage Sites | |
| | Total Area (000 ha) | Number of Sites | Percent of Land Area Protected | Total Area (000 ha) | Number of Sites | Total Area (000 ha) | Number of Sites | Total Area (000 ha) | Number of Sites | Total Area (000 ha) | Number of Sites | Total Area (000 ha) | Number of Sites | Mixed Heritage Sites |
| <i>Africa</i> | | | | | | | | | | | | | | |
| Algeria | 11,898 | 19 | 5.0 | 11,787 | 12 | 110 | 7 | 7,200 | 1 | 5 | 2 | 2 | 1 | 1 |
| Botswana | 10,025 | 9 | 17.2 | 8,787 | 4 | 1,238 | 5 | X | X | X | X | X | X | X |
| Kenya | 3,347 | 36 | 5.8 | 3,277 | 30 | 70 | 6 | 851 | 4 | 19 | 7 | 7 | 3 | 0 |
| Mali | 889 | 7 | 0.7 | 350 | 1 | 539 | 6 | 771 | 1 | 162 | X | X | X | 1 |
| Rwanda | 327 | 2 | 12.4 | 327 | 2 | 0 | 0 | 15 | 1 | X | X | X | X | X |
| Zaire | 8,827 | 9 | 3.8 | 8,794 | 8 | 33 | 1 | 298 | 3 | X | X | 0 | 0 | 4 |
| <i>Americas</i> | | | | | | | | | | | | | | |
| Brazil | 20,525 | 162 | 2.4 | 13,906 | 90 | 6,619 | 72 | X | X | X | X | 2,032 | 20 | 1 |
| Chile | 13,650 | 65 | 18.0 | 8,378 | 32 | 5,271 | 33 | 2,407 | 7 | 5 | 1 | 10,050 | 32 | 0 |
| Costa Rica | 606 | 28 | 11.9 | 476 | 17 | 130 | 11 | 729 | 2 | X | X | 194 | 7 | 1 |
| Jamaica | 0 | 0 | 0.0 | 0 | 0 | 0 | 0 | X | X | X | X | 0 | 0 | 0 |
| Mexico | 9,420 | 61 | 4.8 | 2,223 | 47 | 7,197 | 14 | 1,288 | 6 | 47 | 1 | 1,119 | 11 | 1 |
| United States | 98,342 | 968 | 10.5 | 38,471 | 304 | 59,871 | 664 | 19,108 | 43 | 1,116 | 8 | 54,317 | 107 | 9 |
| <i>Asia/Oceania</i> | | | | | | | | | | | | | | |
| Australia | 45,654 | 728 | 5.9 | 29,575 | 355 | 16,079 | 373 | 4,743 | 12 | 4,478 | 39 | 13,035 | 184 | 8 |
| China | 21,947 | 289 | 2.3 | 101 | 4 | 21,846 | 285 | 1,819 | 7 | X | X | 1,184 | 20 | 2 |
| India | 13,481 | 359 | 4.1 | 3,525 | 59 | 9,956 | 300 | X | X | 193 | 6 | 474 | 14 | 5 |
| Iraq | 0 | 0 | 0.0 | 0 | 0 | 0 | 0 | X | X | X | X | 0 | 0 | 0 |
| Papua New Guinea | 29 | 5 | 0.1 | 7 | 3 | 22 | 2 | X | X | X | X | 0 | 0 | X |
| Philippines | 584 | 28 | 1.9 | 237 | 15 | 347 | 13 | 1,174 | 2 | X | X | 31 | 5 | 0 |
| <i>Europe</i> | | | | | | | | | | | | | | |
| France | 4,779 | 81 | 8.7 | 278 | 9 | 4,501 | 72 | 503 | 5 | 85 | 1 | 849 | 27 | 1 |
| Greece | 104 | 20 | 0.8 | 71 | 10 | 33 | 10 | 9 | 2 | 107 | 11 | 84 | 13 | 2 |
| Netherlands | 355 | 68 | 9.5 | 230 | 26 | 125 | 42 | X | X | 306 | 11 | 54 | 10 | X |
| Poland | 2,230 | 78 | 7.1 | 135 | 13 | 2,095 | 65 | 26 | 4 | 7 | 5 | 73 | 4 | 1 |
| U.S.S.R. | 24,074 | 176 | 1.1 | 23,802 | 170 | 272 | 6 | 10,891 | 20 | 2,987 | 12 | 4,925 | 22 | 0 |

Sources: World Conservation Monitoring Centre and World Resources Institute, 1992.

Notes: Countries were chosen to be generally representative of the world's major ecosystems. X = Not available or not applicable.

For additional information, see the Appendix: Sources and Technical Notes for Tables.

are divided into eight categories by The World Conservation Union (IUCN) in order to reflect different management objectives. Categories I through III are referred to as "totally protected areas": scientific reserves, national parks, and natural monuments. Categories IV through VIII focus on controlled resource exploitation: managed nature reserves, protected landscapes, resources reserves, anthropological reserves, and multiple-use areas. Coverage of totally protected areas is the most relevant measure of the status of biodiversity, although overall protected area coverage is useful too. Ideally, coverage should be expressed both as a fraction of a specific type of community, biogeographic region, or ecoregion and as a fraction of a nation (or other relevant political unit). Marine protected areas should be included in such indicators (and, at the global level, international protected areas such as that proposed for Antarctica as well), but they should be disaggregated from terrestrial and coastal areas.

The U.S. Fish and Wildlife Service's Gap analysis project offers one approach to calculating the extent of each community type under protected status. This analysis overlays state vegetation maps at the 1:100,000 or 1:250,000 scale with maps of protected areas and species distribution (Noss, 1992). Although the project's goals are management-oriented—identifying gaps in the protection of species and communities—the resulting data can serve as indicators of the area and the percentage of community types afforded protection, provide information on habitat fragmentation, and identify species-rich areas.

Indicators of Domesticated Species

Although clearly components of biodiversity, domesticated species are often overlooked in assessments of the status of, and trends in, biodiversity. Several of the most important indicators of biodiversity conservation among domesticated species are:

18. *Accessions of crops and livestock in ex-situ storage (number or percent)*

19. *Accessions of crops regenerated in the past decade (percent)*

The most common indicator of the status of *ex-situ* collections of domesticated species is the number and percentage of accessions for each crop or livestock species. Each accession represents a single collection from a population of the species; for example, from one farmer's field. Though valuable, the number of accessions is not a sufficient indicator of the diversity of land races or breeds that is maintained *ex-situ*. A much more useful statistic would be the number of accessions of distinct varieties as a percentage of the varieties in existence. At the present time, however, such data are not being collected, and estimates of the coverage of genetic diversity generally rely on the best guesses of experienced collectors (Lyman, 1984; Plucknett *et al.*, 1987).

The number of accessions held in a gene bank does not indicate the status of those accessions. In some cases, as much genetic diversity may be lost in gene banks as in the field (Keystone, 1991). The principal cause of the loss of diversity in gene banks is the failure to regenerate samples while they remain viable; this needs to be done every 10 years on average. Thus, a useful indicator of the status of collections in crop gene banks would be the percentage of accessions in a collection that has been grown out in the past decade. For example, the United States National Plant Germplasm System holds some 388,000 accessions; this number is projected to grow to 453,000 accessions by 2001. Over the past five years, 33,000 accessions have been grown out annually. At this pace, about 85 percent of the collection would have been regenerated in the previous decade.

20. *Crops (livestock) grown in an ecoregion or a nation as a percentage of the number grown 30 years previously*

21. *Varieties of each crop (livestock) grown in an ecoregion or a nation as a percentage of the number grown 30 years previously*

22. Coefficient of kinship or parentage of crops

At present, indicators for domesticated species bear only on the status of biodiversity *ex-situ*. This bias reflects the history of the global response to the loss of crop and livestock genetic diversity, which involved primarily an effort to preserve samples of germplasm *ex-situ* before they vanished. These indicators need to be supplemented by measurements of *in-situ* status. The status of diversity in fields has a direct bearing on the vulnerability of individual crops to disease and pests as well as on the vulnerability of regional economies and households to market or environmental changes.

One useful indicator is a comparison of the number of crops grown currently in a region with the number grown 30 years previously. Many traditional agricultural systems rely on a great diversity of crops. The Huastec Indians in Mexico, for example, manage some 300 species in their agricultural and forest plots and home gardens (Alcorn, 1984). Similarly, residents of the Bungoma district of Kenya use at least 100 different species of fruits and vegetables in their diets (Juma, 1989a). But these diverse cropping systems are often lost when cash crop economies are introduced. Too great a simplification of cropping systems may increase the vulnerability of local economies. Moreover, information on the loss of locally important crops is important to ensure that *ex-situ* conservation strategies can be implemented where needed.

Another important indicator is varietal diversity within individual crops. For example, the number of varieties of hard red winter wheat being grown in the United States increased from 5 in 1919 to 164 in 1984 (Cox *et al.*, 1986). From an agronomic standpoint, the number of varieties of a crop being grown in a region provides important information about the potential vulnerability of the crop to outbreaks of disease. In 1970, the U.S. corn crop suffered losses worth \$1 billion when a leaf fungus spread through the genetically uniform crop (Tatum, 1971). In addition, a heterogeneous

array of crop varieties allows their continuing evolution in response to predators and pests and thus helps to maintain the genetic diversity upon which future agricultural productivity depends.

However, the number of varieties being grown does not provide a complete assessment of the actual genetic diversity among the varieties. If all of the varieties descended recently from a common parent, then genetic diversity may be quite low. One means of incorporating information on the lineage of the varieties being grown is to calculate a coefficient of kinship or parentage for the various varieties. Coefficients of kinship and parentage—routine measurements in population genetics—indicate the probability that a pair of alleles drawn at random from the same locus in two individuals will be autozygous (identical by common descent) (Falconer, 1981). A high coefficient would be obtained if one variety were extremely common, or if all varieties grown shared a similar lineage. For example, Cox *et al.* (1986) calculated coefficients of parentage for soft red winter wheats and hard red winter wheats in the United States. For soft red winter wheat, they found that the uniformity of varieties increased significantly during the 1970s, but then dropped sharply in the 1980s. In hard red winter wheat, uniformity declined sharply from 1919 to 1949 and has decreased gradually since that time. Despite a 126 percent increase in the number of cultivars between 1959 and 1979, the genetic diversity increased only slightly during that period due to the close relatedness of the varieties released.