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Item 5.4 of the provisional agenda*

**INDICATORS FOR ASSESSING PROGRESS TOWARDS THE 2010 TARGET:
CONNECTIVITY/FRAGMENTATION OF ECOSYSTEMS***Note by the Executive Secretary***I. SUMMARY**

1. Fragmentation is caused by natural disturbance (e.g., fires, windthrows) or by land use change and habitat loss, e.g. the clearing of natural vegetation for agriculture or road construction, which leads to previously continuous habitats to become divided into separate fragments. As a result of fragmentation, fluxes of radiation, wind, water and nutrients across the landscape are altered significantly. Larger remnants and remnants, which are close to other remnants, are less affected by the fragmentation process.

2. Small fragments of habitat can only support small species populations, which tend to be vulnerable to extinction. Moreover, small fragments of habitat do not contain interior habitat. Habitat along the edge of a fragment has a different climate and favours different species to the interior. Small fragments are therefore unfavourable for those species, which require interior habitat and may lead to the extinction of those species. Species, which are specialized to particular habitats, and species, whose dispersal ability is weak, suffer from fragmentation more than generalist species with good dispersal ability.

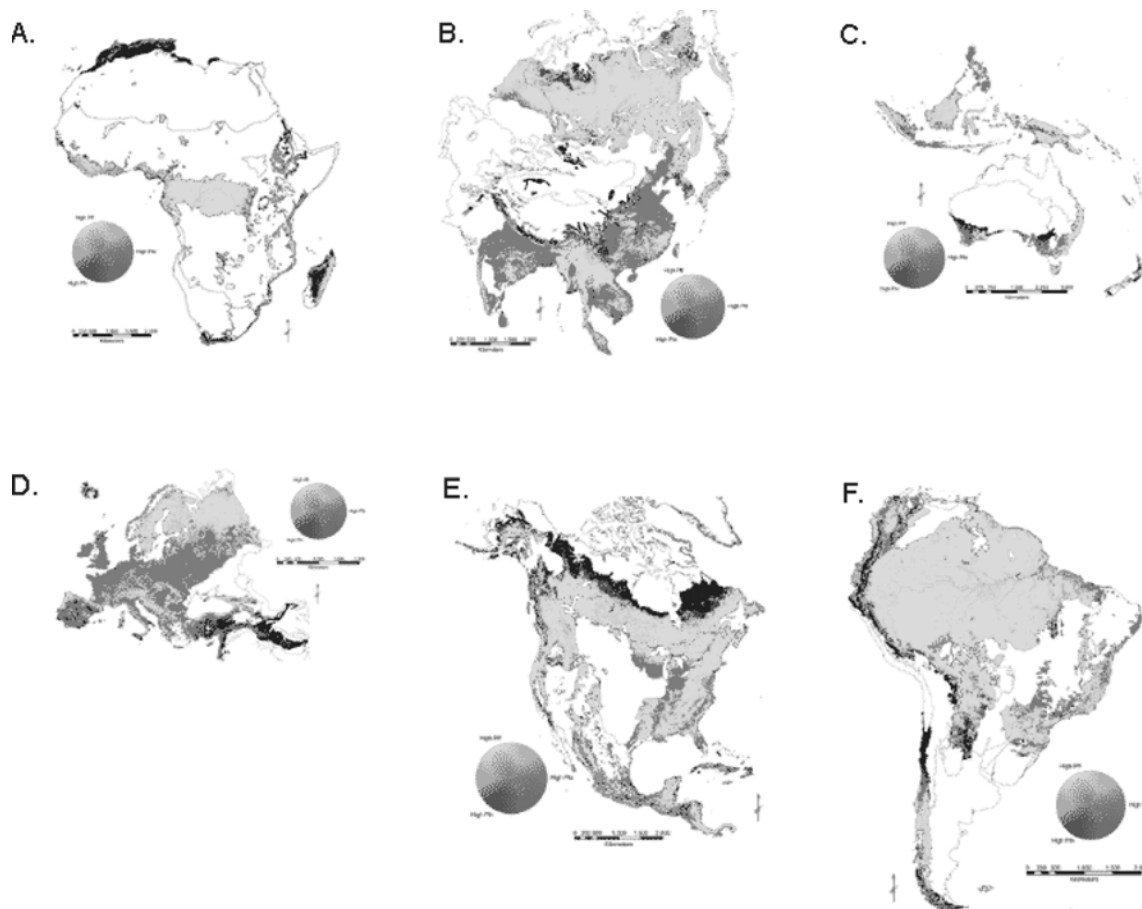
3. Fragmentation is associated with a decrease in patch size and increasing isolation between habitat patches. Also, the size of core areas decreases and the size of edge areas increases.

4. Information on connectivity/fragmentation is available on a number of biomes, including in particular on forests and major river systems. To quantify the spatial patterns of forest cover change, different spatial indices (or metrics) have been developed in the recent years. The main aspects that these attempt to capture are a loss of total habitat area, an increase of patch abundance and density, a decrease of patch size, a reduction in core area, and an increase in patch edges.

* UNEP/CBD/SBSTTA/10/1.

5. The current availability of forest cover datasets is sufficient to allow the assessment of forest fragmentation at global and country level. Therefore, fragmentation can be used as an indicator of ecosystem integrity for forests. A global estimate of forest fragmentation ^{1/} uses a methodology that could be applied to assess connectivity/fragmentation of forests and other ecosystem types (figure 1).

Figure 1. Colour composite (converted to greyscale) showing the components of forest fragmentation (black = unforested land, white = areas not included in the study). Fragmentation is particularly severe in Europe and South and Southeast Asia. (from Wade et al. 2003).

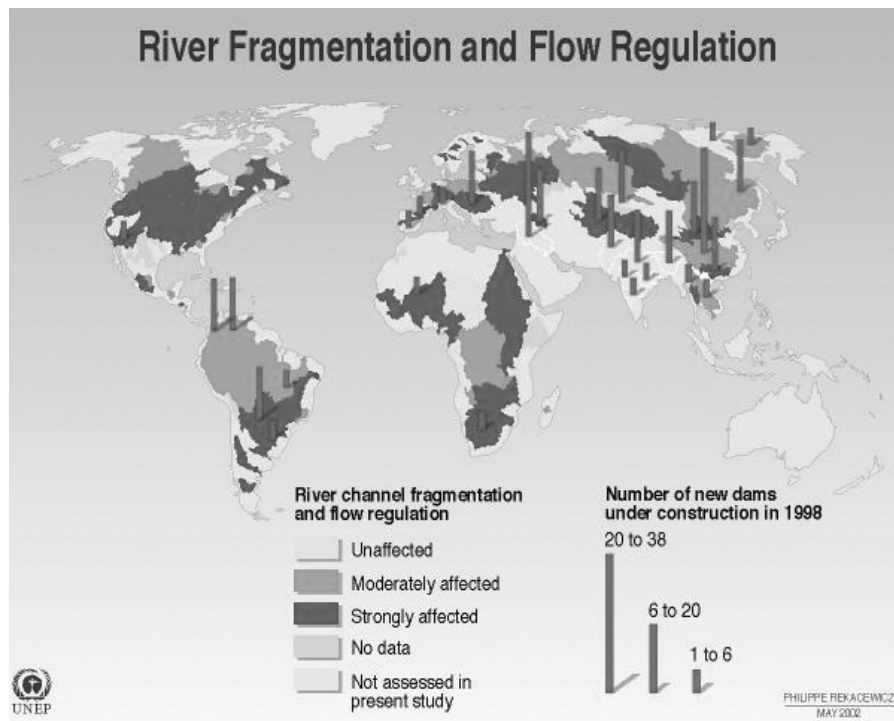


6. Modifications of rivers include river embankments to improve navigation, drainage of wetlands for flood control and agriculture, construction of dams and irrigation channels, and the establishment of inter-basin connections and water transfers. These physical changes in the hydrological cycle disconnect rivers from their floodplains and wetlands and slow water velocity, thereby impacting migratory patterns of fish species and the composition of riparian habitats. Dams also affect the seasonal flow and sediment transport of rivers. ^{2/} Figure 2 provides a graphic presentation on the fragmentation of major rivers worldwide.

^{1/} Wade, T. G. et al. 2003. Conservation Ecology 7(2) [online]. www.consecol.org/vol7/iss2/art7

^{2/} <http://www.biodiv.org/doc/publications/cbd-ts-11.pdf>

Figure 2. River fragmentation through channel fragmentation, dams and flow regulation (modified from UNEP-Vital Water Graphics) ^{3/}



Source: Revenqa et al., World Resources Institute (WRI), Washington DC, 2000.

II. RELATION OF THE INDICATOR TO THE FOCAL AREA

7. The degree of connectivity and fragmentation of habitats are important indicators of ecosystem integrity: more connected and less fragmented ecosystems have a higher likelihood of maintaining their ecological functions and species composition than small habitat patches. By providing a qualitative element, the indicator complements information on trends in extent of selected biomes, ecosystems, and habitats. Because of the varying sensitivity of species to fragmentation, the indicator provides supplementary information to the indicators on trends in abundance and distribution of selected species and on change in status of threatened species.

8. The matrix surrounding fragmented habitats commonly supports abundant populations of exotic weeds or generalist animals that can invade remaining habitat fragments. There may be a possible correlation between alien invasions and habitat fragmentation. The likelihood of human-induced ecosystem failure also increases in highly fragmented ecosystems. The fragmentation of large river systems through the construction of dams and other structures along rivers alters river flows and has consequences for water quality parameters such as suspended sediments and sediment deposition.

III. GENERAL DESCRIPTION OF THE INDICATOR

9. Habitat fragmentation has been recognized as a major threat to ecosystems. Fragmentation is the subdivision of a habitat or land cover type either by a natural disturbance (e.g., fires, windthrows) or by human activities (e.g. roads, agriculture). Some researchers distinguish a variety of activities that can lead directly or indirectly to increase the fragmentation of habitat, such as the construction of roads, residential

^{3/} <http://www.unep.org/vitalwater/23.htm>

and commercial development, invasion of weed species, pollution, and changes in microclimatic conditions. ^{4/}

10. Fragmentation has a major impact on biodiversity, increasing isolation of habitats, endangering species of plants, mammals and birds, and modifying species' population dynamics. ^{5/} Fragmentation may have negative effects on species richness, ^{6/} by reducing the probability of successful dispersal and establishment ^{7/} as well as reducing the capacity of a patch of habitat to sustain a resident population. Moreover, fragments lose species because of the effects of fire and wind on forest edges, lack of mutualists, displacement of residents by weedy species, and by increasing the vulnerability of small populations to chance extinction. ^{8/} Those species susceptible to direct harvest by humans are more vulnerable in smaller, more accessible fragments or in larger parcels transected by new or improved roads. In the case of forest ecosystems, species diversity may be affected by the division of remaining forest cover into fragments. ^{9/}, ^{10/} Some threatened tree species are seriously affected by forest fragmentation. Populations of these species may decline owing to a decrease in seed production when the population size decreases and to the appearance of invasive species preventing recruitment. ^{11/}

11. However, the effects of habitat fragmentation on species diversity vary among different habitats and taxa. The ecological consequences of fragmentation can differ depending on the exact patterns or spatial configuration imposed on a landscape and how it changes both temporally and spatially. Pattern change is often accompanied by changes in the composition and persistence of species dependent on a particular habitat. ^{12/} The more subtle questions such as the permeability of different land cover types for individual species are too complex to be tackled in a national to global scale indicator, but should not be forgotten in landscape management.

12. Information on connectivity/fragmentation is available on a number of biomes, including in particular on forests and major river systems. In the case of forested habitats, interpretation of the patterns of forest cover change requires consideration of the distribution of forest types as well as the characteristics of forest species present and their ability to cope with fragmentation or deforestation. ^{13/} To quantify the spatial patterns of forest cover change, different spatial indices (or metrics) have been developed in the recent years. The main aspects that these attempt to capture are a loss of total habitat area, an increase of patch abundance and density, a decrease of patch size, a reduction in core area, and an increase in patch edges. ^{14/}, ^{15/}

^{4/} Lathrop, R., J. Bognar. 1998. Applying GIS and landscape ecological principles to evaluate land conservation alternatives. *Landscape and urban planning* 41: 27-41.

^{5/} Skole, D., C. Tucker. 1993. Tropical deforestation and habitat fragmentation in the Amazon: satellite data from 1978 to 1988. *Science* 260: 1905-1909.

^{6/} Iida, S., T. Nakashizuka. 1995. Forest fragmentation and its effect on species diversity in sub-urban coppice forests in Japan. *Forest Ecology & Management* 73: 197-210.

^{7/} Mace, G., A. Balmford, J. R. Ginsberg. 1998. *Conservation in a changing world*. Cambridge University Press, United Kingdom. 320 p.

^{8/} Brokaw, N. 1998. Fragments past, present and future. *TREE* 13: 382-383.

^{9/} Kapos, V., I. Lysenko, R. Lesslie. 2000. Assessing forest integrity and Naturalness in Relation to Biodiversity. *Global Forest Resources Assessment 2000*. UNEP-WCMC, FAO. 58 p.

^{10/} Hill, J. L., P. J. Curran. 2001. Species composition in fragmented forests: conservation implications of changing forest area. *Applied Geography* 21: 157-174.

^{11/} Gigord, L., F. Picot, J. Shykoff. 1999. Effects of habitat fragmentation on *Dombeya acutangula* (Sterculiaceae), a native tree on La Réunion (Indian Ocean). *Biological Conservation* 88: 43-51.

^{12/} Trani, M. K., R. H. Giles. 1999. An analysis of deforestation: metrics used to describe pattern change. *Forest Ecology & Management* 114: 459-470.

^{13/} Dale, V.H., S. M. Pearson. 1997. Quantifying habitat fragmentation due to land use change in Amazonia. In: Laurance, W., R. Bierregaard (eds.). *Tropical Forest Remnants*. The University of Chicago Press, Chicago, pp. 400-414.

^{14/} Franklin, S. 2001. *Remote Sensing for Sustainable Forest Management*. Lewis Publishers. USA. 407 p.

13. The current availability of forest cover datasets is sufficient to allow the assessment of forest fragmentation at global and country level. Therefore, fragmentation can be used as an indicator of ecosystem integrity for forests. A global estimate of forest fragmentation uses a methodology that could be applied to assess connectivity/fragmentation of forests and other ecosystem types (figure 1 above).

14. An assessment and mapping of forest fragmentation based on 1 km resolution land-cover maps for the globe has been conducted using a model that distinguishes different types of fragmentation. ^{16/} Only one of six biomes in Africa, and one of four in Europe were more than half connected forest (table 1). Relatively high proportions of interior forest were found in biomes in Africa and South America, and in all boreal biomes. Europe was particularly impacted by human fragmentation in all forest biomes. Africa was affected more by natural fragmentation in four of six biomes, but the area contained in three of these biomes as very small. Almost 50 per cent of South American tropical and subtropical moist broadleaf forest biome was interior forest, compared with only 16 per cent in Asia.

Table 1. Percentage of connected (C) and interior (I) forest pixels by continent and biome (see section V for additional technical details). (Wade et al. 2003) ^{17/}

Forest biome	Africa		Asia		Australia		Europe		N. America		S. America	
	C	I	C	I	C	I	C	I	C	I	C	I
Tropical & Subtropical Moist Broadleaf Forest	69.58	38.15	43.64	16.11	61.27	20.99	N/A	N/A	59.57	12.65	81.56	49.12
Tropical & Subtropical Dry Broadleaf Forest	28.15	2.01	18.58	2.47	46.89	3.77	N/A	N/A	60.26	19.83	60.02	23.70
Tropical & Subtropical Coniferous Forest	N/A	N/A	30.83	7.11	25.49	13.02	N/A	N/A	73.48	23.03	N/A	N/A
Temperate Broadleaf & Mixed Forest	35.65	0.00	38.08	12.32	65.29	27.53	17.02	2.02	64.77	27.06	74.98	26.79
Temperate Conifer For.	40.34	1.31	57.84	24.79	N/A	N/A	37.45	2.09	80.03	32.87	N/A	N/A
Boreal Forests/Taiga	N/A	N/A	85.95	48.52	N/A	N/A	83.03	43.26	74.75	41.77	N/A	N/A
Mediterranean	16.66	0.37	N/A	N/A	26.83	3.30	13.99	0.38	65.75	18.03	18.00	7.70
Mangroves	31.94	1.08	17.38	0.57	70.40	30.38	N/A	N/A	32.77	2.20	56.10	9.83

15. As similar analysis would have to be repeated to provide trends information. By analysing multitemporal land cover maps derived from satellite imagery, the spatial patterns of deforestation and fragmentation in southern Chile have been assessed. ^{18/} Figure 3 shows the decline in total core area of forest for an edge distance of 300 m. This reduction was associated with a division of large forest fragments due to urban expansion and agricultural clearance. During the study period, the largest

^{15/} McGarigal, K. 2002. Landscape pattern metrics. In: A. H. El-Shaarawi and W. W. Piegorsch, (eds.). Encyclopedia of Environmetrics Volume 2. John Wiley & Sons, Sussex, England. Pp. 1135-1142.

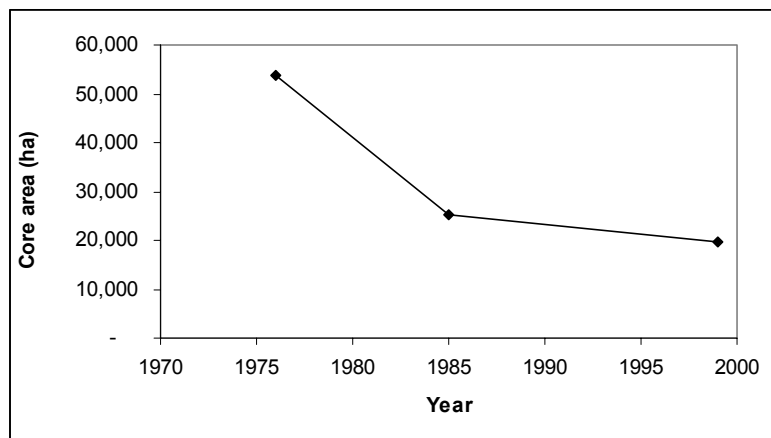
^{16/} Wade, T. G., K. H. Riitters, J. D. Wickham, and K. B. Jones. 2003. Distribution and causes of global forest fragmentation. Conservation Ecology 7(2): 7.

^{17/} For any combination of continent and biome, the sum of percentages may exceed 100% because connected forest includes interior forest by definition, and the sum may be less than 100% as not all forest is connected or interior.

^{18/} Echeverria, C. 2003. Deforestation and forest fragmentation of temperate forests in Chile. M. Phil. Thesis. University of Cambridge. 111 p.

undisturbed forest areas were affected by a rapid division that was associated with an increase in edge length. Similar trends are observed from other countries. ^{19/}

Figure 3. Variation in total core area in temperate forest in southern Chile. (from Echeverria 2003)



16. The management of freshwater through dams, levees, canals, and other infrastructure, has had predominantly negative impacts on the biodiversity of inland waters and coastal ecosystems, including fragmentation and destruction of habitat, loss of species and reduction of sediments destined for the coastal zone. Although the negative ecological consequences of large numbers of small dams may exceed those of large dams, reliable information is currently only available on the numbers of large dams. There are 45,000 large dams exceeding 15 metres in height and almost 40 per cent of the large river systems in the world are fragmented as a consequence of the construction of dams and other structures along rivers.

IV. POLICY RELEVANCE

17. In decision III/9 on the implementation of Articles 6 and 8 of the Convention, the Conference of the Parties considered fragmentation, along with species loss and habitat degradation, as factors that call for conservation, sustainable use and habitat restoration. In accordance with the operation guidance on the ecosystem approach, a number of programmes of work, including those on forest (decision VI/22), agricultural (decision VI/5), mountain biological diversity (decision VII/27) include activities to increase the understanding of the consequences of ecosystem and habitat fragmentation and to prevent and mitigate biodiversity losses due to fragmentation and conversion to other land uses.

18. The programme of work on protected areas (decision VII/28) seeks to mitigate ecosystem fragmentation through the establishment and maintenance of systems of protected areas and such tools as the creation of corridors. Its overall purpose is to support the establishment and maintenance of comprehensive, effectively managed, and ecologically representative national and regional systems of protected areas that collectively, *inter alia*, through a global network, contribute to achieving the three objectives of the Convention and the 2010 target.

19. To avoid unnecessary fragmentation of ecosystems and habitats is a key aspect of national and regional land use plans and other relevant instruments such as environmental impact assessment at the project and the strategic levels and cumulative impact assessment. ^{20/}

^{19/} For example: Imbernon, J.; Branthomme, A. 2001. Characterization of landscape patterns of deforestation in tropical rain forests. *International Journal of Remote Sensing* 22(9): 1753-1765.

^{20/} See also decision VI/7 A of the Conference of the Parties.

V. TECHNICAL INFORMATION

20. Different habitats have different natural levels of fragmentation. For example, forests in arid lands are naturally more patchy than tropical rain forests, and support species adapted to that level of patchiness. The indicator must therefore focus on changes in the level of fragmentation, rather than making the assumption that existing fragmentation levels are comparable across habitats.

21. To quantify the spatial patterns of forest cover change, different spatial indices (or metrics) have been developed in the recent years. The main aspects that these attempt to capture are a loss of total habitat area, an increase of patch abundance and density, a decrease of patch size, a reduction in core area, and an increase in patch edges. ^{21/} A few of the most generally applicable indicators are as follows:

(a) Patch density refers to the number of fragments per unit area as a basic measure of the fragmentation of large patches;

(b) The patch size distribution is a key component of ecosystem fragmentation, providing information on the progressive change through time in the size of ecosystem fragments;

(c) The length of edge between land uses is useful for assessing habitat availability for species that either prefer or avoid certain types of ecotones;

(d) Core metrics represent the interior area of patches after a user-specified edge buffer is eliminated. The edge buffer represents the distance at which the core or interior of a patch is unaffected by the edge of the patch, ^{22/} and hence requires ecosystem-specific information on edge effects. Core area integrates the effects of patch size, shape, and edge effect distance into a single measure and has been used as an indication of the extent of large forest patches in a landscape; ^{23/}

(e) In landscapes dominated by patches of a wide range of sizes, metrics such as mean patch size; or number of patches; might be more suitable to characterize temporal and spatial differences in landscape structure;

^{21/} Franklin, S. 2001. Remote Sensing for Sustainable Forest Management. Lewis Publishers. USA. 407 p.

^{22/} McGarigal, K. 2002. Landscape pattern metrics. In: A. H. El-Shaarawi and W. W. Piegorsch, (eds.). Encyclopedia of Environmetrics Volume 2. John Wiley & Sons, Sussex, England. Pp. 1135-1142.

^{23/} Wolter, P., M. White. 2002. Recent forest cover type transitions and landscape structural changes in northeast Minnesota, USA. Landscape ecology 17: 133-15.

(f) Connectivity refers to the functional connections among habitat patches (Rouget et al., 2003). The disruption of landscape connectivity may have substantial consequences for the distribution and persistence of species. ^{24/} A simple index of connectivity can be calculated as the relationship between the largest size patch and total area of a cover type. ^{25/}

22. An assessment and mapping of forest fragmentation based on 1 km resolution land-cover maps for the globe has been conducted using a model that distinguishes different types of fragmentation. ^{26/}, ^{27/} The fragmentation model is based on a “moving window” algorithm represented by a grid of 9 x 9 pixels (8,100 ha) in which two values are used to characterize a forest pixel at the centre of a moving window. The first is the proportion of forest in a window where the central pixel is forest (Pf); the second is the overall forest connectivity (Pff) and is the number of pixel pairs where both pixels are forest divided by the number of pixel pairs with at least one forest pixel. Total fragmentation was defined as the sum of natural (Pfa) and anthropogenic (Pfn) fragmentation, and the complement of overall forest connectivity. The forest connectivity index was summarized based on threshold values of 60 per cent (connected forest) and 100 per cent (interior forest) (see table 1 above). The proportion of connected forest in a biome is a general indicator of the degree of fragmentation, and the proportion that is interior forest indicates how much forest is relatively remote from other land cover types.

23. The model is scale-independent. However, it is important that decision makers apply it at a scale appropriate to the policy under development. Global assessments to monitor interior forest over time might be done using this technique. The size of the moving window should be adjusted according to the resolution of available land cover data, if country level assessments are required. It is suggested to complement this analysis with other indicators related to the changes in density, shape, size of forest patches. Expertise on geographic information system analysis is required to undertake fragmentation analyses.

24. The current availability of forest cover datasets is sufficient to allow the assessment of forest fragmentation at global and country level. Therefore, fragmentation can be used as an indicator of ecosystem integrity for forests. The applicability of the indicator to other terrestrial ecosystem types has been less well studied, but it seems transferable in principle.

VI. APPLICATION OF THE INDICATOR AT NATIONAL/REGIONAL LEVEL

25. As demonstrated through examples in sections III and V, the indicator can be applied at all scales from local to global. Data need to be available in a resolution appropriate for the task.

VII. SUGGESTIONS FOR THE IMPROVEMENT OF THE INDICATOR

26. There is a need for a broader understanding of the relationship between fragmentation and other indicators, e.g., extent of ecosystems, species population trends, change in threat status, alien invasions, ecosystem failure.

^{24/} Tischendorf, L., L. Fahrig. 2000. How should we measure landscape connectivity? *Landscape Ecology* 15: 633-641.

^{25/} Trani, M. K., R. H. Giles. 1999. An analysis of deforestation: metrics used to describe pattern change. *Forest Ecology & Management* 114: 459-470.

^{26/} Wade, T. G., K. H. Riitters, J. D. Wickham, and K. B. Jones. 2003. Distribution and causes of global forest fragmentation. *Conservation Ecology* 7(2): 7.

^{27/} Riitters, K., R. Wickham, R. O'Neill, B. Jones. E. Smith. 2000. Global-scale patterns of forest fragmentation. *Conservation Ecology* 4: 3.

27. A measure of habitat distribution by patch size is inexpensive to generate but the distinction between human-induced and natural fragmentation is more complex and time series information might need to be generated.

28. The usefulness and compatibility of information generated from ongoing wilderness mapping efforts (for example, by the Wildlife Conservation Society) for the indicator on connectivity/fragmentation of ecosystems should be examined.

29. Qualifications regarding the varying degrees of the impact of fragmentation on species (e.g. lower impact on smaller species; varying tolerance to fragmentation etc.) should be included.

30. The phenomenon of social fragmentation, i.e. the number of owners per area “parcellization” should be considered but requires different data sets.
