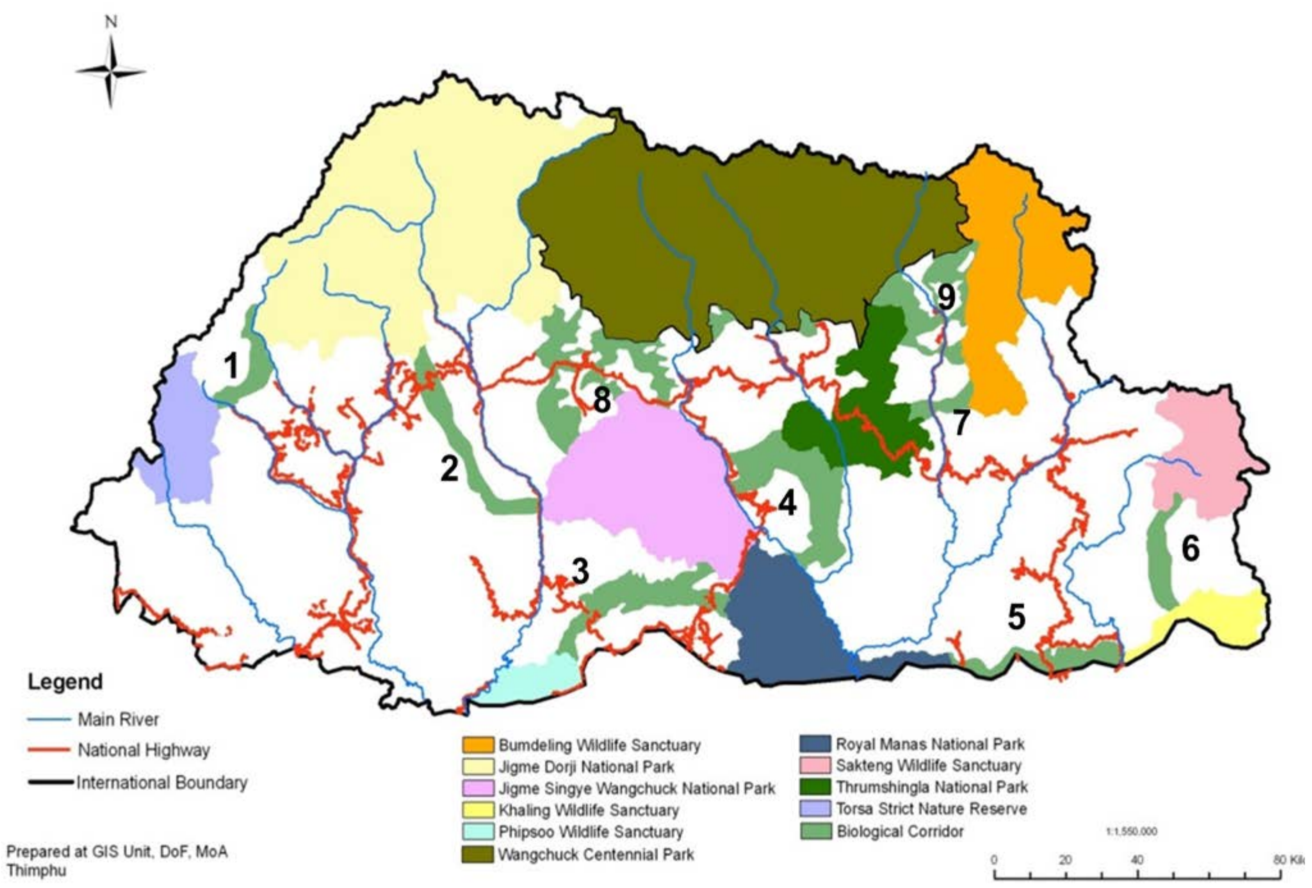
Regulatory Framework for Biological Corridors in Bhutan

Part III: Policy Recommendations and Framework for Developing Corridor Management Plans



Map of Protected Areas and Biological Corridors of Bhutan, 2009. The characteristics of the Biological Corridors are described in the Situation Review. Corridors were delineated in 1999. At that time Corridor 8 (3 strands) and 9 (3 strands) were part of a North Corridor Complex (almost as large as Corridors 1 through 7 combined); most of the North Corridor was subsumed into Wangchuck Centennial Park when that Park was established in 2008. The small corridor areas along the southern edge of Wangchuck Centennial NP are "orphaned" fragments of the former North Corridor.

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Preface

WWF-Bhutan and Nature Conservation Division (Department of Forest and Park Services, Ministry of Agriculture) commissioned this Framework because a functional network of connected protected areas is essential to conserve Bhutan's diverse natural communities and wildlife in the face of human development and climate change. This work was guided by input from 4 days of workshops involving about 103 participants (see Part I: Proceedings of regional consultation workshops) and an assessment of current conditions (see Part II: Situation Report).

Executive Summary

Corridors are a cost-effective, reliable strategy to conserve metapopulations of wide-ranging species, gene flow for all species, and allow species to adapt to climate change. Bhutan is a world leader in attempting to use corridors to create a durable network of protected areas. However, 11 years after the corridors were declared, they have not become operational conservation corridors on the ground. This Framework is intended to operationalize Bhutan's system of wildlife corridors and harmonize conservation of corridors with transportation and other land-uses. This Framework consists of two major sections: policy recommendations and a template for developing Corridor Management Plans for each corridor.

The major policy recommendations are (1) Recognize Biological Corridors as units of the Protected Area system. (2) Operationalize all Biological Corridors by January 1 2015, through development of a Corridor Management Plan for each corridor in collaboration among stakeholders. Although eventually each Biological Corridor should have its own staff, for the time being the Corridor Management Plan will be implemented by the Territorial Forest Divisions.

The Framework recommends a science-based, collaborative approach to developing each Corridor Management Plan within an 18-month time line. The first major step is to modify the 1999 corridor boundaries; this is especially important for corridors partially subsumed into Wangchuck Centennial Park in 2008. The Framework suggests how planners can consider focal species, climate change, connected river systems, and minimum widths in modifying the 1999 boundaries. A related step is to use

zonation procedures to harmonize various land uses and ensure corridor integrity. The Framework provides detailed guidelines for building roads and canals in Biological Corridors by using crossing structures integrated with fencing to minimize the impact of roads on corridor function. The Framework also provides less-detailed guidelines related to hydroelectric projects, electric transmission lines, managing human populations, reducing overgrazing and livestock-human conflicts, and Community Forests and Forest Management Units in Biological Corridors. The Framework also recommends how to devise a monitoring program for each Corridor Management Plan.

Introduction

Connectivity is the ability of a landscape to support plant and animal movement, including dispersal movements that can prevent extinction and allow recolonization after local extinction, gene flow, seasonal migration, and shift of a species' geographic range in response to climate change. Connectivity is not a property of a landscape alone, but rather is the result of an interaction between the landscape and each species needing to move across that landscape (Taylor 1993, Beier & Noss 1998). Around the world, human activities such as urbanization and roads have halted gene flow and other types of movement for plants, reptiles, mammals, and even some species of birds (e.g., Epps et al. 2005, Riley et al. 2009, Delaney et al. 2010). Thus there is an urgent need to conserve connectivity as landscapes develop.

Corridors are not the only way to conserve connectivity. Indeed, conserving natural conditions across the entire landscape is the best way to conserve connectivity, but corridors are the most practical compromise in landscapes that must also support human uses are desired.

Two major reviews (Beier & Noss. 1998. Conservation Biology 12:1241-1252., and Gilbert-Norton et al. 2010. Conservation Biology DOI: 10.1111/j.1523-1739.2010.01450.x) conclude that well-designed corridors do promote animal movement, and that corridors do not have negative impacts. Another study (Ford & Clevenger 2010. Conservation Biology *in press*) specifically showed that predators do not use bottlenecks in corridors to trap prey. In short, corridors are a cost-effective, reliable strategy to conserve metapopulations of wide-ranging species, gene flow for all species, and allow species to adapt to climate change.

Poorly-designed corridors – that is, corridors that are too narrow or that contain insufficient habitat for each focal species – will not support animal movement (e,g, Horskins et al. 2006). Corridors should be designed to serve the movement needs of several focal species, including habitat specialists and species with limited mobility. A corridor designed to serve only a high-mobile habitat generalist such as a large carnivore is not likely to meet the needs of habitat specialists and species with limited mobility.

In North America, the Yellowstone to Yukon corridor (Y2Y), the Algonquin to Adirondack corridor (A2A), California Essential Habitat Connectivity (2010), and Arizona Wildlife Linkage Assessment (2006) have produced coarse maps depicting areas where corridors should be designed. These maps have captured the imagination of managers and citizens, but have not by themselves conserved any corridors. Inspired by these regional visions, managers have achieved real corridor conservation by developing and implementing fine-scale corridor conservation plans. These plans consist of fine-scale maps and management guidelines for roads, human settlements, livestock, night lighting, fencing, and other human activities.

Bhutan is a world leader in attempting to use corridors to create a durable network of protected areas. However, 11 years after the corridors were declared, they have not become operational conservation corridors on the ground. This Framework is intended to operationalize Bhutan's system of wildlife corridors and harmonize conservation of corridors with transportation, other land-uses, and Bhutan's guiding philosophies of Gross National Happiness and the Middle Path. To achieve this, certain high-level policy changes are needed, and detailed Corridor Management Plans must be written. The purpose of this Framework is to recommend suitable policy changes and provide reasonably detailed, step-by-step guidelines for writing a Corridor Management Plan.

2. Policy Recommendations

The following recommendations flow from Part I: Proceedings (especially the Discussion section) and Part II: Situation Review. The rationale for each policy statement is briefly summarized here; please read the other two documents for detailed justifications.

1. Recognize Biological Corridors as units of the Protected Area system.

Rationale: Bhutan's Biological Corridors are an integral part of the protected area system, and essential to conservation of populations and gene flow of the system. Bhutan claims 51% of the nation is protected – this implies that Bhutan considers Biological Corridors part of the protected area network. The Protected Area complex is a network that cannot be conserved is a collection of islands, but must be managed as an interconnected network.

This policy does not mean that Biological Corridors would be "the same as" other protected areas. Instead, Biological Corridors are a different type of Protected Area than Strict Nature Reserves, National Parks, and Wildlife Sanctuaries, namely areas with the distinct goal of promoting movement and gene flow of plants & animals.

This policy also does not mean that rural livelihoods will be diminished by "taking away" land. Indeed, rural livelihoods have been enhanced in and adjacent to Bhutan's Protected Areas due to ICDPs, improved roads and water, new jobs, and alternative livelihoods. A recent study by Burton et al. in Science similarly showed throughout the developing world rural livelihoods were better near Protected Areas than away from them.

2. Operationalize all Biological Corridors by January 1 2015, through development of a Corridor Management Plan for each corridor in collaboration among stakeholders. Stakeholders will include affected geogs, electric utilities, road-building agencies, and other interests. Each Corridor Management Plan should be science-based to ensure that wildlife movement will be conserved, and will include a plan for monitoring and evaluation. Section 3 of this Framework describes procedures for developing each plan. Donor funding should be sought to carry out such operationalization.

3. The 2007 Rule states that Biological Corridors "will be managed centrally by the Department" while the accompanying Executive Order states that management will be "implemented by the Territorial Divisions." It is proposed that Biological Corridors be managed by corridor managers in the field and centrally coordinated by Nature Conservation Division. Because such staffing is unlikely to be approved by the Civil Service Commission given Parliament's directive for no net growth of government, and because there are not enough trained personnel to fill current conservation and forestry posts, the goal of staffing each Biological Corridor remains a long-term objective for the time being.

Rationale: Most corridors span multiple Territorial Forest Divisions and dzongkhags. Bhutan is decentralizing most management functions to the local level. One entity should be responsible for management, monitoring, and plan revision. If management is the job of all entities, it is the job of nobody.

4. The guidelines on Roads in Section 3.3 of this Framework should be adopted as policy without waiting for adjusting of corridor boundaries or writing Corridor Management Plans.

Rationale: Bhutan is starting an ambitious road-building program. It is much cheaper to build wildlife crossing structures when a road is first constructed than to retro-fit wildlife crossing structures after the road is built.

5. Amend F&NCR Chapter I.2(3) to read: Biological Corridor shall mean an area set aside to connect one or more Protected Areas for movement and gene flow by plants and animals.

Rationale: The existing language does not recognize the need for gene flow, and does not recognize that plants (in addition to animals) need connectivity.

6. Penalties for violations: Allow Department of Forests & Park Services and Nature Conservation Division to set penalties rather than embedding the amounts in the Act. Penalties should provide a meaningful deterrent, and should emphasize restoration of conditions harmed by the violation.

Rationale: If penalties are too harsh and inflexible, they will not be enforced at all. Restoration (undoing the violation) should be required where possible.

Note: This policy recommendation, and recommendation #7, would apply not only to Biological Corridors, but to all of Bhutan. The draft Bills being considered by Parliament in 2010 (Forest and Nature Conservation Bill; Protected Area and Wildlife Bill) emphasize restoration of damage, sets penalties that are 2 or 3 times the damage done, and allows the government to revise penalties from time to time.

7. NCD should consider issuing regulations to allow farmers to kill wild pigs and legally sell the pig meat. Snares and other indiscriminate methods of take should not be permitted.

Rationale: Such a change could reduce pig numbers, increase farmer income and food security, and promote tolerance of wildlife. About 80% of farmers interviewed in Corridor #2 supported this idea. The government already allows farmers to shoot pigs near farms; over the years the legal distance has increased to 200m, and may soon be increased to 500m. The main change recommended here would be to allow farmers to legally sell the pig meat.

3. Framework for Developing a Corridor Management Plan

3.1 Timeline and Roles of Stakeholders in developing the Plan

Time 0: Establish a Steering Committee consisting of representatives from Office of the Coordinator of Biological Corridors in Nature Conservation Division, staff of each Protected Area to be served by the corridor, and relevant Territorial Forest Divisions. Any hired consultant should meet regularly with this steering committee, which will make key decisions about work flow, meeting agendas, analytic steps, and document contents.

At this time, a Community Advisory Group should also be formed. The CAG should have representatives of affected geogs, dzonghkags, and agencies such as Bhutan Power Company, Department of Roads, Druk Green, DFDD, Livestock Division, conservation NGOs. The CAG will not be a standing group involved in management of the corridor, but will be convened solely to participate in developing the Corridor Management Plan. The CAG will meet 4 times as follows:

- 2 months. The CAG meets the persons charged to develop the plan. The plan developers present their work plan (previously vetted by the Steering Committee) for discussion, modification, and approval by the CAG. The CAG advises the planners of existing and proposed projects that may affect the Biological Corridor, such as Community Forests, wild resources needed by the community from the corridor area, Forest Management Units, roads, and other infrastructure. CAG members suggest focal species that should be considered.
- 6 months: Planners present key questions that arose during their work, and seek feedback from advisory group.
- 12 months: Planners present draft maps and

plans to the CAG prior to the meeting. CAG provides feedback at the meeting.

- 18 months: Rollout of Corridor Management Plan.

Two components of the Plan should be subject to Peer Review by two respected conservation biologists or planners who are independent of the planning team:

- The Work Plan should be sent to peer reviewers about 2 weeks prior to first Community Advisory Group Meeting, and reviewers should provide comments within 3 weeks, so that comments of both the CAG and peer reviewers can prompt timely changes in the Work Plan. The first work plan should be based closely on the suggestions in the rest of Section 3 of this Framework. After the first two Corridor Management Plans have been completed, NCD may issue a standard work plan to be used in all other Corridor Management Plans. Future peer review of the work plan would not be necessary.
- The Draft Corridor Management Plan should be sent to peer reviewers 6 weeks prior to rollout of the Plan.

The Steering Committee will participate in all CAG meetings and will supervise the peer review process to ensure that comments are considered.

3.2 Modify boundaries of the corridor and zone the corridor. Consider whether an additional corridor is needed in southwestern Bhutan.

As noted in Part II: Situation Report, some corridor boundaries need to be revised to (a) include more areas with gentle slopes, (b) allow more comprehensive planning, (c) expand bottlenecks, (d) compensate for Forest Management Units, Community Forests, and other changes that occurred since corridors were designated in 1999, (e) ensure the corridors can support metapopulations and gene flow for focal species that need multiple generations to move through the corridor, (f) perhaps reduce some corridors in light of the increased connectivity provided by the new Wangchuck Centennial Park, (g) make corridors more robust to climate change.

Some persons may fear that modifying corridor boundaries might disrupt Bhutan’s efforts since 1999 to conserve corridors. This is unlikely for several reasons.

1. None of the effort invested in corridors since 1999 would be rendered useless by a change in the boundary. For instance, no pillars or signage have been created to mark the boundary. The strategic operational principles adopted by NCD (2004), the lessons of the LINKPA program (Johnsingh and Norbu 2006), and the ongoing effort in Corridor 1 with the International Center for Integrated Mountain Development will readily transfer to corridors with modified boundaries.
2. The general locations of the corridors will not change (with the possible exception of cases described in 3.2.1). The 1999 corridors were positioned to minimize conflict with human uses. That was a good idea then, and it is a good idea today. Any radically different corridor location would run through landscapes heavily used by humans, which no new analysis will recommend.
3. The changes will probably cause a small net increase in the total area of all corridors. Although some corridors may be widened substantially along portions of the corridor, there may be opportunities to trim some of the parallel corridor strands in Corridor 8 (especially if it is planned in concert with Corridor 2) and in Corridor 9 (especially if it is planned in concert with Corridor 7).
4. If some corridor strands in the Corridor 2&8 complex and the Corridor 7&9 complex are consolidated, the amount of edge will decrease. This will reduce long-term management costs.

At the final workshop on 25 May 2010, three participants expressed strong opinions that an additional Biological Corridor should be designated in southwestern Bhutan, enhancing connectivity between Torsa SNR and Phipsoo WS, and from this region toward a tiger reserve in India. NCD should consider the need for a corridor in this region, and make appropriate recommendations to Parliament. If the government supports this concept, a Corridor Management Plan should be developed for the new corridor.

3.2.1 Consider Corridors 2 & 8 as one complex, and Corridors 7 & 9 as one complex, when considering boundary modifications.

With the creation of Wangchuck Centennial Park in 2008, the 3 northern Protected Areas (Wangchuck Centennial NP, Jigme Dorji NP and Bumdeling WS) create a fully connected block of habitat spanning Bhutan's northern border and even touching Thrumshingla NP. This new conservation landscape calls for a re-consideration of four corridors, and this reconsideration should consider those four corridors as two units for planning purposes.

1. Corridors 2 and 8. These two corridors include four strands leading northward from Jigme Singye NP toward Wangchuck-Jigme Dorji Parks. Although redundant corridors are a good strategy to avoid wagering all connectivity on a single corridor, some consolidation of these four strands may be warranted.
2. Corridors 7 and 9. These corridors provide four strands connecting among Bomdeling WS, Thrumshingla NP, and Wangchuck Centennial Park. More than one strand may be wise – for instance if one strand provides continuity for species needing alpine continuity and another strand serves lowland species. But it is likely that a new analysis would suggest reducing the number of strands, and perhaps changing their location.

Focal species (section 3.2.2) and topographic diversity (3.2.3) should be considered within each of these two large regions to create the new corridor boundaries.

The Map (front cover) depicts several small corridor areas along the southern edge of Wangchuck Centennial NP. These fragments were "orphaned" when Wangchuck Centennial NP subsumed the former North Corridor. NCD should consider needs of focal species and make a recommendation either to add some or all of these areas to Wangchuck Centennial NP or drop them from the system of Protected Areas and Biological Corridors.

3.2.2 Using focal species to delineate boundaries

Boundaries should be set to meet the needs of focal species (this section) and to provide continuity of topographic elements (section 3.2.3). Most focal species will be mammals but reptiles, fishes, amphibians, plants, and invertebrates may also be appropriate focal species. Lambeck (1997) introduced the focal species concept, and explained how these species can be identified. The primary consideration should be to develop a group of focal species that collectively provide an "umbrella" for all native species. In other words, if the corridor meets the needs of the focal species, it will probably provide movement for all species.

Because large carnivores like tigers, dholes, and bears live at low density and are among the first to be harmed by loss of connectivity, they are appropriate focal species for corridor design (Beier 1993; Servheen et al. 2001; Singleton et al. 2002). They also make popular flagship species to increase stakeholder support for linkage conservation. Nonetheless, a linkage should not be designed solely for large carnivores, or any single species. Many species need linkages to maintain genetic diversity and metapopulation stability. Furthermore, most large carnivores are habitat generalists that can move through marginal and degraded habitats, and a corridor designed for them does not serve most habitat specialists with limited mobility (Beier et al. 2009). The umbrella effect of large carnivores best serves biodiversity if these species are part of a corridor designed for a broad array of native species.

Planners should ask managers and biologists familiar with the area to suggest focal species. A good suite of focal species would include species in each of several categories; one species may qualify in more than one category:

- *Area-sensitive species:* species with large home ranges or requiring long-distance dispersal for metapopulation persistence (e.g., tiger, bear, takin). These species will be the first to disappear or become ecologically trivial when linkages are severed.
- *Barrier-sensitive species:* species most reluctant to traverse roads, fences, canals, urban areas, and other barriers in the planning area.
- *Less mobile species:* species whose mobility is limited due to extreme habitat specialization, small home range, or short dispersal movements. These species will often be corridor-dwellers (Beier and Loe 1992)—that is, they will require multiple generations to move their genes between Parks or Wildlife Sanctuaries.
- *Habitat specialists:* species strongly associated with a major vegetation type or topographic element in the area.
- *Non-flying migratory populations:* Seasonal migration is crucial for some mammals. Although some birds and flying invertebrates also migrate, they typically can fly for tens or hundreds of miles across unsuitable habitat, so their migration is unlikely to be affected by the corridor.

Beier et al. (2008) describe quantitative, GIS-based procedures to design corridors for focal species, and provide ArcGIS 9 tools based on least-cost modeling at www.corridordesign.org. Quantitative procedures have scientific and political advantages. Scientifically, these procedures can be updated as new information becomes available, and sometimes they suggest a good corridor configuration that was not obvious based on expert opinion. However, few species in Bhutan have been studied well enough to parameterize least-cost models, and the time and expense needed to develop species models and conduct the analyses may outweigh the scientific benefits. Politically, quantitative procedures provide a transparent and defensible rationale that can overcome objections by skeptics and opponents. Given the broad political support for conservation in Bhutan, the political benefit of quantitative analysis may be small.

Regardless of whether expert opinion or quantitative GIS procedures are used, the Corridor Management Plan should list the focal species considered, and explain how the corridor will serve the needs of each species. The Corridor Management Plan should include maps of known or modeled populations of each focal species. Assumptions underlying models should be stated clearly. Planners should bear in mind that future generations will judge the success of the plan based on how well it serves these species. Planners should pay particular attention to the need for habitat patches that are large enough to support viable populations and close enough together to allow for inter-patch dispersal for species that require multiple generations to traverse the linkage. For such species, the linkage must support a collection of breeding patches separated by distances within the dispersal range of the species, such that movement and gene flow can occur in steppingstone fashion over several generations.

3.2.3 Using topographic diversity to modify corridor boundaries to be robust to climate change

Climate change has arrived. During the past century, the earth's temperatures have warmed faster than at any other time within the past 650,000 years, and mountain snowpack is melting earlier in the spring season (Moser et al. 2009). The future will almost certainly bring increased winter rainfall (and less snow), earlier spring runoff, and increased frequency of extreme storm events. In the context of corridor design, the most important finding is that the geographic ranges of many plants and animals will shift. Range shifts of tens to hundred of km poleward and toward higher elevations have already been documented (Parmesan et al. 2005).

Adaptation to climate change is necessary. Even under the most optimistic scenarios of emissions and carbon sequestration programs, past emissions will drive temperature and precipitation changes for at least 50 years (IPCC 2001). Fossil evidence shows that extensive shifts in "species' geographical ranges have been the most important response of biota to past large, rapid climatic changes" (Huntley 2005:121). Managers must start planning to support future range shifts by plants and animals (Lovejoy and Hannah 2005, Hannah et al. 2002).

Expanding protected areas and establishing biological corridors are the most effective adaptation strategies to support range shifts and conserve biodiversity during climate change (Lovejoy and Hannah 2005, Hannah and Hansen 2005, Heller and Zavaleta 2009).

Williams et al. (2005) and Phillips et al. (2008) attempted to design corridors by modeling climate change, modeling species response to climate change, and identifying corridors that would support range shift by focal species. Unfortunately, these models are expensive and time consuming, and they produce such unreliable results that Overpeck et al. (2005:99) concluded that the "lesson for conservationists is not to put too much faith in simulations of future regional climate change" in designing robust conservation strategies.

A simple and inexpensive alternative way to design corridors to facilitate range shift is to ensure that the corridor has continuous strands of each of several "land facets." A land facet is a recurring area with relatively uniform topographic and soil attributes (Wessels et al. 1999). Examples of land facets would be "South-facing ridges with thin rocky soils" or "Valley bottoms with thick moist soils." Each land facet is likely to support distinct groups of plants and animals. Hunter et al. (1988:380) first suggested that such landscape units would be useful in conservation planning, when they wrote "we advocate basing the coarse-filter approach on physical environments as 'arenas' of biological activity, rather than on… the temporary occupants of those arenas." However, the idea is much older than that, and is grounded in the life zone concept of C. Hart Merriam (1890) and in the state-factor model of ecosystems (Jenny 1941). The approach is also supported by the new focus on conserving the ecological and evolutionary processes that maintain and generate biodiversity (Cowling et al. 1999, Noss 2001, Moritz 2002, Cowling et al. 2003, Rouget et al. 2006, Pressey et al. 2007, Klein et al. 2009). Beier and Brost (2010) present the conceptual basis of the land facet approach to corridor design.

Quantitative, GIS-based procedures for land facets have the same scientific and political advantages and limitations discussed in Section 3.2.2 with respect to modeling corridors for focal species.

An additional difficulty in quantitative modeling is the lack of good soil maps. In light of this lack, the developers of Corridor Management Plans can reasonably use simple GIS procedures to

- identify land facets based solely on 4 topographic variables that can be computed from freely-available digital elevation models. The important variables are topographic position (ridge, slope, valley), expected annual solar insolation (a function of latitude, aspect, slope, and shading by adjacent topography), elevation, and slope.
- examine the resulting maps to determine if every regionally important land facet is well-represented and reasonably continuous throughout the corridor
- modify the boundary to increase inclusion of poorly-represented facets.

Such analyses can be done quickly using free digital elevation data. ArcGIS 9.3 tools to design corridors based on land facets are available for free download at www.corridordesign.org. The Department of Forests has well-trained GIS staff who can do the work.

3.2.4 Riverine Connectivity

Valley bottoms are natural travel routes for many wildlife species, and rivers and streams provide riparian vegetation and water that are the only habitats used by some species. Thus the corridor should provide continuity of rivers and streams. Unfortunately, rivers, streams, and valley bottoms are also favored locations for farms, cities, highways, canals, hydroelectric plants and other human land uses that are incompatible with use or travel by some species of wildlife. Quite likely all of the 1999 corridors provide less-than-optimal riverine connectivity.

In revising the corridor boundaries, planners should examine maps of the river systems and attempt to improve riverine connectivity. No special GIS or quantitative procedures are needed. As in 1999, compromises with human land uses will doubtless occur. The Corridor Management Plan should describe and justify these compromises.

This planning step could logically have been included with the procedures in 3.2.3, but rivers and riparian areas are so important that they justify special consideration. This consideration would take only a few hours, and will add to the credibility and honesty of the Corridor Management Plan.

3.2.5 Minimum width

The question of minimum width should not be posed as "How narrow a corridor might possibly be useful to the focal species?" This would be analogous to asking an engineer "What are the fewest number of rivets that might keep this wing on the airplane?" Planners should reframe the question as "What is the narrowest width that is not likely to be regretted after the adjacent area is converted to human uses?"

Chokepoints or bottlenecks can prevent movement and gene flow through a corridor. To avoid this problem, a minimum width should be imposed on the corridor. The minimum should be at least wide enough to provide live-in habitat for species that need more than one generation to move through the corridor. Harrison (1992) proposed a minimum as the width of one individual's home range (assuming home range width is half its length). Thus, a minimum corridor width of 1 km would accommodate home ranges of up to about 2 km^2, which is larger than home ranges of most reptiles, amphibians, and small mammals, and a width of 2-3 km might serve larger species such as tigers, bears, and deer.

Edge effects are another reason to impose a minimum width. Edge effects arise from pets and livestock, artificial night lighting, noise, nest predation, nest parasitism, and invasive species. In North American, negative edge effects are biologically significant at distances of up to 300 m (25 studies summarized by Environmental Law Institute [2003]), so a corridor only 1 km wide would have only a 400-m swath free of edge effects. Given that rural Bhutanese graze livestock and gather forest products more intensively than most rural North Americans, edge effects probably persist at least 300m in Bhutan.

In addition, wide linkages are beneficial because they (a) provide for metapopulations of linkage-dwelling species (including those not used as focal species), (b) reduce pollution into aquatic linkages, and (c) help plants and animals shift their ranges in response to climate change.

In light of the above, the corridor should be 3 km wide along most of its length, and a minimum of 2 km wide, with less than 10% of the length of the corridor in bottlenecks narrower than 2 km. Previous steps to consider needs of focal species, continuity of land facets, and riverine connectivity will probably achieve this minimum width for most of the corridor.

Next, planners should obtain or create maps depicting existing and proposed Community Forests, Forest Management Units, villages, households, roads, and other potential barriers. For existing barriers, planners should widen or shift the corridor design where possible, and point out opportunities for habitat restoration or project mitigation. In this phase of planning, planners should not assume that every proposed development will occur. In particular, if a proposed development would severely compromise the corridor, the strategy of non-negotiable principles (NCD 2004) mandates that planners should vigorously point out the impropriety of the proposal. In other cases, the proposed development may be harmonized with the corridor through mitigations to the project, or by widening or shifting the corridor design.

To achieve the minimum width, in some cases planners will have to include villages or Forest Management Units in the corridor. By including such areas in the multiple-use zone, planners create an opportunity to manage human uses compatibly with the corridor, and minimize chokepoints. The Corridor Management Plan should include a description of chokepoints (see 3.2.6), and outline plans to mitigate their impacts on the corridor.

3.2.6 Field Assessment of barriers and chokepoints

Before corridor boundaries are assessed, planners should conduct field visits to assess of potential chokepoints and barriers, including villages, dams, roads, Forest Management Units, and other conditions that may affect whether the preliminary boundaries are appropriate. The results of the field survey should be used (a) to modify the corridor design, (b) to inform a description of remaining chokepoints and barriers in the Corridor Management Plan, and (c) to identify opportunities for habitat restoration and barrier mitigation.

Major roads and canals will present the most formidable potential barriers, so they should be evaluated in detail. This would include characterizing existing structures, such as bridges or culverts that may accommodate wildlife crossings. Although most such structures were initially built to accommodate streamflow, research and monitoring have confirmed that these structures can facilitate wildlife movement. Therefore, all existing structures (e.g., bridge, underpass, overpass, culvert, pipe) should be photo-documented and the following data collected: shape; height, width, and length of the passageway; floor type (metal, dirt, concrete, natural); passageway construction (concrete, metal, other); visibility to other side; light level; and vegetative cover within and near the passageway. Field biologists should also record their impression of current and potential levels of animal movement at all potential barriers and crossing structures.

Wildlife trails, pug marks, or droppings, or stream crossings can indicate areas where crossing structures could be installed. Such opportunities should be described, and each important location should be recorded with a Global Positioning System (GPS) device.

Field biologists should also identify other habitat restoration needs and opportunities, such as removing barriers to stream flow or removing large patches of invasive plants. Existing urban and rural development, mining operations that may impede the utility of the linkage should be described and geo-referenced.

Finally, field workers should note natural landmarks that can provide natural “boundary pillars” or reference points for Section 3.2.7.

3.2.7 Modify boundaries

Finally, the corridor boundaries should be modified to conform to major natural features such as ridgelines. This will help planners describe the corridor boundary to local residents. The plan should require signs to mark where each road and trail enters the corridor, and should describe other strategies to mark and publicize the boundary. Where the boundary must be shifted to a natural feature, it is better to expand the corridor slightly than to narrow it substantially below the minimum width.

> ***Enable rather than constrain***
>
> Roads and most human uses will be prohibited in core zones. However, an outright prohibition on roads (or hydroelectric project, or other human uses) in the corridor would be at odds with Bhutan's legitimate policies to expand the nation's infrastructure. Therefore, Sections 3.3 through 3.8 try to harmonize mandates by setting out guidelines that will allow such activities to proceed with minimal impact to wildlife movement. In this way, each Corridor Management Plan can emphasize enabling over constraining. Large blocks of text from each of these Sections can be modified and inserted into each Corridor Management Plan.

3.2.8 Zonation

The Corridor Management Plan should include a description of the planning area, including human population density, dominant land uses, economic and social conditions, Tshar Gyam Consultants (2004) and Johnsingh and Norbu (2006) provide an example of such data for Corridor #4.

With these data in hand, and in consultation with local community leaders, planners should develop a map of zones within the corridor. Zones should include

- core zones in which no livestock grazing or human uses except regulated research and monitoring may occur. If possible, the core zone should from a continuous swath between the larger protected areas, but in some areas it may be necessary to map disjunct "mini-cores" to serve as steppingstones for animals to move between the parks as suggested by Johnsingh & Norbu (2006). To create such steppingstones, the planner should examine maps of habitat patches (known or modeled) for focal species. Planners should work with the local population to identify alternatives for undesirable current uses in the provisional core zone.
- multiple-use zones, including Community Forests, Forest Management Units, villages, and farms. There may be several types of multiple-use zones depending on the anticipated uses. No new settlements or in-migration should be allowed (but a household should be permitted to subdivide its holdings and rebuild their home).
- a buffer zone up to 5 km wide immediately outside the corridor, conforming to natural boundaries such as rivers and ridgelines. The purpose of the buffer is to provide an extra layer of protection for ecosystems in the corridor and to help manage edge effects. Most traditional land uses will be permitted in the buffer zone, but measures will reduce unwanted spillover into the corridor. Educational programs, ICDPs, and related efforts should be targeted at people in the buffer zone as well as in the corridor.

For each zone type, the Plan should state permitted and prohibited activities. Bomdeling WS is one of the few Protected Areas to write a zonation plan. That plan can be used as a guide for future zonation.

3.3 Harmonizing road-building and canal-building with the corridor

This section covers highways, other paved roads, farm roads, and water-conveyance structures such as canals that convey water for irrigation or hydropower plants. Although most of this section focuses explicitly on roads, many of the same principles apply to canals, which can be an even greater barrier to animal movement than a major highway (Peris and Morales 2004, Rautenstrauch and Krausman 1989). This section focuses especially on crossing structures, which can be highly effective measures for mitigation.

Highways exist or are planned to cross every Biological Corridor except Corridor #1. Environmentally-friendly road construction techniques were introduced to Bhutan in 1999 by the Rural Access Project I, and has since been used only in externally-funded highway projects. The representatives of Bhutan Department of Roads who participated in the March 2010 workshops were receptive to expanding these practices to include steps to make highways and roads permeable for wildlife. They would welcome training in such mitigation measures, and the Department would need funding to implement the projects.

Table. The ecological effects of roads vary with species traits. (from Forman et al. 2003)

Characteristics making a species vulnerable to road effects	**Effect of roads**		
	Road mortality	**Habitat loss**	**Reduced connectivity**
Attraction to road habitat	★		
High intrinsic mobility	★		
Habitat generalist	★		
Multiple-resource needs	★		★
Large area requirement/low density	★	★	★
Low reproductive rate	★	★	★
Behavioral avoidance of roads			★

The physical footprint of roads is considerable. For example, a single expressway (typical width = 50 m, including median and shoulder) crossing diagonally across a 1x1-km section of land results in the loss of 4.4% of habitat area for any species that cannot live in the right-of-way. But the *ecological* footprint of the road network is much larger (see Table). Direct ecological effects of roads include road mortality, habitat fragmentation and loss, and reduced connectivity, and the severity of these effects depends on the characteristics of a given species. Direct roadkill affects most species, with severe documented impacts on wide-ranging predators. In a 4-year study in Arizona, Rosen and Lowe (1994) found an average of at least 22.5 snakes per km per year killed due to vehicle collisions. Roads cause habitat fragmentation because they break large habitat areas into smaller habitat patches that support fewer individuals, which can increase loss of genetic diversity and risk of local extinction. Additionally, roads may prevent access to essential physical or biological features necessary for breeding, feeding, or sheltering.

In addition to these obvious effects, noise from traffic or road construction may alter habitat use and activity patterns, increase stress, reduce reproductive success, and increase predation risk for terrestrial vertebrates (Bowles 1995, Larkin et al. 1996). Roads also increase the spread of exotic plants and animals, promote erosion, create barriers to fish, and pollute water sources with roadway chemicals (Forman et al. 2003). Recent studies demonstrate that vehicles deposit 300 to 800 exotic seeds per square meter per year to roadside areas, often from several kilometers away (von der Lippe and Kowarik 2007). Highway lighting also has important adverse impacts on animals (Rich and Longcore 2006).

The environmental effect analysis for any highway project should consider habitat fragmentation, loss of habitat connectivity, effects on designated critical habitats, and direct or indirect effects to wild animals and plants (Forman and Alexander 1998), as well as dangers to humans due to vehicle-wildlife collisions. Meese et al. (2009) provide guidance on data collection and impact assessment to help evaluate where avoidance, minimization, or mitigation for road projects should occur.

Where to locate crossing structures

In locations where a road crosses a Protected Area or Biological Corridor, the strongest enhancement and mitigation measures should be used. Protected status represents a significant public investment and commitment to ecological integrity, and roads should not compromise that investment. In contrast, it may or may not be appropriate to fully mitigate an existing or proposed road outside a Protected Area, depending on intended future land use.

Planners can select locations of crossing structures using some combination of:

- Field data such as road kill, wildlife tracks or trails, locations of radio-tagged animals, or repeated observations of wildlife.
- Modeled wildlife corridors. Ideally, these models should be parameterized using field data collected in or near the linkage area.
- Places where streams or drainages cross roads. Many animals use valley bottoms as travel routes or for water, thick cover, or food that occurs in riparian areas. Structures are usually needed in these locations to prevent water from damaging the road. For such structures to be useful for wildlife, the bridge must be long enough to include some vegetation above the scour zone and high water line.

Types of Crossing Structures

The Wildlife Crossings Guidance Manual (Meese et al. 2009) provides detailed guidance, specific to particular groups of wildlife, regarding crossing structures, fencing, median barriers, signs, lighting, speed bumps, vegetation management, animal detection systems, and animal escape devices. The Wildlife Crossings Guidance Manual addresses both modification of existing highways and design of new roads. Clevenger and Huijser (2009) provide thorough, well-illustrated technical guidelines for the planning, design and evaluation of wildlife crossing structures and associated fencing and gates to facilitate road-crossing for particular species and species groups in different landscapes. The Wildlife and Roads website of the Transportation Research Board (http://www.wildlifeandroads.org/) offers a decision tree for transportation planners and examples of successful mitigations, and provides links to other helpful documents and websites. In this section, we draw on these documents and other literature to provide general guidance for enhancing wildlife connectivity across roads.

Wildlife crossing structures, integrated with roadside fencing, can facilitate wildlife movement across roads. These structures include wildlife overpasses, underpasses, bridges, and culverts. Although many of these structures were not originally constructed with ecological connectivity in mind, many species use them (Clevenger et al. 2001; Forman et al. 2003). No single crossing structure will allow all species to cross a road. For example rodents prefer to use small culverts, while deer prefer vegetated overpasses or open terrain below high bridges. A concrete box culvert may be readily accepted by a large carnivore, but not by a deer (Clevenger and Waltho 2005). Small mammals, such as rodents, prefer small culverts to wildlife overpasses (McDonald and St Clair 2004). Some mammals avoid crossing two-lane roads, even when traffic is as low as 100 vehicles per day (McGregor et al. 2008); thus crossing structures may be needed even on lightly-used small roads.

Wildlife overpasses are most often designed to improve opportunities for large mammals to cross busy highways. As of 2003, about 50 overpasses had been built in the world, but these numbers are increasing dramatically. Overpasses are typically 30 to 50 m wide, but can be as wide as 200 m. Overpasses are readily used by large mammals in Europe (van Wieren and Worm 2001) and North America (Clevenger and Waltho 2005).

Wildlife underpasses include viaducts, bridges, culverts, and pipes, and are often designed to ensure adequate drainage beneath highways. Bridged crossing structures (where the road is supported on piers or abutments above a watercourse) differ from culverts (a round or rectangular tube under a road) in several ways. The most important difference is that the streambed under a bridge is mostly native rock and soil (instead of concrete or corrugated metal in a culvert) and the area under the bridge is large enough that a semblance of a natural stream channel returns a few years after construction. Even when rip-rap or other scour protection is installed to protect bridge piers or abutments, stream morphology and hydrology usually return to near-natural conditions in bridged streams, and vegetation often grows under bridges. In contrast, vegetation does not grow inside a culvert, and hydrology and stream morphology are permanently altered not only within the culvert, but for some distance upstream and downstream from it.

Bridged underpasses are best for deer and other animals that prefer open crossing structures, and tall, wide bridges are best. Deer avoid small underpasses, and only use underpasses under large spanning bridges (Ng et al. 2004). The average size of underpasses used by deer in Pennsylvania was 15 ft (4.6 m) wide by 8 ft (2.4 m) high (Brudin 2003). Because most small mammals, amphibians, reptiles, and insects need vegetative cover for security, bridged undercrossings should extend to uplands beyond the scour zone of the stream, and should be high enough to allow enough light for vegetation to grow underneath. In the Netherlands, rows of stumps or branches under crossing structures increased connectivity for smaller species crossing floodplains under bridges (Forman et al. 2003). Black bear and mountain lion prefer less-open structures (Clevenger and Waltho 2005).

Culverts, if well-designed and located, can be an excellent way to mitigate the effects of roads for small and medium sized mammals (Clevenger et al. 2001; McDonald and St Clair 2004). Pipe culverts and concrete box culverts are used by many species, including rodents, shrews, foxes, rabbits, armadillos, river otters, opossums, raccoons, ground squirrels, skunks, coyotes, bobcats, mountain lions, black bear, great blue heron, long-tailed weasel, amphibians, lizards, snakes, and southern leopard frogs (Yanes et al. 1995, Brudin 2003, Dodd et al. 2004, Ng et al. 2004). Black bear and mountain lion prefer less open structures; large culverts can provide connectivity for these species (Clevenger and Waltho 2005). In south Texas, bobcats often used 1.85-m x 1.85-m box culverts to cross highways and preferred structures near suitable scrub habitat (Cain et al. 2003).

Culvert usage can be enhanced by providing a natural substrate bottom, and in locations where the floor of a culvert is persistently covered with water, a ledge established above water level can provide terrestrial species with a dry path through the structure (Cain et al. 2003). It is important that both ends of the culvert be flush with the surrounding terrain so that animals can easily enter and exit. When culverts are built solely to accommodate peak flows, the upper ends are often partway up the fill slope, far above the natural stream bottom, and the lower ends either have a concrete pour-off of 8-12 inches (20 cm – 30 cm) or develop a pour-off lip due to scouring action of water. A pour-off of several inches makes it unlikely that many small mammals, snakes, and amphibians will find or use the culvert.

Based on the increasing number of scientific studies on wildlife use of crossing structures, these guidelines for crossing structures should facilitate wildlife passage across roads and canals:

1. Multiple types of crossing structures should be constructed and maintained to provide connectivity for all species likely to use a given area (Little 2003). Different species prefer different types of structures (Clevenger et al. 2001; McDonald and St Clair 2004; Clevenger and Waltho 2005; Mata et al. 2005). For deer, an open structure such as a bridge is crucial. For medium-sized mammals, black bear, and wild cats, large box culverts with natural earthen substrate flooring are optimal (Evink 2002). For small mammals, pipe culverts with a diameter between 1 and 3 feet (0.3 and 0.9 meters) are preferable (Clevenger et al. 2001; McDonald and St Clair 2004).

2. Crossing structures should be spaced based on home range size of species to be accommodated. Because most reptiles, small mammals, and amphibians have small home ranges, metal or cement box culverts should be installed at intervals of 150-300 m (Clevenger et al. 2001). For ungulates (deer) and large carnivores, larger crossing structures such as bridges, viaducts, or overpasses should be located no more than 1.5 km apart (Mata et al. 2005; Clevenger and Wierzchowski 2006). Inadequate size and insufficient number of crossings are the two primary causes of poor use by wildlife (Ruediger 2001).

3. Suitable habitat for species should occur on both sides of the crossing structure (Ruediger 2001; Barnum 2003; Cain et al. 2003; Ng et al. 2004). This guideline applies to both local and landscape scales. On a local scale, vegetative cover should be present near entrances to give animals security, and reduce negative effects of lighting and noise (Clevenger et al. 2001; McDonald and St Clair 2004). A lack of suitable habitat adjacent to culverts originally built for hydrologic function may prevent their use as potential wildlife crossing structures (Cain et al. 2003). On the landscape scale, "crossing structures will only be as effective as the land and resource management strategies around them" (Clevenger et al. 2005). Suitable habitat must be present throughout the linkage for animals to use a crossing structure.

4. Suitable habitat should occur *within* the large crossing structures. This recommendation can best be achieved by having a bridge high enough to allow sufficient light for vegetation to grow under the bridge, and by making sure that the bridge spans some upland habitat that is not regularly scoured by floods. Where this is not possible, rows of stumps or branches under large span bridges can provide cover for smaller animals such as reptiles, amphibians, rodents, and invertebrates, although regular maintenance is required to replace artificial cover removed by floods. Within culverts, mammals and reptiles prefer earthen to concrete or metal floors.

5. Structures should be monitored for, and cleared of, obstructions such as detritus or silt blockages that impede movement. Small mammals, carnivores, and reptiles avoid crossing structures with significant detritus blockages (Yanes et al. 1995; Cain et al. 2003; Dodd et al. 2004). In southern California and Arizona, over half of box culverts less than 8 x 8 ft (2.4 m x 2.4 m) have large accumulations of branches, sand, or garbage that impede animal movement (PB, personal observation). Bridged undercrossings rarely have similar problems.

6. Fencing should keep animals off the road and direct them towards crossing structures, and should never block entrances to crossing structures (Yanes et al. 1995, Gagnon et al. 2007). In Florida, construction of a barrier wall to guide animals into a culvert system resulted in 93.5% reduction in roadkill, and also increased the total number of species using the culvert from 28 to 42 (Dodd et al. 2004). Fences, guard rails, and embankments at least 2 m high discourage animals from crossing roads (Barnum 2003; Cain et al. 2003; Malo et al. 2004). One-way ramps on roadside fencing can allow an animal to escape if it is trapped on a road (Forman et al. 2003). In Jigme Dorji NP, takin used "ladder steps" cut into steep cut slopes to excape from the highway.

Because of the low traffic levels on Bhutan's highways, fencing can be deferred for several years until traffic levels increase. Fencing will eventually be needed on all national roads in Protected Areas, but may not be needed on Park roads.

7. Raised sections of road discourage animals from crossing roads, and should be used when possible to encourage animals to use crossing structures. Clevenger et al. (2003) found that vertebrates were 93% less susceptible to road-kills on sections of road raised on embankments, compared to road segments at the natural grade of the surrounding terrain. This guideline is most useful in flat terrain, and thus applies to a small portion of Bhutan.

8. Manage human activity near each crossing structure. Clevenger and Waltho (2000) suggest that human use of crossing structures should be restricted and foot trails relocated away from structures intended for wildlife movement. However, a large crossing structure (a long, high bridge) should be able to accommodate both recreational and wildlife use. Furthermore, if recreational users are educated to maintain utility of the structure for wildlife, they can be allies in conserving wildlife corridors.

9. Design crossing structures specifically to provide for animal movement. Because traffic noise within an undercrossing can discourage passage by wildlife, new, quieter designs are needed to minimize vehicle noise in underpasses (Gagnon et al. 2007). Ungulates prefer undercrossings with sloped earthen sides to vertical concrete sides (Dodd et al. 2007). High openness ratio (height x width divided by length) promotes animal travel. Perhaps the best way to achieve this open ratio is to minimize the distance an animal must travel within the structure (Dodd et al. 2007). Most culverts are designed to carry water under a road and minimize erosion hazard to the road. Culvert designs adequate for transporting water often have pour-offs at the downstream ends that prevent wildlife usage. At least one culvert every 150-300 m of road should have both upstream and downstream openings flush with the surrounding terrain, and with native landcover up to both culvert openings, as noted above.

10. Consider climate change in the design of crossing structures. During the last century, extreme storm events have become more frequent, and climate change will accelerate this trend in the future (IPCC 2001, Moser et al. 2009). Therefore crossing structures should be built to accommodate flows exceeding historic floods. Bridge spans should be long enough to span some upland habitat that will not be scoured by future floods. Finally, crossing structures to accommodate large mammals should be built even in Biological Corridors where large mammals do not occur today but may occur in the future.

The Corridor Management Plan should include some version of the text provided in this section. The Plan should specify that the Chief Forest Officer of the Corridor should carefully monitor implementation and adherence to mitigation measures during construction and operation of infrastructure.

3.4 Hydroelectric plants and transmission lines

Hydroelectric plants

In Bhutan, hydroelectric projects do not create reservoirs and tall dams. Instead, a portion of the stream flow is diverted into a tunnel which leads to the generators. Most run-of-river power plants consist of a dam across the full width of the river for running the turbines. Water not needed for generating electricity spills over the dam at a spillway. Such installations have a reservoir behind the dam but flooding is minimal. Although this type of hydroelectric project reduces some ecological problems, it may affect wildlife movement in several ways:

1. Downstream-moving fish may be drawn into the power plant intake flow (entrained) and pass through the turbine. Entrained fish are exposed to pressure changes, cavitation, shear, turbulence, and collisions with walls or turbine blades, which may cause disorientation, physiological stress, injury, and death. Mortality in turbines may exceed 30 percent. A variety of intake screens, spill flows, and other measures have been tried with mixed success. New "fish-friendly" turbine designs create a larger passage for smoother water flow and a more uniform pressure distribution, reducing damaging shear stress. The turbines are about 90% as efficient as conventional turbines, and kill < 2% of entrained fish. The new turbines can be retrofit into existing plants.

Fish-friendly turbines should be required in all new hydroelectric projects, whether or not the projects are located in a corridor. When turbines in existing plants are replaced, fish-friendly turbines should be used.

2. Upstream moving fish and other aquatic organisms that cannot swim up the spillway. A

variety of fish ladders have been tested at dams around the world. Ladder designs that have been demonstrated to allow upstream fish passage should be required in all new hydroelectric projects, whether or not the projects are located in a corridor.

3. Dewatering the stream. During normal flows, the diversion structure removes only some of the water, allowing the rest to flow over the spillway. However during dry periods of the year, the river may be completely dewatered. All new hydroelectric projects should be designed to maintain minimum ecological flow, defined as enough water to support fish throughout the year, and maintain natural riparian vegetation.

Transmission lines

Transmission and distribution lines cause several impacts to wildlife habitat and wildlife movement:

1. Direct loss of forested habitat. The right of way of a typical high-voltage transmission line is 30m or more. Multiplied by hundreds of km of line, this represents a significant loss of forest.

2. Increased edge effects. The open right of way supports plants and animals that are not typical of the surrounding forest; some of these species may be invasive exotic species. These species can encroach into what were the forest interiors. This encroachment can have impacts on the number, health, and survival of interior forest species. Exotic plant species may arrive through natural dispersal or may be inadvertently brought in by construction activities; disturbance caused by construction provides ideal conditions for some non-native and exotic species. If fire-loving plant species become established in the right of way, these plants can support frequent fires that further degrade the forest.

3. Roads. A road system must be created and maintained to install and maintain the towers. These roads may promote trespass and illegal activities. Roads

4. Birds are killed in collisions with powerlines. Every year hundreds of millions of birds are killed in collisions with powerlines and towers in the US (APLIC 2006). Because the carcasses disappear quickly, these numbers can be estimated only by searching for carcasses every few hours.

5. Primates, raptors, and other large birds can be electrocuted.

The number of birds electrocuted by powerlines is less than 5% of the number killed in powerline collisions (APLIC 2006). Nonetheless in certain locations powerlines are attractive nest or perch sites for raptors and other large birds, and can be a significant source of mortality for particular species. These electrocution events can also disrupt power delivery.

To avoid, minimize, and mitigate these unwanted effects, all transmission lines in Biological Corridors should implement the following measures:

- To the extent possible, route the lines outside of Biological Corridors and other Protected Areas.
- Wash construction vehicles to remove seeds of non-forest and non-native species before vehicles enter the area.
- Close access roads to unauthorized traffic.
- Allow tree and shrub species that reach heights of 4-5 m to grow within the right of way. This can maximize continuity of forest cover and shade out undesirable species.
- To reduce electrocution, use aerial bundled cable or other insulators to isolate the wires from the pylons. Simple structures can be added to prevent birds from perching near pylons, but the effectiveness of these devices depends on the behavior of each bird species. It is critically important to test designs on captive or trained birds to make sure they prevent perching. Some raptors may also be attracted to an added perch above the wires; however, this can have unintended negative impacts if the perches increase the level of raptor predation on sensitive prey species. Placing high-voltage

transmission lines underground is now the norm in much of northern Europe, but may not appropriate in steep terrain because requires complete removal of vegetation and deep disturbance to soil. Detailed guidelines with best practices as of 2006 are available at www.aplic.org; the Avian Power Line Interaction Committee is in the process of updating this document.

- Avoid placing towers in rivers and wetlands.

3.5 Villages, farming, and livestock

The 1974 Forest Policy stated: "The present practice of allowing grazing rights in perpetuity within the forest area over large tracts to individuals is damaging to the soil, vegetation cover and the re-generation process… [Henceforth] it will be the responsibility of the Department to regulate grazing in such a way as to avoid harm to the forest wealth."

But in 2010, 36 years later, grazing occurs in every hectare of every Protected Area in Bhutan, and there is no real limit on numbers of cows and yaks in Protected Areas. Overgrazing has negative effects on plants, soil, wild ungulates, predators, and human-wildlife conflicts[1]. If Bhutan is to begin making progress on this issue, each Corridor Management Plan (and each Protected Area Management Plan) needs to

- Describe desired future conditions in terms of human footprint, including desired configuration and size of villages and farms, and desired levels of livestock grazing consistent with ecological integrity of each zone.
- Describe interventions to reach the desired future conditions. Such interventions should include the following 5 measures. The first 3 are already being used in Bhutan, the last two would be new:
  1. Shift to improved cattle breeds.
  2. Trade rights to graze in core areas for rights to graze elsewhere.
  3. Promote alternative livelihoods, such as sale of *Cordyceps*, that cause less damage than livestock grazing.
  4. Purchase grazing rights from willing sellers.
  5. Impose fines for releasing old cows into Protected Areas and confiscate trespass livestock at the owner's expense.
- Explicitly link these interventions to *permanent retirement of some grazing rights in core areas*. To date, managers have simply *hoped* that interventions will motivate farmers to lower livestock numbers, but this is often not effective. For example, recent policies successfully provided an excellent alternative livelihood to yak herders by issuing permits to sell *Cordyceps*. But because the permits were not tied to reduced yak numbers, herders are using their new income to increase their yak herds. This is counterproductive to conservation.

The effort to manage livestock in core zones will take several decades, unless runaway urbanization (next paragraph) causes a sudden and undesirable collapse of pastoralism. It is important to start the process, regularly monitor progress toward desired ecological conditions, and revise interventions in light of changing conditions.

Johnsingh and Norbu (2006) suggest promotion of family planning, schooling to enable educated youth to obtain jobs outside the Corridor, and voluntary emigration to help maintain a low human population density in corridors. Indeed, many rural villages are increasingly dominated by an aging population, while young people are migrating to urban areas. Economic forces may depopulate some

[1] In Thrumshingla NP, over 75% of the Park area is under registered grazing grounds used by over 11,700 cattle (Johnsingh and Norbu 2006). Overgrazing can lead to transmission of diseases to wild ungulates, retaliatory killing of predators, depletion of forage for wild ungulates, lack of regeneration of forage species due to trampling and overgrazing (Davidson 1998, Wang et al. 2006). Yonzon (2000) observed that all broadleaf and conifer forests in Thrumshingla NP accessible to cattle were overgrazed. Under such circumstances Wang et al (2006a) report increased wildlife damage to crops.

rural areas in a way that promotes conservation, but if such economic forces are unchecked, they may eradicate Bhutan's culture of pastoralism from huge areas of the country and make Thimphu into a sprawling western-style city built around the automobile. Although a decrease in livestock numbers in core areas is desirable, extinguishing livestock from most of Bhutan is not desirable. Nor is it desirable to have most of Bhutan's population commuting by automobile from Thimphu suburbs. To avoid such outcomes, Bhutan should distribute urban growth to several regional centers, should build livable cities where people can walk and bicycle to jobs and shopping areas, and improve rural quality of life so that pastoralism remains well distributed throughout the country in locations most suitable for grazing. If well-planned, urbanization can benefit people, conservation, and pastoralism.

NCD (2008) provide a comprehensive overview of strategies for reducing human wildlife conflicts in Bhutan. Additional strategies are suggested in results of interviews conducted in one of the Biological Corridors. In March 2010, Dorji Rinchen, assisted by NCD and Park staff, interviewed 87 households inside or within 500 m of Corridor #2. All respondents said their crops were damaged by wildlife, and attributed damage to barking deer, sambar, wild pig, porcupine, Assamese macaques, grey langurs, Himalayan black bear and goral. Most farmers believed that crop damage had increased over the last five years. They report no government or NGO assistance (compensation, culling, fence material, advice) to address crop damage. They felt the most useful types of assistance would be barbed wire fencing materials, crop compensation, culling wild pig, and exchange of agriculture land in deep forest. About 75% supported a hypothetical new regulation to allow farmers to shoot wild pigs, and legally sell the pig meat; such a scheme would make them more tolerant of wildlife. Interviewers described a hypothetical insurance scheme to compensate farmers for crops damaged by wildlife. The scheme would pay only for damage within fenced fields, excluding pig damage. About 83% supported the idea, and about 70% thought the insurance scheme should be run by the geog.

Table: Willingness of farmers in and near Corridor #2 to support or try particular measures to reduce predation.

	In favor; willing to try	Would consider	Opposed; would not try
Improved husbandry	89%	1%	10%
Avoid areas with high risk for predation	22%	36%	43%
Financial compensation	92%	7%	1%
Let farmers kill individual problem animals	11%	30%	59%
Have government kill individual problem animals	32%	33%	35%
Have the government kill all predators	16%	8%	77%

The 87 respondent households held a total of 647 cattle, 81 horses, 49 sheep and goats, 43 yak, and 31 pigs. They reported losing 108 cattle (17% of total holdings), 16 horses (20%), and no yak, sheep, goats, or pigs to wild predators during the previous 12 months, and attributed most losses attributed to wild dogs, followed by leopards, tigers, and Himalayan black bear. Even if the reported numbers of livestock killed are exaggerated, loss to predators is clearly substantial. All livestock losses to predators occurred in the forest and none occurred close to homes. When asked whether they would support particular measures to reduce predation, 89% would adopt new husbandry practices, and only 16% favored having the government kill all predators (see Table).

The interviewers described a hypothetical insurance scheme that would compensate farmers for livestock killed by predators, with highest payments for improved breeds of livestock that were killed inside stalls or fenced areas near homes. Important wildlife areas distant from villages would be mapped, and no payments would be provided in those areas. About 80% of respondents said they would support such a scheme, and 93% respondents believed the scheme make them more tolerant of predators; 80% thought the scheme should be run by geog instead of dzongkhag, private insurance company, or national government.

We suggest that planners conduct similar interviews in each planning area to determine schemes, such as crop or predation schemes, that can reduce human-wildlife conflict and promote tolerance of wildlife in corridors. Any compensation scheme should reward farmers for wildlife-friendly behaviors (stall feeding, improved breeds, fencing) rather than paying for all wildlife damage.

NCD should consider issuing regulations to allow farmers to kill wild pigs and legally sell the pig meat. Such a change could reduce pig numbers, increase farmer income and food security, and promote tolerance of wildlife. Snares and other indiscriminate methods of take should not be permitted. Wanchuck et al. (2001) reported that traditional hunting methods were effective on boar; they also suggested a Special Hunting Forced could be used. The Bhutan Observer (& October 2009) reported on the controversy surrounding a pilot pig-hunting program; most of the on-line responses to this story seemed to favor the idea.

3.6 Managing harvest of firewood, timber, and non-wood forest products (Community Forests and FMUs)

Since 2002, over 100 Community Forests (CF) have been established in Bhutan, many of them in Biological Corridors and other Protected Areas. Most CFs have been established since 2008, and there are no data on how many CFs occur in corridors today. As part of developing each Corridor Management Plan, existing CFs should be identified and mapped.

Currently no data exist to set allowable levels for harvest of timber, firewood, and non-wood forest products from CFs and corridors. The Corridor Management Plan should include a plan to monitor status of resources that are collected in the largest quantities, or resources that are expected to be most susceptible to over-exploitation. Monitoring data should be used to set desired harvest levels over time. The Corridor Management Plan should also specify the extent to which specific non-wood forest products collected by community members may be sold commercially.

To harmonize the goals of resource protection and resource use, Nature Conservation Division and Department of Forest and Park Services should enter into dialogue with Community Forest managers to insert Corridor Rules into the Community Forest bylaws. The Community Forest should be the primary area used by the community for resource extraction, so that pressure on the corridor is reduced. The Community Forest should not be viewed as a community "savings account" while the community reduces the natural capital of the corridor.

Forest Management Units (FMUs) have been established in only a third of the land that Forest Resources Development Division identified as suitable for Forest Management Units. Although Forest Management Units are sorely needed (see Part I and Part II), Bhutan should try to locate Forest Management Units outside of Biological Corridors.

Forest Management Units may be even more disruptive in Biological Corridors than in other Protected Areas, because corridors are much narrower than Protected Areas (Figure), and land outside of Biological Corridors probably will be dominated by human uses in a few decades. A corridor is only as strong as its weakest link, so a disturbance that occupies a 1x1 km^2 portion of a corridor could stop gene flow and movement between the protected areas the corridor is intended to connect. In May 2010, I visited a FMU near Paro that has been operating for 8 years. The operation caused minimal disturbance to the soil, left most of the forest canopy intact in the logged areas, and avoided any logging at all in some parts of the FMU. Although this visual inspection suggests FMUs are well-managed, there are no rigorous data showing that FMUs are compatible with animal movement and occupancy by less mobile species that require populations well-distributed throughout the corridor to achieve gene flow.

If FMUs are allowed in Biological Corridors (they occur in some corridors already), then

(a) The corridor should be wide enough that the FMU does not span the width of the corridor. This may require widening some existing corridor designs.
(b) Monitoring shall take place to determine the impact of timber operations on animal occupancy, movement, and gene flow, as well as any increase in exotic or invasive species. The results of research should then inform management of the FMU, and decisions regarding whether to allow new FMUs in Biological Corridors. At a minimum, research on presence, abundance, and movement of focal species in existing FMUs should be conducted before any additional FMUs are placed in a corridor, and regular monitoring should occur at 5-year intervals.

3.7 Opportunities for ecotourism, ICDP, research, and filming

The Corridor Management Plan should consider potential for ecotourism, building on the pilot ecotourism project in Thrumshingla NP. This would include an estimate of the desired levels of visitors in various part of the corridor, a plan to train eco-guides, and setting of fees for vehicle parking, guiding, porters, and home stays. Local communities should be empowered as the primary agent of action. Camping fees, taxes on porter incomes, and royalties on lodging can go directly to the geog or dzongkhag development committee. The Corridor Management Plan may also include mechanisms to share revenues from filming and research with local communities.

A permit system should be established for research and filming. Nature Conservation Division and DoFPS should review the permit applications, with final approval by Council for RNR Research of Bhutan (Ministry of Agriculture).

Each permit should attract a fee. The fees should support the Protected Area or Biological Corridor in which the activity occurs. Research should be conducted only by Bhutanese nationals.

In Bhutan, local communities set the criteria for eligibility for Integrated Conservation & Development Projects both inside and outside of Protected Areas, and determine how Integrated Conservation & Development Project benefits will be distributed. These practices should continue. Planners should take care not to create unrealistic expectations about the benefits to accrue from ecotourism, ICDP, and other enterprises. The Plan should ensure that benefits are distributed fairly to households in the buffer zone as well as households in the corridor.

3.8 Educational campaign

The Corridor Management Plan should include a plan to publicizing the corridor boundary and inform households of activities that are prohibited, permitted, or encouraged in the various zones of the corridor. Educational material should emphasize benefits of the corridor to wildlife and people, but should also be honest about the inconveniences.

Households in and near the corridor should be encouraged to take ownership of the corridor. Community Forests in the corridors will create buffers near core zones; because the community owns the forest, they will guard and protect the land. The community should be engaged as responsible for welfare of nature rather than being shut out.

The biological information, maps, figures, tables, and photographs in the Corridor Management Plan should be adapted for interpretive programs targeted at adults, and integrated into permanent education programs in local schools. The school programs must include an activity for every school year, and at least one year in which students meet local staff managing the corridor. Public education must encourage residents to be active stewards of the land and generate a sense of ownership of local habitats. Such voluntary cooperation is essential to make sure the corridor works.

4. Monitoring and Revision of the Plan

Bhutan is a world leader in implementing corridors at a country-wide extent. Doubtless, Bhutan will not get everything right on the first try. But if the Corridor Management Plan includes an adaptive management approach, managers can quickly learn what worked, and what didn't work. Monitoring the effectiveness of the corridor is crucial to an adaptive management approach.

The efficacy of the Corridor can be evaluated in two ways (Johnsingh and Norbu 2006). One is by regular quantification, especially in suspected chokepoints, for sign of focal species that are expected to be most sensitive to threats occurring in the corridor. If signs are found throughout the Corridor area and in the potential chokepoint, then the corridor is probably being used. However Horskins et al. (2006) and Delaney et al. (2010) found no gene flow was occurring through heavily impacted corridors and landscapes even though animals occurred throughout the areas. Therefore, managers should also use a second line of evidence, namely analyzing DNA in scats and hair samples from the corridor and from the Protected Areas linked by the corridor. If the animals on both ends of the corridor are closely related and the degree of genetic relatedness does not decline over time, then the corridor can be considered successful. Such genetic monitoring requires collecting baseline data as soon as possible, and recurring sampling at intervals of about 5 years. In 2010, Ugyen Wangchuck Institute for Conservation of the Environment was developing capacity to conduct such analyses and store genetic tissues. Either UWICE or another capable institution would have to collaborate on such an effort.

If animals are not present or gene flow is not occurring, then the Corridor Manager[2], with support from NCD, should identify the likely causes of this failure, take corrective measures, and use continued monitoring to assess the new interventions.

In addition to the biological monitoring on actual use of the corridor by animals, managers should also monitor trends in human use and impacts of management interventions in the corridor.

Such monitoring and adaptive response should be an ongoing part of implementing and managing the corridor. However, the scheme as described so far focuses mostly on specific chokepoints and interventions. It is also important to periodically consider the entire management plan in light of past experience and anticipated new threats and trends.

Therefore the Corridor Management Plan should be periodically revised. Because most lessons will be learned during the early years of implementation, the first revision should occur 5 years after the Corridor is becomes operational, and the second revision should occur 10 years after the first revision. The CFO and NCD at that point should conduct an overall review of the entire program, and determine a schedule for future revisions.

[2] The term "Corridor Manager" is used in a generic sense in the Framework. Eventually each Biological Corridor should have its own dedicated staff. However, Bhutan cannot afford to staff these units in the near future. Furthermore, Bhutan does not have enough trained persons to fill all positions in existing Protected Areas. For the foreseeable future, as specified by the 2007 Biological Corridor Rule, the "Corridor Manager" shall be the two affected Territorial Division officers. (All but one corridor spans two Territorial Divisions). The current practice is to identify a Focal Person in each TD, and for NCD to train that person. This practice should continue and be expanded to include training of additional TD staff.

5. Outline of a Corridor Management Plan

The box below provides an outline to be used in a Corridor Management Plan. Most items are listed in the same order they are described in this Framework, with the Exception of "Description of the planning area" which is covered in 3.2.8.

5. Outline of a Corridor Management Plan

- Executive Summary
- Introduction
- Description of the planning area
- Justification for corridor boundaries
  - Utility for Focal species
  - Representation of land facets
  - Riverine connectivity
  - Description of chokepoints and barriers
  - Boundary delineation plan
- Zoning Map and justification
- Roads
- Human populations
- Hydroelectric projects and transmission lines
- HWC
- Livestock grazing
- Managing harvest of firewood, timber, and non-wood forest products (Community Forests and FMUs
- Opportunities for ecotourism, ICDP, research, and filming
- Educational campaign
- Monitoring Program

Maintaining and enhancing functional ecological connectivity across Bhutan in the face of human development and climate change is no easy task, and no single agency or small group of agencies can tackle it alone: Every citizen and government agency has a unique role to play in conserving Biological Corridors while also pursuing their own mission—whether it involves improving transportation, delivering water and power, providing ecotourism, promoting rural livelihoods, or conserving biological diversity. Conservation of corridors fits all missions to some degree.

Department of Roads and other Ministries and Departments are encouraged to incorporate principles from this Framework, and the Corridor Management Plans, into their long term planning and project planning.

Territorial Forest Divisions, dzongkhags, geogs, and Community Forests will be involved in development, implementation, and revision of each Corridor Management Plan. The Plan can help guide management, restoration, public education, or land acquisition efforts by dzongkhags and geogs, or by non-governmental organizations such as Royal Society for Preservation of Nature. Scientific organizations such as Ugyen Wangchuck Institute for Conservation of the Environment can undertake research to improve elements of corridor planning and use genetic techniques to monitor corridor effectiveness. They can also promote training of persons who will develop and implement the plans. The tourism industry can support ecotourism projects in Biological Corridors.

External donors are critically important for supporting all elements of this Framework and the Corridor Management Plans that will be developed. Conservation donors should especially support development of Corridor Management Plans, and should support efforts by Nature Conservation Division to increase Bhutan's human capacity to develop and implement plans. Development donors should build the cost of planning and crossing structures into their highway, hydropower, and other projects.

6. Capacity Building

Assuming that corridors 2 and 8 are managed as one Biological Corridor, and 7 and 9 are similarly merged, then 7 Corridor Management Plans must be written. If one or more new corridors are designated in southwestern Bhutan, this number would increase. Regardless of whether each corridor has a dedicated staff or staffing continues to be provided by Territorial Divisions, continuing support for management must be maintained in perpetuity. Currently Bhutan has a staff of one Coordinator for Biological Corridors in NCD. Clearly additional capacity is needed.

6.1 Writing the Plans

It will take about 18 months to write each of the 7 Corridor Management Plans. The first plan should be initiated by 1 January 2011, and the last plan should be completed by 1 January 2015. The first plan should address one of the more complex landscapes (that is, the combination of #2 & #8, or the combination of #7 and #9). Because surprises are most likely to arise during this first plan, and because the planning team will be exploring many problems for the first time, the second plan should not begin until the first plan is nearly completed. At that time, the planning teams can begin a new plan every 2 months, managing several plans in various stages of completion.

I suggest that each Plan have 3 primary authors: the NCD Coordinator, a second ecologist in NCD, and the prospective Corridor Manager. Each of these persons should have a degree related to ecology and management of natural resources. The writers will need the half-time service of a GIS analyst for the 5-year planning effort.

If an external consultant is hired to help develop one of the first plans, the consultant should not write the plan, but should serve in an advisory and training capacity, interacting with Plan writers and other DFPS staff on a daily basis for about 6 weeks to provide training. Instead of (or in addition to) using an outside consultant, NCD could send a bright and dedicated staff person for a MS or PhD degree with a special emphasis on design and implementation of wildlife corridors.

6.2 Staffing the Biological Corridor

Each corridor will need staff to carry out activities in extension, ICDP, monitoring, educational outreach, and law enforcement. The Corridor Manager will have to maintain regular communications with managers of Protected Areas served by the corridor, geogs, dzongkhags, Community Forest boards, Forest Resource Development Division, Department of Roads, Bhutan Power Company, and Druk Green Energy. The monitoring staff will need support from NCD to develop a monitoring program and interpret the data produced from it. In this regard, the Corridor Managers (currently staff of the Territorial Divisions) will need personnel to carry out monitoring activities, and NCD will need additional capacity to design and analyze monitoring programs. As mentioned in Section 4, the monitoring program should involve both regular assessment of animal presence, and periodic (every 5 to 10 years) assessment of genetic evidence of gene flow. Partnerships with UWICE or faculty in Bhutan's Natural Resource College could be an effective way to build this research capacity.

Staff persons are also needed to develop develop ecotourism, ICDPs, and other projects that are synergistic with the goals of the corridor. Other important tasks include running education programs in all schools, informing people of regulations and opportunities, and maintaining informational kiosks. The residences of these staff persons, especially those involved in law enforcement, should be distributed in a way that maximizes presence in key areas of the corridor.

6.3 Operation

At least two NCD staff will be needed to assist in plan revisions, design monitoring programs and interpret monitoring data, provide training for new corridor staff, and provide continuing education for corridor staff. The NCD staff will also need continuing education, including post-baccalaureate degrees for at least 2 staff persons working on Biological Corridors.

6.4 Other capacity needs

Engineers working for Department of Roads and Bhutan Power Company may need additional training in environmentally friendly operations. The International Conference on Ecology and Transportation (ICOET) is held every 2 years and is an excellent opportunity to network with other engineers working on similar issues.

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Glossary and acronyms

B2C2 – Bhutan Biological Conservation Complex

dzongkhags – the 22 administrative districts of Bhutan

FMU – Forest Management Unit, an area actively managed by the Forest Resources Development Division for timber harvest and other goals.

geog – the smallest public administration unit, made up of a block of villages gup – the head of a geog, elected by the local community

NCD Nature Conservation Division (Department of Forest and Park Services)

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