




BIODIVERSITY BASELINE ASSESSMENT

PHIPSOO WILDLIFE SANCTUARY IN BHUTAN

OCTOBER 2018

ASIAN DEVELOPMENT BANK

ADB

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On the front cover: Critical habitat of Phipsoo and its associated range of biodiversity.

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On the field. The biodiversity study team comprising wildlife consultants from the Asian Development Bank (ADB) and rangers of the Phipsoo Wildlife Sanctuary at the survey site (photo by ADB).

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Phipsoo Field Office. The biodiversity study team on a visit to the Phipsoo Field Station (photo by ADB).

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ABBREVIATIONS

ADB	Asian Development Bank
ANOVA	analysis of variance
ANCOVA	analysis of covariance
BBA	baseline biodiversity assessment
cm	centimeter
CMP	conservation management plan
CR	critically endangered (IUCN Red List)
DOR	Department of Roads
EIA	environmental impact assessment
EN	endangered (IUCN Red List)
FNCA	Forest and Nature Conservation Act of Bhutan (1999)
GIS	geographic information system
ha	hectare
IBAT	Integrated Biodiversity Assessment Tool
IFC	International Finance Corporation
IUCN	International Union for the Conservation of Nature
km	kilometer
km^2	square kilometer
LC	least concern (IUCN Red List)
m	meter
m^2	square meter
masl	meters above sea level
NDVI	Normalized Difference Vegetation Index
NEC	National Environment Commission
NT	near threatened (IUCN Red List)
PWS	Phipsoo Wildlife Sanctuary
RMNP	Royal Manas National Park
RSPN	Royal Society for Protection of Nature
SDI	Shannon–Weaver Diversity Indices
SE	standard error (of means)
SPS	Safeguard Policy Statement
VU	vulnerable (IUCN Red List)
WCD	Wildlife Conservation Division
WWF-Bhutan	World Wildlife Fund for Nature-Bhutan

EXECUTIVE SUMMARY

A. PROJECT BACKGROUND

This baseline biodiversity assessment (BBA) was conducted in preparation for a proposed road that would have crossed through the Phipsoo Wildlife Sanctuary (PWS), Bhutan's smallest protected area (269 square kilometers), which harbors high biodiversity. Due to PWS' protected status and high biodiversity, the BBA was undertaken to provide a biological baseline for the sanctuary and the proposed road project. The conduct of this BBA was guided by the Safeguard Policy Statement (SPS) (2009) of the Asian Development Bank (ADB).

Although the road project was later cancelled by the Government of Bhutan in spring 2015, suspending the BBA, substantial information and insights were gained during the field studies. The purpose of this report was to document the BBA information, such that it may foster more informed management of PWS.

To accomplish the BBA, the inventory and sampling were stratified within four PWS assessment zones corresponding to terrain, elevation, and associated vegetation type: (i) border lowlands, (ii) lower foothills, (iii) middle foothills, and (iv) upper foothills zones.

B. ASSIMILATION OF EXISTING BIODIVERSITY INFORMATION

Desktop screening was conducted using the online Integrated Biodiversity Assessment Tool (IBAT) to generate 79 species following the International Union for the Conservation of Nature (IUCN) list, which might occur in or near (within 50 kilometers [km]) PWS. Of those, a total of 29 species were confirmed at PWS, including 27 afforded IUCN status (12 by the Forest and Nature Conservation Act of Bhutan [FNCA] Schedule I); and two that are only listed as FNCA Schedule I species. Mammals accounted for the majority (74%) of the confirmed species. Along with sal (*Shorea robusta*) with its limited distribution in Bhutan, 20 of the species were evaluated as candidates for potential critical habitat designation under ADB's SPS.

Records from extensive mammalian camera trapping done by PWS rangers from March to August (6 months) 2014 at 29 sites across all four assessment zones were analyzed. A total of 8,322 individuals comprising 24 different mammalian species were camera trapped,

including 15 IUCN-listed species and six of Bhutan's 11 known species of felids (cats). The means the four assessment zones were compared for the number of species, proportion of all animals per site, and Shannon–Weaver Diversity Indices (SDI) (Shannon and Weaver 1949). SDI is a widely used measure of biodiversity combining species richness and how rare or common they are (species evenness). Nearly twice as many mammal species were recorded at middle foothill camera sites (9.8 species) than border lowland sites (5.0 species). The mean proportion or percentage of total animals recorded at each site by species differed significantly among zones; nearly half (47.2%) of all animals were recorded at middle foothill sites, which was greater than the percentage recorded at border lowland (15.7%) and lower foothill (12.6%) sites. The mean SDI for the middle foothills camera sites was substantially higher (>40%) than those for the other three assessment zones. Based on this camera trapping, the middle foothills zone exhibited the highest mammalian biodiversity.

C. BIODIVERSITY BASELINE ASSESSMENT RESULTS

Much of the BBA fieldwork was conducted during January and February 2015, though the first remote camera was installed in late December 2014. The remote cameras were recovered for analysis in May 2015.

Forest overstory tree inventory was conducted at 33 sampling sites using a "plotless" wedge prism sampling approach. 67 different tree species were inventoried across all sites, with an average of 5.0 species per site. An average of 11.7 trees per site were counted, which yielded an average basal area of 22.4 square meters per hectare (m^2/ha). Among assessment zones, none of the mean biodiversity metrics differed significantly. Sal was the most common tree species inventoried, accounting for 12.8% of the total species composition across all PWS inventory sites. Sal was especially prevalent in the lower foothills zone, comprising 17.3% of the forest composition.

During overstory tree inventory, snags (dead standing trees important to birds and other animals) were also inventoried, as well as orchids. Snags were counted at 29 sites and found to have densities averaging between 2.2 snags per ha and 3.3 snags per ha across assessment zones, with large snags (>50 centimeters [cm]), generally most valuable to wildlife, averaging from 1.0 snag per ha to 1.8 snags per ha. A total of 15 orchid genera were inventoried at 13 sampling sites; the inventory doubled the previously known number of orchid genera at PWS.

A total of 16 separate winter avian surveys were conducted during the course of the BBA. During these surveys, a total of 120 species of birds were documented. This total included 46 species that had not been previously documented as occurring at PWS, representing a 35% increase in the number of known species, now at 177. Ten of the species documented were considered "abundant" while another 22 were considered "common"; combined, these species accounted for 72% of all birds. Of the 131 bird species previously known to

occur at PWS, 55 species (42%) were not detected during the study's winter BBA; some of these species likely were wintering elsewhere in Asia. In comparing avian survey results across assessment zones, the statistical analyses yielded no significant comparisons among biodiversity metrics; avian communities across PWS zones were relatively similar.

The winter 2015 mammalian species camera trapping provided a substantial amount of data to assess and compare biodiversity across PWS assessment zones, complemented the 2014 PWS camera trapping, and provided 8 months of monitoring data (no data was collected during September–December). The cameras yielded a total of 17,857 images, of which 16,313 were mammals; 452 were birds, 652 were humans (including poachers); and 429 were livestock. Usable data was recovered from 38 cameras representing 33 discrete sites across PWS; cameras were operational an average of 110.7 days per site (3.7 months). The analysis determined a total of 4,300 individual mammal images within 2,227 separate groups, accounting for 28 different species, or four more than the 2014 PWS camera trapping. Fifteen of the species were IUCN-listed. Six more species not camera trapped previously during the 2014 PWS camera trapping exercise were found in the winter 2015 camera trapping data.

Endangered Asian elephants (*Elephas maximus*) accounted for the most individuals documented at PWS during the BBA monitoring. There were 1,297 elephants in 376 groups at 29 camera sites spread evenly across assessment zones. This was the most *evenly* distributed of all species. One of the most dramatic differences between the 2014 PWS and 2015 BBA camera trapping was the over twofold increase in winter elephant use of the border lowland and lower foothills zones in 2015. The second most common species recorded at PWS was gaur (*Bos gaurus*), with 1,113 individuals. Three species of deer were camera trapped; 700 barking deer (*Muntiacus mutjak*) were recorded at all but one of the 33 sites, making them the most widely distributed animal recorded, though 92% of records occurred in the upper lower and middle foothills sites. Six species of felids were recorded; most common was the common leopard (*Panthera pardus*) of which 50 were recorded. Endangered tigers (*Panthera tigris*) were recorded on nine occasions at six sites, of which 89% were in the lower and middle foothills zones.

The statistical testing for differences among PWS assessment zone mammalian biodiversity metrics yielded significant results. There were differences among the mean number of species camera trapped per site across zones, for all species and IUCN-listed species only. The mean number of border lowlands zone species was 36%–43% lower than the other zones. The difference among mean proportions of total animals for all species among PWS assessment zones was highly significant, with the border lowland mean proportion of animals being one-third less than the other zone means. Mean SDI per site within border lowland sites was 29%–32% lower than the higher assessment zones.

A comparison was made between the results for the 15 camera trapping sites at which monitoring was conducted during both the PWS 2014 and winter 2015 BBA camera monitoring. Similar results were found between years for SDI and the number of species per site. The 2014 and 2015 camera trapping data were merged to derive average biodiversity metrics that spanned 8 months of the calendar year. The merged lower and middle foothills mean number of mammal species per site were >60% higher than the border

lowlands mean. The mean proportion of total animals for all species recorded in the lower and middle foothills zones were 106% and 219% higher, respectively, than the border lowlands sites. The mean SDI for the middle foothills zone was 38% higher than the border lowlands zone.

Temporal relationships of mammal camera trapping records were assessed. Overall, 54.1% of the individual mammals recorded were active during nighttime (dark) hours. The percentage of nighttime records ranged from 43% to 100%; for all IUCN-listed species combined, 60% occurred during nighttime hours. The daily activity pattern for all PWS species combined exhibited three peaks across the day, with the largest occurring in late afternoon and early evening.

Fish species were sampled at five sites spread along the length of the Nichula River. Eight species of fish were found, including one endangered species netted at a single site, one IUCN vulnerable (VU) species netted at all five sites, and one near threatened (NT) species netted at three sampling sites. Sampling of the Phipsoo and Longa rivers had been planned for spring 2015, but could not be conducted due to the cancellation of the project.

Four critically endangered (CR) white-bellied herons (*Adrea insignis*) were spotted at three separate locations; two on the Longa River and one on the Phipsoo River; all locations were within the lower foothills zone. Three of the herons were identified as subadults not engaged in breeding.

Sixteen endangered (EN) golden langur (*Trachypithecus geei*) groups, accounting for 136 individuals (8.5 per group) were inventoried. A single group of langurs was sighted within the border lowlands zone (6%), while all others were recorded within the higher lower and middle foothills zones.

Four species of hornbills were documented during the BBA; hornbills are generally considered to be indicators of intact and contiguous mature forest canopy needed for nesting and foraging, especially the presence and diversity of mature fruit-bearing trees. Three quarters of 26 group observations of VU rufous-necked (*Aceros nipalensis*), great (*Buceros bicornis*), Oriental pied (*Anthracocerus albirostris*), and wreathed (*Aceros undulates*) hornbills occurred in the lower and middle foothills zones; 24% were in the border lowlands.

Thirteen khar (salt lick) formations were inventoried across PWS, most within the lower and middle foothills zones of the sanctuary. They are vitally important to endangered Asian elephants and several other large mammal species as a source of supplemental dietary sodium, especially for pregnant and lactating females. Highly concentrated wildlife use occurs around PWS' khar formations.

Grassland habitats primarily occur within and adjacent to the Longa and Phipsoo river drainages and are very important to Asian elephants and other species for foraging. Elephants and gaur transport the seeds of invasive species, particularly the genus *Chromolaena* (Siam weed) from neighboring India to PWS in their feces where the species have become well established in all grasslands. The baseline inventory found that invasive species constitute 24.0%–43.5% of total ground cover, a substantial component

of the grasslands that impacts plant productivity, health, and vigor. Aggressive pursuit of a science-based strategy for grassland restoration is vital for Asian elephant and other species recovery.

A rapid inventory of tree stumps was conducted along the Indian border west of the Ranga Kohala in an area representative of heavy illegal tree harvest. The illegal harvest has been so heavy in that area that it has opened the native tree canopy to the point that many remaining trees have been subject to windfall. From the geographic information system (GIS) inventory, it was possible to superimpose four 1 ha plots to determine that the average number of cut trees was 22.6 stumps per ha, with 73.3% of the harvested trees being sal. As many as 2,500 trees were estimated to have been poached from PWS, and illegal harvesting was found to be progressing upward on the slopes since accessible trees have largely been liquidated in some areas.

Scaled values were compiled for 10 biodiversity metrics measured as part of the BBA to develop comparable biodiversity indices for each of the three lower assessment zones. Based on the biodiversity indices, the lower and middle foothills zones exhibit comparable overall biodiversity, which were twice as high as that exhibited by the border lowlands zone. Much of the border lowlands zone has been modified by human-influenced impacts that have contributed to the zone's lower biodiversity. This zone also has limited proximity to PWS' perennial river ecosystems that bisect the higher elevation lower and middle foothills zones that contribute to their higher biodiversity.

D. CLASSIFICATION OF MODIFIED, NATURAL, AND CRITICAL HABITATS

ADB's SPS provides a framework for the classification of natural and modified habitats; these habitats are then assessed as to whether they constitute critical habitat for any critically endangered, endangered, or FNCA Schedule 1 candidate species. It was found that much of the southernmost 0.5 km–1 km band of PWS constitutes modified or degraded habitat altered by human-induced impacts ranging from tree plantations and villages, to illegal tree harvest, and even an open-pit mine; combined, they account for 2,604 ha or 9.7% of PWS' area.

Much of the borderland forest habitat on the eastern half of PWS has been modified by the harvest of native forest species with subsequent replanting of teak (*Tectona grandis*) in plantation plots dating back to the 1950s and 1960s; these plots exhibit lower plant diversity than natural habitats. PWS rangers delineated four blocks encompassing approximately 50 plantations, ranging in size from 3 ha to 1,169 ha and totaling 1,206.5 ha. Natural habitats (503 ha) in the vicinity of the abandoned village of Pingkhua and the village of Nichula have been modified by human settlement activities. Illegal tree harvest spans an approximately 15 km band (890 ha) along the Indo–Bhutan border, though the extent and severity of harvest across this entire band were not determined due to the suspension of BBA field activities.

To assess the difference in biodiversity between natural and modified habitats, the 2015 mammalian camera trapping metrics for camera sites within modified habitats were compared with those for nearby camera sites within natural habitat. The mean SDI in modified habitat was nearly half that of the adjacent natural habitat sites, and the number of species was 36% lower in modified habitats. This provides insight into the impact of habitat modification from human activities on mammalian biodiversity.

Though further analysis and consultation are needed for all 20 critical habitat candidates, two species were determined to warrant potential critical habitat designation: the critically endangered white-bellied heron and the endangered tiger. Proposed critical habitats for these species were delineated within PWS' biodiversity "core" constituting 160 km^2 (60% of PWS), which extends up to an elevation of 1,200 meters above sea level. The lower Longa and Phipsoo rivers constitute important habitat for the heron, especially for dispersing immature and subadult birds. Here, foraging rates may be substantially higher than along major rivers where hydroelectric power plant construction may have negatively affected habitat suitability, thereby impacting populations. PWS and its excellent foraging habitat may be critical to promoting the survival and eventual recruitment of young, subadult herons into the breeding population. The greatest threat to herons at PWS is the potential for continued mass fish poisoning by Indian poachers along the Longa River drainage, which has been noted by PWS forest rangers in the past. These activities could devastate entire aquatic ecosystems.

Three sets of tiger tracks were documented, two of which were very fresh, distinctly different in size, and separated by 15 km; thus, indicating that at least two adult tigers inhabit or utilize PWS. These tigers are critical to Bhutan attaining source site status of at least 25 breeding females to support global tiger recovery. The tiger's greatest threat at PWS is opportunistic take by poachers for sale on the Asian black market. Antipoaching field stations within both the Longa and Pingkhua river drainages would dramatically reduce this risk. The 2014 and 2015 camera trapping recorded 30 total tiger observations, of which 97% occurred in the lower and middle foothills zones constituting a critical habitat core for tigers.

Illegal and regular incursions into PWS by poachers continue to occur even though the sanctuary has been operationalized with increased law enforcement presence. If reconsidered by the Government of Bhutan, a future road could present an opportunity to enhance resource protection and ecosystem integrity over current levels, and enhance management and facilitate implementation of PWS' conservation management plan—provided the road project includes resource protection and capacity enhancement measures for PWS. PWS rangers would be able to conduct intensified patrolling of the entire sanctuary and dramatically reduce illegal incursions for poaching and damage to PWS resources. Enhanced infrastructure (e.g., observation towers, antipoaching outposts) to support law enforcement efforts would further enhance resource protection and ranger safety.

E. FUTURE MANAGEMENT CONSIDERATIONS

The impact of poaching on PWS' wildlife and trees, and particularly the species for which critical habitat exists (tiger and white-bellied heron) was documented. Current PWS patrol efforts are having only limited success in deterring the ongoing poaching activities. The PWS management plan details the need for additional infrastructure to support patrol efforts and deter poaching via improved road access and new antipoaching outposts. Construction of outposts in the Longa and Pingkhua river vicinities will be vital to resource protection, especially an outpost along the Longa River with its proximity to while-bellied heron critical habitat.

The engagement of an expert on Siam weed (*Chromolaena* spp.) ecology and control is recommended to assist with development and implementation of a sound invasive species control and monitoring strategy for PWS that complements the sanctuary's ongoing control activities. This strategy must utilize and rigorously evaluate multiple control treatments under sound experimental design with adequate controls to assess effectiveness for wide application. Once a viable treatment strategy is developed, it should be sustained over a multiyear period with follow-up monitoring to evaluate success. This program is needed to protect the ecological integrity of the sanctuary's grasslands, which are vital to many species including the EN Asian elephant.

PWS has tremendous potential for public education, interpretation, and ultimately ecotourism programs, which are currently undeveloped due to its remote location, poor access, and security or safety issues. The pursuit of education and interpretation could create and elevate public awareness of PWS, which will ultimately increase appreciation, understanding, and support for its programs. These programs could be pursued incrementally, starting with passive programs involving interpretative signage at pullouts along a new road if ever reconsidered, and then developing observation infrastructure (e.g., viewing towers or platforms) to support wildlife viewing.

Longer-range opportunities to pursue limited, high-quality, wildlife-based ecotourism with guided operations for birdwatching and other wildlife viewing opportunities would bring increased awareness and prestige to PWS. Further, such ecotourism programs could present a significant and sustainable funding vehicle to implement PWS conservation management plan goals and foster diversified economic development in the region.

Early sunrise on the horizon. The sun rises over the plains of India as seen from Phipsoo Wildlife Sanctuary (photo by ADB).

1. INTRODUCTION

This document was prepared to report findings of a biodiversity baseline assessment (BBA) conducted within the Phipsoo Wildlife Sanctuary (PWS) during 2014–2015 as part of an environmental impact assessment (EIA) for a proposed road project.[1]

Diverse field activities were carried out in January and February 2015, with remote cameras recovered in May 2015. During the BBA field activities, substantial insights were gained into PWS' biodiversity and the current threats it faces. At the same time, the results of previous 2014 remote camera trapping over 6 months by PWS forest rangers was secured from the Wildlife Conservation Division (WCD) and subsequently analyzed for inclusion in this report. This data was augmented by the data obtained from the team's cameras, which yielded another 4 months of camera monitoring.

The collective information and insights gained under the assessment provides a clear understanding of PWS' biodiversity baseline. The purpose of this BBA report is to document the substantial data and insights gathered such that they may help inform and benefit future management of PWS and its outstanding biodiversity.

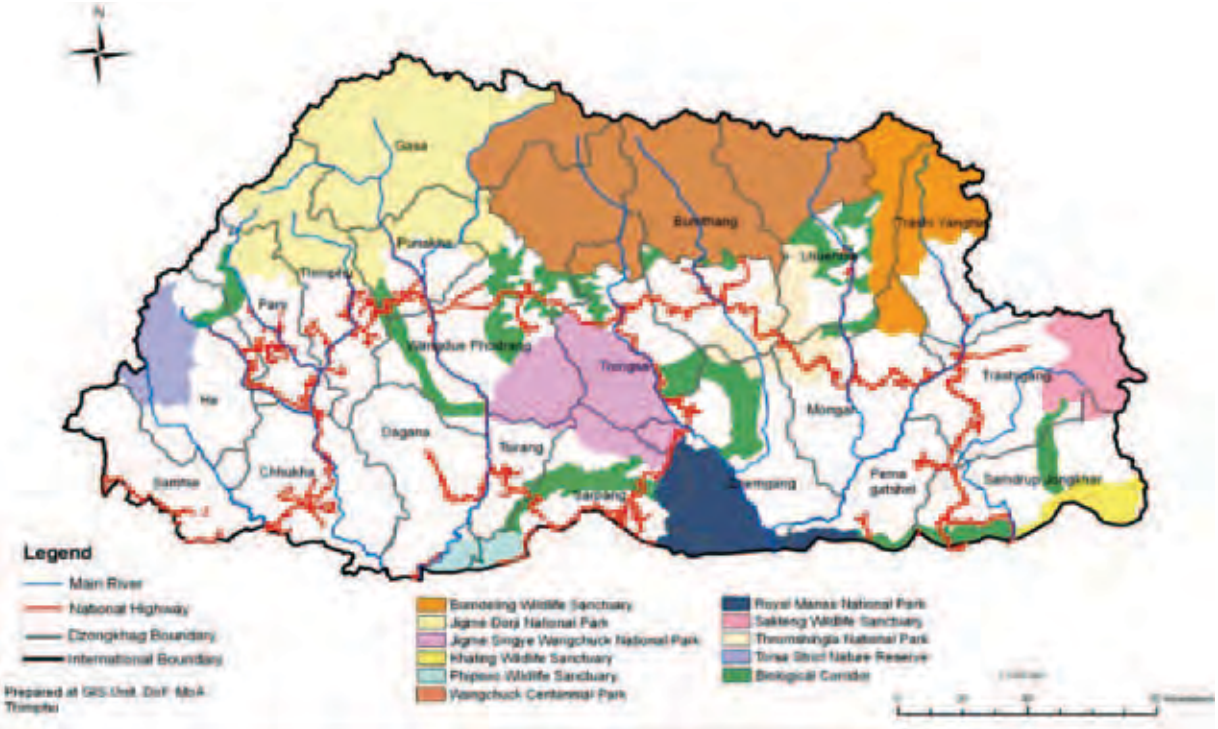
[1] The road project was later cancelled by the Government of Bhutan. Significant security and safety issues were faced by the project during the field works in late 2014 and early 2015.

Rich landscapes. Himalayan foothills at the center of Phipsoo Wildlife Sanctuary (photo by ADB).

II. PHIPSOO WILDLIFE SANCTUARY DESCRIPTION

Encompassing an area of 269 square kilometers (km^2), PWS is the smallest of Bhutan's 10 protected areas. It is located in the county's south-central Himalayan foothills along the Indo–Bhutan border adjacent to the Plains of India (Map 1). PWS is flanked on the west by the Sunkosh River, the Senge River to the east, and to the north by the steep Dhaneshri Ridge rising to 1,700 meters above sea level (masl). Five perennial rivers bisect the sanctuary, including (from east to west) the Longa, Phipsoo, Pingkhua, Ranga, and Nichula rivers (Map 2). These rivers contribute substantially to PWS' biodiversity and constitute travel corridors for many of the animals that reside there. With the exception of one narrow single-track road on the eastern third of its southern border, there is no road access within PWS.

Map 1: Protected Areas and Biological Corridors of Bhutan

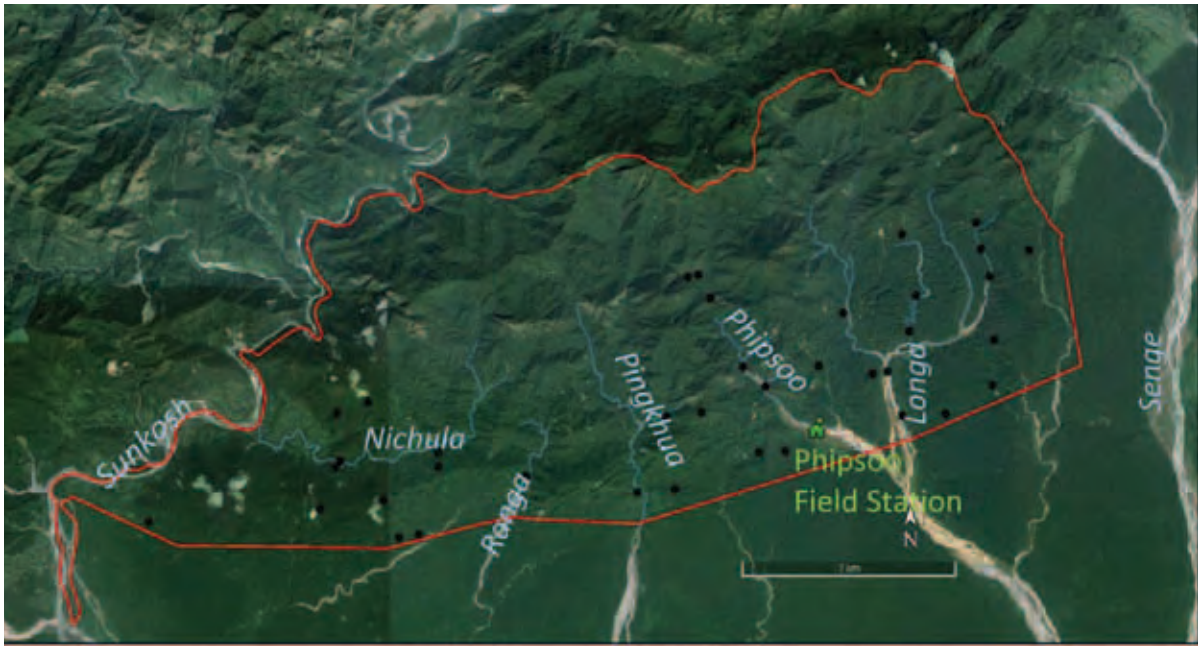


Note: Bhutan's protected areas consist of national parks; wildlife sanctuaries (including Phipsoo Wildlife Sanctuary see shaded light blue area); and nature preserves, with biological corridors (in green) linking the protected areas.

Source: Department of Forest, Ministry of Agriculture.

PWS lies within the Indo-Malayan biogeographic province and reflects outstanding diversity. Preliminary surveys recorded 637 species of plants within PWS (PWS CMP, Norbu and Tobgay 2012). Three broad categories of subtropical vegetation occur within PWS (Map 3), related to the influences of variable and increasing topography and elevation: (i) semi-evergreen forest (≈100–300 masl) (Figure 2); (ii) moist deciduous forest (≈300–700 masl) (Figure 2); and (iii) moist evergreen forest (≈700–1,200 masl).

Map 2: Phipsoo Wildlife Sanctuary and Its Five Interior Perennial Rivers



Note: Phipsoo Wildlife Sanctuary has five interior perennial rivers (blue lines) and rivers flanking it on the east (Senge) and west (Sunkosh); as well as the Phipsoo Field Station. Black dots correspond to camera and forest overstory sampling sites.

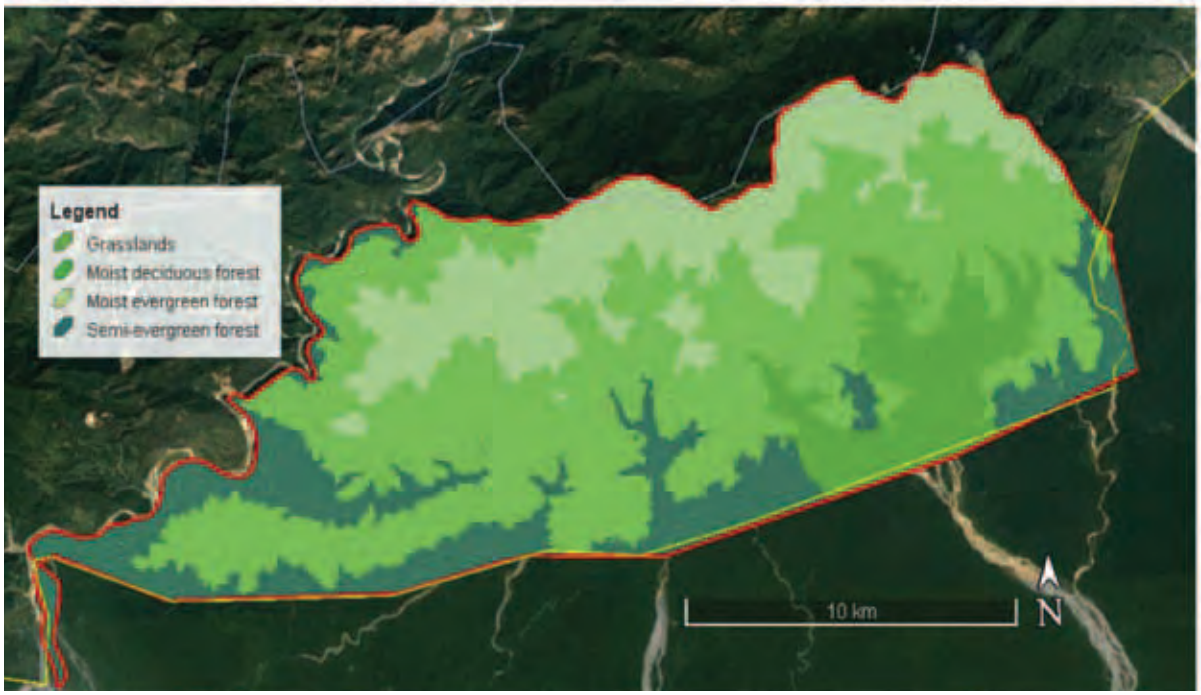
Source: Asian Development Bank.

Extensive riverine and/or grassland vegetation occurs adjacent to the Longa and Phipsoo rivers. These grasslands are very important to several species of wildlife that inhabit PWS, including Asian elephants (*Elephas maximus*).

Associated with the diversity of vegetation types and intact dense forest canopy, PWS harbors considerable wildlife species diversity on both national and regional scales. The intact habitats of PWS are increasingly important due to the ongoing loss and fragmentation of forests in neighboring Assam and West Bengal, India. The sanctuary represents the easternmost limit of the Chital (spotted) deer (*Axis axis*) and sal (*Shorea robusta*)-dominated forests. It is also the westernmost limit of the endangered golden langur (*Trachypithecus geei*) and the threatened agar tree (*Aquilaria malaccensis*). Its intact habitats support a number of other globally endangered and threatened species such as Asian elephant, tiger (*Panthera tigris*), and rufous-necked hornbill (*Aceros nipalensis*).

Phipsoo River. One of five perennial rivers in the Phipsoo Wildlife Sanctuary, Phipsoo River has a wide floodplain along the Indian border but narrows as it reaches the center of the sanctuary (photos by ADB).

Map 3: Distribution of Subtropical Forest Vegetation across Phipsoo Wildlife Sanctuary



Note: The subtropical forest vegetation includes semi-evergreen, moist evergreen, and moist deciduous forests. Also shown are the major grasslands located along the Longa and Phipsoo river drainages.

Source: Asian Development Bank.

At least two critically endangered species have been documented as occurring in PWS: the white-bellied heron (*Adrea insignis*) and the Chinese pangolin (*Manis pentadactyla*), both documented during the BBA. To date, 131 species of birds have been documented in the sanctuary (PWS CMP, Norbu and Tobgay 2012).

Subtropical, moist habitats. Phipsoo Wildlife Sanctuary is composed of typically subtropical semi-evergreen (left) and moist deciduous forest (right) habitats (photos by ADB).

Grassland habitats. The Longa (left) and Phipsoo (right) river drainages run through adjacent grassland habitats (photos by ADB).

Since PWS became operational, its forest rangers have worked under the specter of threats from various militant groups and resource poachers. Security issues were also faced as field studies were conducted for the BBA in December 2014. These military and security issues remain a concern and highlight the real and constant risk faced by PWS' rangers, as documented in the CMP (Norbu and Tobgay 2012). The BBA added to this exposure even after the study plan was modified substantially, and substantial biological insights were gained in spite of the duress under which the assessment was conducted.

Degrading natural environments. Loss and fragmentation of wildlife habitats adjacent to Phipsoo Wildlife Sanctuary are observed in neighboring Assam and West Bengal, India, due to deforestation and conversion of land into tea plantations (photos by ADB).

In the wild. A female leopard and its cub on Dude Ridge captured through camera trapping as part of the biodiversity baseline assessment in 2015 (photo by ADB).

III. COORDINATION AND CONSULTATION

With a project of this scope and scale, especially involving one of Bhutan's premiere protected areas and associated security concerns, considerable coordination and consultation was paramount. This coordination occurred not only at the onset of the BBA, but throughout the planning and duration of the study, including the ensuing field activities. Frequent logistical coordination with the Department of Roads (DOR) and WCD was carried out throughout the BBA.

Much of the upfront project coordination occurred in October 2014 when meetings were held with the Ministry of Works and Human Settlements; Royal Society for Protection of Nature (RSPN); WCD; Department of Forests and Park Services, and the Gross National Happiness Commission.

As part of the refined coordination on the biodiversity assessment study plan and planned field activities, as well as upon review of the stipulations included in the Department of Forests and Park Services' clearance for BBA field activities, further coordination meetings were held with WCD and WWF-Bhutan in December 2014.
WWF-Bhutan agreed to provide logistical and technical support for accomplishment of the BBA, including sharing data and integrating the project into their Transboundary Manas Conservation Area initiative.

Following the initial field activities, with heightened security concerns, a project status meeting and a security update meeting were held in January 2015 with DOR, WCD, and PWS.

After the project was cancelled and BBA field activities were stopped, a "closeout" workshop was held in October 2015 with all partners (Ministry of Works and Human Settlements, Ministry of Forests, DOR, WCD, World Wildlife Fund for Nature [WWF]-Bhutan, RSPN, and Asian Development Bank [ADB]) to discuss the findings of the study.

Roaming free. A Sambar doe and fawn captured through camera trapping in 2015 (photo by ADB).

IV. METHODOLOGY FOLLOWED FOR DATA COLLECTION AND ANALYSIS

A. GENERAL BIODIVERSITY BASELINE ASSESSMENT APPROACH

The PWS BBA was intended to provide a comprehensive biological baseline to determine if a road could be built through PWS consistent with ADB's Safeguard Policy Statement (SPS) (2009). However, since a decision was subsequently made by the Government of Bhutan to cancel consideration of a road through PWS, this report serves to document the results of the BBA field work and contribute to the increased understanding of the sanctuary's biodiversity baseline.

A detailed study plan was developed to guide field activities to accomplish the BBA, with an initial programmed span of a year of field assessment (Table 1). Even under the December 2014 study plan, which embodied a rigorous, systematic approach to assessing biodiversity on a grid system overlaying the entirety of PWS, the general approach to quantifying biodiversity was still largely characteristic of a "rapid biological assessment". In coordinating with PWS staff, this approach with its four planned field excursions to PWS through October 2015 was projected to require human resources (PWS rangers, porters, and ADB consultants) approaching 625 person-days for *each* excursion. This reflected the logistical challenges faced when working in a remote area with limited access and a steep terrain.

Due to elevated security concerns during the initial stages of the field studies in December 2014, the study plan was further streamlined to minimize risks to the study team. Thus, the study plan's rapid assessment approach was hastened. Planned field excursions were reduced from four to two. A stratified approach was used instead of the originally planned rigorous systematic grid approach, which largely limited field activities to the southern two-thirds of PWS (though the 2014 PWS–WCD camera trapping covered the entire sanctuary). Modified avian and forest survey protocols were used to reduce excessive exposure risk at sampling sites. This was the context under which the BBA was conducted. Though abbreviated by the changes to the study plan and suspension of BBA activities after a single field excursion (excluding the recovery of remote cameras), (Table 1), substantial information and insights on PWS' biodiversity was gained.

With the amendment to the BBA study plan necessitated by security concerns, an alternative approach was developed for the conduct of the BBA. Sampling activities were stratified within four assessment zones corresponding to PWS terrain and elevation (e.g., border lowlands; and lower, middle, and upper foothills) and anticipated

Table 1: Study Plan for Biodiversity Baseline Assessment Tasks, 2015

Biodiversity Assessment Task	Month Task Conducted (planned versus accomplished)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mammalian camera trapping												
Avian survey												
Overstory tree and snag sampling												
Understory plant, orchid sampling												
Fish population survey												
Reptile and amphibian survey												
Butterfly survey												
IUCN-listed wildlife species survey												
Assessment of special habitats												

IUCN = International Union for the Conservation of Nature.

Note: Programmed tasks in green; accomplished tasks in orange.

Source: Asian Development Bank.

corresponding vegetation type (Table 2). The lower three assessment zones were sampled with a relatively proportional effort. Field assessment activities were not conducted in the upper foothills zone due to streamlining to address security and logistical concerns. This stratification approach served as the basis for documenting and comparing biodiversity across PWS. The assimilation of existing biodiversity information and the BBA field activities and analyses were based on this zone approach.

Table 2: Biodiversity Assessment Zones and Associated Vegetation Types

Assessment Zone	Elevation (masl)	Vegetation Type
Border Lowlands	≈100–300	Semi-evergreen forest
Lower Foothills	≈300–700	Moist deciduous forest
Middle Foothills	≈700–1,100	Moist evergreen forest
Upper Foothills	≈1,100–1,700	

masl = meters above sea level.

Note: Biodiversity sampling in the assessment zones and associated vegetation types were stratified at Phipsoo Wildlife Sanctuary. The color scheme associated with the lower three zones is applied throughout this BBA report.

Source: Asian Development Bank.

B. ASSIMILATION OF EXISTING BIODIVERSITY INFORMATION

In addition to conducting planned field activities under the amended January 2015 study plan, existing information relative to PWS' biodiversity was assimilated and analyzed. This information and analysis ranged from conducting desktop biodiversity assessment, analyzing the 2014 PWS/WCD camera trapping data, to completing normalized difference vegetation index (NDVI) modeling.

1. Desktop Biodiversity Screening

Desktop screening was conducted to compile a listing of species of concern for use in study plan development and to determine if PWS' natural and modified habitats potentially constitute critical habitat for any threatened or endangered species. The online Integrated Biodiversity Assessment Tool (IBAT) was used to generate a listing of IUCN-listed species that might occur in or adjacent (within 50 kilometers [km]) to PWS. Desktop analysis was conducted using the IBAT, IUCN profiles, and other information to negotiate ADB's SPS decision framework to assess whether PWS natural habitats for each of the critically endangered, endangered, or FNCA Schedule 1 candidate species potentially constitutes critical habitat globally important to their survival and recovery.

2. Forest Plantation Inventory

On the eastern half of the sanctuary up to the Pingkhua River drainage, much forest habitat has reportedly been modified by the harvest of native forest species with subsequent replanting of teak (*Tectona grandis*) in plantation plots dating back to the 1950s and 1960s. These plantation forests exhibit considerably lower plant species diversity than natural habitats remaining in the area. PWS rangers reported they had inventoried and mapped approximately 50 plantation plots within this area of PWS, and provided their inventory for its use in delineating potential modified or degraded habitats.

Teak plantation in the sanctuary. A modified habitat with lower vegetative diversity than the natural habitat (photo by ADB).

3. Normalized Difference Vegetation Index Modeling

The NDVI can be used to assess differences in satellite imagery spectral bands to yield a measure of the fraction of absorbed photosynthetically active radiation present in vegetation at a given time. This fraction can be compared across years and correlated to various parameters such as canopy closure. The study plan incorporated a comparison of satellite imagery employing NDVI methodology to assess measurable differences or trends in forest canopy cover over time.

WWF-Bhutan was conducting an NDVI assessment at a regional scale that overlapped with the PWS, and provided the study team with files of their NDVI imagery of PWS taken in 2001 and 2010 to facilitate the assessment and comparison. This information may provide insights into the impact of any trends in forest vegetation or canopy and wildlife populations, as well as aid in the delineation of natural and modified habitats at PWS. After first ensuring that the imagery was accurately registered spatially, the canopy density class distributions over time were compared. The distribution and proportion of rasters where canopy density was measurably different (e.g., change in density class) were assessed to detect whether the canopy was more or less dense. The spatial distribution of rasters exhibiting canopy density class differences was mapped for evaluation of patterns of change.

4. PWS–WDC Mammalian Camera Trapping

During 2014, PWS rangers, with the financial support of WWF-Bhutan, conducted extensive remote camera trapping at 29 sites across PWS. Camera trapping was conducted by PWS rangers on March–August 2014 (6 months). A copy of the summary data for each camera trapping site was provided by the WCD, and the study reformatted the data for

subsequent analysis. The summary data included records for mammals (24 species), birds (16 species), domestic animals, and humans. As the primary focus of the camera trapping was to document the relative species richness and abundance of mammalian species, only the results were analyzed and statistical analyses for mammals was conducted. 40% of the sites had ≤ 1 bird record, and birds accounted for only 2.5% of all animals recorded by the cameras. The results for poachers making incursions into PWS from neighboring India was also documented.

Mammal data was summarized by camera site using data provided by WCD; and included total records for each species at each camera site. The analysis relied on both the number of different species and total number of individual animals for each species recorded by the cameras at each site. The 29 camera sites were assigned to one of the four assessment zones, including the lower three used in the BBA (Table 1) and the upper foothills zone where cameras were installed; this provided near-total monitoring coverage of PWS.

The Shannon–Weaver Diversity Indices (SDI) was calculated for each camera trapping site, a widely accepted measure of species biodiversity (Shannon and Weaver 1949 and Jost 2006). SDI reflects biodiversity as a function of the number of different species in a community (species richness), and the proportion of individuals of each species compared to the number of individuals of other species in the community—or a relative reflection of how rare or common each species is (species evenness). Analysis of variance (ANOVA) was employed to compare means among the four assessment zones for various

Nighttime stroll. Asian elephants roam around the sanctuary (photo from Bhutan Wildlfie Conservation Division).

camera trapping data parameters to elucidate meaningful differences among zones. Where ANOVA yielded significant differences ($\alpha \leq 0.05$), a post-hoc testing was conducted between group comparisons of means using modified Tukey testing for unequal sample sizes. The means among zones for these biodiversity parameters or metrics were compared based on the following:

(i) number of species recorded per site;
(ii) number of total animals recorded per site;
(iii) proportion of the total animals recorded at each site, averaged across all mammal species (proportion data were ArcSin transformed for ANOVA comparison); and
(iv) SDI for each site.

C. BIODIVERSITY BASELINE ASSESSMENT METHODS

Surveys were conducted for a wide range of taxa, including forest vegetation, birds, mammals, fish, and other animals; as well as inventorying and assessing special habitats such as khar (salt lick) formations, grasslands, and illegal harvest of sal and other trees.

1. Forest Overstory Tree, Orchid, and Snag Inventory

Previous PWS forest surveys identified over 160 species of trees within PWS (PWS CMP, Norbu and Tobgay 2012). The intent of the forest inventory was to yield comparable baseline estimates of tree species diversity and overstory composition (tree density and basal area) among assessment zones. Overstory tree species baseline data was gathered to yield information similar to assessments done in other sal-dominated forests in the region (Sah 2000 and Gautam and Devoe 2006). PWS rangers and WCD staff with extensive forestry and botany expertise assisted with the inventory.

A "plotless" (or point) overstory tree sampling approach was employed using wedge prisms (Basal Area Factor 10) to estimate tree density and basal area contributed by different species present in the PWS forest canopy (Avery 1975). Such an approach is considered plotless as the sampling of trees is dependent on tree distribution and size; larger trees were "tallied" further away from the sampling point than smaller trees. The number of trees "tallied" using the wedge prism for each site was multiplied by the basal area factor and converted to metric units to yield the number of trees per hectare and basal area per hectare contributed by each species. Sampling was conducted at a single point for each site (Map 2), with points generally corresponding to the trees upon which the remote cameras were affixed.

Snags (dead standing trees), which are important to several species of birds for nesting and feeding, were inventoried at the sample sites using a 50-m radius plot centered upon the point where overstory tree prism sampling was conducted. All snags were counted within the plots (0.8 ha in size) and assigned to size classes: (i) small (<20 cm in diameter), (ii) medium (21 cm–50 cm), and (iii) large (>50 cm). Snag densities were converted to number per hectare by size class.

"Plotless" overstory tree sampling. This approach involves the use of wedge prism to survey trees based on distribution and size in a site (photo by ADB).

Orchids are considered indicator species due to their environmental sensitivity to forest canopy integrity, air quality, and other factors. Fifteen species of orchids were previously documented at PWS (PWS CMP, Norbu and Tobgay 2012). Orchid occurrence was studied within a single 20 m^2 plot at each forest sampling site. Plants were identified according to genus and their predominant growth habit: (i) epiphyte (on trees), (ii) terrestrial, or (iii) lithophyte (on rocks or rocky substrate).

2. Avian Species Inventory

Previously, 131 species of birds were documented as occurring within PWS (PWS CMP, Norbu and Tobgay 2012). The original study plan called for using avian point counts to sample PWS' bird communities, as they are one of the most commonly used survey techniques for determining avian species composition and abundance (Bibby and Burgess 1992, 2000). Point counts are especially useful in difficult terrain where it is not possible to establish transects or other techniques (Bibby and Burgess 1992), such as PWS. Point counts typically last 1.5–2.0 hours depending on bird activity (Bibby and Burgess 1992) where the surveyor wanders slowly around a site encompassing an area of approximately 3 ha in search of or following up on bird vocalizations. This approach would entail considerable "lingering". In light of the security concerns, the avian inventory protocol was modified to be more of a "moving" point count. In the latter, birds were surveyed (visually and by vocalizations) while travelling between camera trapping sites. While cameras were installed and vegetation was sampled at sites, typically taking up to 45 minutes, the avian survey then took on more of the character of a true point count.



Diversity of species. Different biodiversity baseline assessment methods reveal the presence of various species, such as (i) the snag-dependent greater flameback (photo by iStock.com) and (ii) an epephytic orchid (photo by ADB). Avian surveys were conducted in different sites, including (iii) Ranga Kohala (photo by ADB).

Avian surveys were conducted during the early morning hours immediately after sunrise when birds were most active and calling most consistent, typically over a 4-hour period (Ralph et al. 1995). Surveys were also done in the late afternoon or evening when birds were again active. Winter season surveys were conducted in January and February 2015. Morning and afternoon survey results were recorded separately, as were surveys that crossed assessment zones. Surveys were only conducted under suitable conditions (e.g., no high winds). An experienced PWS ranger assisted with all surveys to maintain consistency across days, surveys, and zones.

The BBA study plan programmed a second spring season avian survey for April and May 2015; however, this survey did not occur due to suspension of the BBA.

3. Mammalian Species Inventory

Like the 2014 mammalian camera trapping effort undertaken by PWS rangers, camera trapping was used to obtain mammalian species composition, distribution, and relative density information across zones (Tripathi et al. 2012). Efforts were focused on the southern two-thirds of PWS. It also complemented the prior 2014 effort and yielded 8 months of baseline monitoring of mammalian species diversity and relative abundance. A total of 45 remote infrared-triggered cameras (Maps 2 and 7) were installed at 40 sites during January and February 2015.

The cameras were spread fairly evenly across the southern two-thirds of PWS and within the lower three assessment zones, except the area west of the Pingkhua River drainage, which had higher security risks. Cameras were installed at 17 of the original sites used by

Camera trapping. A trunk-mounted camera is packed in elephant dung to prevent tampering by animals (photo by ADB).

PWS WCD for their 2014 camera trapping. In addition, WCD requested that multiple cameras be installed at some sites to better target and detect the presence of smaller mammal species, which was done at six sites. Several new camera sites were also selected primarily to target species not yet documented at PWS, such as otters (*Latura*, *Laturogale*, *Aonyx* spp.) and Chinese pangolin (*Manis pentadactyla*).

Cameras were typically mounted to the trunks of trees, though they also were installed on higher limbs when potential theft or tampering by elephants was a concern. Cameras were programmed to record a 3-image series on a 5-second delay to capture passing animals, as well as 10-second video clips. Cameras were tested prior to arming. Lower, exposed cameras were packed in elephant (or gaur) dung to discourage tampering by elephants.

Cameras were recovered in May 2015 prior to full onset of the summer monsoon. Their memory SD (secure digital) cards were removed and copied for analysis of data by a single individual to maintain consistency. Individual animals and associated groups were counted a single time even when their images spanned multiple (often dozens, and even hundreds in the case of lingering gaur) camera images. Typically, a group was considered "different" for analysis if no images of animals were recorded for at least an hour. It is important to stress that some of the same animals were invariably recounted on different days or even the same day. Animals were classified into species, as well as by sex and age (adult, subadult, and young) when evident. As with the 2014 camera trapping data, only mammalian species were considered in the analysis. However, bird records were also compiled, but were found to represent less than 1% of all records. Records involving poachers making incursions into PWS were also recorded. Representative photos and videos were cataloged for future reference.

Test runs. A field test done for an infrared trail camera at Phipsoo Wildlife Sanctuary (photo by ADB).

Mammal activity and temporal relationships were assessed to determine the number of hourly images for all species combined, and individually for the more common species (or groups of species; e.g., civets, felids). The proportion of records that occurred during nighttime (nocturnal) versus daytime hours (diurnal) was also calculated.

4. Overstory Tree, Avian, and Mammalian Species Biodiversity Metrics and Statistics

For the forest overstory tree, avian, and mammalian species inventory information, the data was summarized and analyzed in a similar manner for all three taxa to develop metrics for measuring and comparing biodiversity across assessment zones. As described for the 2014 PWS camera trapping data (Section IV. B. 4), the same biodiversity parameters or metrics (e.g., SDI, number of species, and mean proportion of total records) for the new BBA data were calculated and means for the three assessment zones (Table 2) were compared. The proportions of total records to account for unequal numbers of sites across assessment zones were corrected.

In addition to the above, measures of species overlap and species composition similarity between paired comparisons of the three assessment zones (e.g., border lowlands versus lower forest, border lowlands versus middle forest, and lower forest versus middle forest); and among all three zones were calculated. The number of species occurring in both zones (all three in the case of comparing all zones) was counted and divided by the total number of combined species that occur in both zones (or all three in the case of comparing all zones) to yield the proportion of species overlap. Species composition similarity was

calculated by summing the lower percentage of each overlapping species' contribution toward the total observations or records for that species for each zone comparison (Jost 2006).

As with the 2014 PWS camera trapping, ANOVA was used to compare biodiversity metric means among the assessment zones for data pertaining to each taxon to elucidate meaningful differences. Where ANOVA yielded significant differences, post-hoc testing was conducted for between-group comparisons of means using Tukey testing for unequal sample sizes.

The results of mammal camera trapping by PWS in 2014 was compared to the 2015 BBA effort for those sites at which cameras were operational during both efforts. *t*-testing was used to compare the means between years for SDI, number of species, and proportion of total animals. The records for the 15 camera trapping sites operated in both 2014 and 2015 were merged to derive combined means for 8 months of camera trapping. These means were compared using analysis of covariance (ANCOVA), where "year" was factored into the analysis as a covariant to correct for any differences among the 2014 and 2015 efforts, to determine differences among assessment zones for the biodiversity metrics.

Comparisons were made between mean mammalian SDI and number of species between those sites located within modified habitat (n = 6) and immediately adjacent natural habitat (n = 7) located within the border lowland and lower foothills assessment zones near the Indo–Bhutan border. These means were compared by *t*-testing. This analysis allowed the assessment of impacts of conversion from natural to modified or degraded habitats on mammalian species diversity.

For temporal mammalian species records distribution by hour of the day, a Chi-square (X^2) comparison was used to determine if the observed number of records were different from the expected number (assuming even numbers each hour). This helped determine whether observed mammal activity patterns were more nocturnal or diurnal than expected.

5. Fish Species Inventory

Fish inventory or sampling was planned along four of PWS' rivers; however, only the Nichula River was sampled during the January–February 2015 study. Multiple fish seine nets (5 m–10 m) were employed to sample fish in various stream and river types (e.g., pools, riffles) at five sites spread along the Nichula River (Figure 9). Sampling sites were 30 m–50 m lengths of the river along which fish were driven into a "blocking" net and seined. Seined fish were placed into a bucket, counted, and measured with a tape measure (Figure 9); and identified using the RMNP freshwater fishes guide (Dorji and Wangchuck 2014) using a magnifying lens as needed. Representative photographs were taken of each fish species.

Due to cancellation of the project, sampling along the Phipsoo, Ranga, and Pingkhua rivers was not accomplished though fish were observed to be plentiful in pools and riffles along all three rivers.

Fish sampling. A seine net is used to catch fish for collecting data on size, length, and numbers for the species inventory (photos by ADB).

6. Other IUCN-Listed Wildlife Species Inventory

During the conduct of other BBA field activities at PWS, the presence and distribution of other IUCN-listed wildlife species were also documented. These observations augmented the formal surveys (e.g., avian and mammalian inventories) and provided additional insights to help establish a PWS biodiversity baseline. Substantial data was collected for white-bellied heron, golden langur, and hornbill species.

White-bellied heron. The IUCN CR-listed white-bellied heron does not breed at PWS, and PWS' habitat has not previously been identified as important to the species (e.g., Pradhan et al. 2011). Herons breed along Bhutan's major rivers, including the Sunkosh River to the west of PWS, nesting only in Chir pines (*Pinus roxburghii*) that are not present in the sanctuary. Pradhan et al. (2011) documented the relatively low (compared to global heron species) fish foraging success rate by herons along major rivers; PWS' rivers may provide foraging habitat for herons. PWS rangers previously reported observing a limited number (3–4) of herons along the Longa and Phipsoo rivers, including one near the Phipsoo field station in November 2014. During all BBA activities, especially when traversing river courses, the study team searched for herons and/or signs of them with binoculars. Observations were documented and GPS locations recorded.

Golden langur. Though PWS represents just 4% of the extant global range for the IUCN EN golden langur (the most of any IUCN-listed species at PWS), the sanctuary's contiguous, mature forest likely constitutes some of the best remaining habitat for the species in Asia compared to its habitats in India (Das et al. 2008). PWS also lies at the westernmost extent of the langur's distribution. As the team travelled across PWS and its forested habitats, it documented the presence and distribution of all langur groups and recorded group GPS locations.



IUCN-listed wildlife species. The (i) white-bellied heron (photo by PWS), (ii) golden langur (photo by ADB), and (iii) great hornbill (photo by ADB) are among species found in Phipsoo Wildlife Sanctuary.

Hornbills. Hornbills are generally considered to be indicators of intact and contiguous mature forest canopy needed for nesting and foraging, especially the presence of and diversity of mature fruit-bearing trees (Jinamoy et al. 2014). During the BBA field efforts in January and February 2015, the team documented all visual observations and calling of four species of hornbills at PWS: great (*Buceros bicornis*), Oriental pied (*Anthracocerus albirostris*), wreathed (*Aceros undulates*), and IUCN-listed VU rufous-necked hornbills. GPS locations were recorded for all hornbill locations.

7. Special Habitat Inventory and Assessment

The location of the major khar (salt lick) formations across PWS was inventoried, and grassland health assessment relative to the presence of invasive species that are affecting grassland health and vigor was conducted. The stumps of sal and other tree species harvested by poachers along the Indian border were also inventoried.

Khar formations. Numerous known khar formations are located across PWS, most within the lower and middle foothills zones of the sanctuary. All khars were inventoried and their GPS locations recorded. These formations are vitally important to Asian elephants. They are also important to several other large mammal species, including gaur (*Bos gaurus*), Himalayan serrow (*Capricornis thar*), sambar (*Rusa unicolor*), and barking deer (*Muntiacus muntjac*), among others.

Salt obtained from khar formations supplements animals' dietary need for sodium, especially for pregnant and lactating females. This supplemental salt from khar formations is particularly important in areas where sodium deficiencies occur in preferred forage plants. Concentrated wildlife use occurs around most of the PWS khars; three mammalian inventory cameras were installed at khars to document use by wildlife.

Khar at Phipsoo Wildlife Sanctuary. Evidence of elephant use seen in a khar formation (photos by ADB).

Grassland habitat condition assessment. Grassland habitats primarily occur within and adjacent to the Longa and Phipsoo river drainages (Map 2). Grassland habitats are especially important to IUCN EN Asian elephants at PWS, and to other species including gaur, spotted deer, and hog deer for foraging. Elephants constitute the last extant large "mega-herbivore" species (Choudhury et al. 2008), and as such they rely on productive habitats to meet their high dietary needs. They are foraging generalists and browse and graze on many plants, feeding up to 20 hours per day, consuming up to 150 kg of plants per day. They also defecate frequently, producing 100 kg per day of dung, which helps disperse germinating seeds.

Asian elephant. The most abundant mammalian species in Phipsoo Wildlife Sanctuary (photo by iStock.com).

Conducive to plant growth. Rich grassland habitat along the Longa River shows encroachment of the (i) invasive species *Chromolaena spp*. Movement of animals also support (ii) plant growth as their dung transport seeds along Ranga Kohala. (Photos by ADB)

Elephants at PWS once travelled frequently between Bhutan and India, though these movements have diminished somewhat due to severe habitat loss and fragmentation. However, elephants, gaur, and other species through their feces continue to transport the seeds of invasive species from neighboring Assam and West Bengal to PWS where they have become well established within nearly all grasslands across the sanctuary. In particular, plants of the genus *Chromolaena* (Siam weed) have become widespread and now compete directly with the native vegetation and indirectly exhibit strong allelopathic effects, all diminishing grassland productivity and health (Tripathi et al. 2012).

Baseline inventory of the percentage ground cover consisted of native versus invasive species at several grassland sites, employing a line intercept transect methodology (Canfield 1941). A 30 m tape was randomly located and stretched through the grasslands. The distance along the tape occupied by native grass, shrub, or invasive species was recorded, and summed to estimate their percentage of ground cover. Two to three transects were conducted at each of the inventoried sites along the Ranga and Phipsoo rivers.

Due to cancellation of the project and suspension of BBA field activities, further grassland assessment was not conducted.

Illegal tree harvest inventory. The illegal harvest of trees at PWS has been documented as a concern (PWS CMP, Norbu and Tobgay 2012). Illegal tree harvest is most prevalent along the Indian border west of the Pingkhua River. This illegal harvest has focused on protected and limited-distribution sal, though other species have also been harvested. While the illegal harvest of trees has been reported by PWS rangers and WWF-Bhutan,

Prevaling concern. The diameter of a sal tree stump is measured as part of an illegal tree harvest inventory (photo by ADB).

no quantifiable inventory has been conducted, nor has there been any assessment of the impact of such harvest to forest composition and canopy integrity.

During the BBA field studies across PWS, all stumps from illegally harvested trees were documented and photographed, with GPS locations. Tree stumps were identified as to species, and the diameter of the stump was measured. Additionally, in the area where illegal harvest was most prevalent, west of Ranga Kohala, the team endeavored to conduct an intensive area count to yield an estimate of the stumps per hectare by species and size. From the GIS inventory, it was possible to superimpose four 1 ha plots on top of the intensively sampled area to estimate stump density.

Further inventory of stumps from illegally harvested trees and transects on the lower slopes of the foothills to investigate moving up of illegal tree harvesting could not be carried out due to cancellation of the project and suspension of BBA activities.

8. Biodiversity Indices

For relative comparison purposes among assessment zones, as well as to summarize the overall biodiversity associated with each assessment zone, biodiversity indices were derived from 10 measured metrics. The measured values for each metric were scaled to equal 1.0 across all three zones, and assigned proportional values to each individual zone. Overall, an average biodiversity index was derived for each zone considering the 10 scaled metric values. The 10 metrics used to derive the indices included overstory

tree, avian, and mammalian SDI; proportion of total mammals; number of orchid species; number of white-bellied heron, golden langur, and hornbill observations; number of khar locations; and number of tiger camera records within each zone. The average ArcSin-transformed biodiversity metrics were compared among assessment zones with ANOVA to assess differences. Where differences were found, post-hoc testing of between-group comparisons of means was conducted using Tukey testing.

Gradient colors. A dried fungi with shades of red, orange, yellow, and brown on its surface (photo by ADB).

V. ASSIMILATION OF EXISTING BIODIVERSITY INFORMATION

A. DESKTOP BIODIVERSITY SCREENING

The desktop biodiversity query of the Integrated Biodiversity Assessment Tool (IBAT) generated a list of 79 IUCN-listed species that might occur in or adjacent (within 50 km) to PWS: 43 bird, 29 mammal, 4 reptile, 2 invertebrate, and 1 amphibian species. The IBAT query also identified that PWS is classified as an IUCN Category IV protected area and considered a key biodiversity area. Other nationally recognized key biodiversity areas occur within 10 km: Ripu–Chirang Reserve Forest (legally protected area and proposed for wildlife sanctuary status) in India and the Sarpang–Gelephu Foothills encompassing PWS. PWS lies within 50 km of Bhutan's IUCN Category II protected Jigme Singye Wangchuck and Royal Manas national parks to which it is linked via Bhutan's network of corridors (Map 1), as well as the Category IV Buxa Tiger Reserve and National Park in neighboring India. The entire region falls within WWF-Bhutan's Transboundary Manus Conservation Area.

Further desktop analysis was conducted using the respective IUCN species profiles and range maps and other resources (e.g., PWS CMP, Norbu and Tobgay 2012, 2014 PWS mammalian camera trapping) to assess the presence of the 79 IBAT-listed (and other) species at PWS. This, along with the results of the 2015 BBA (which added six previously undocumented species) allowed the development of a refined listing of confirmed IUCN- and FNCA Schedule I-listed species, summarized in Table 3. A total of 29 listed species were confirmed at PWS, including 27 afforded IUCN status (12 also with FNCA Schedule I status) and two included as FNCA Schedule 1 species. Mammals accounted for the majority (74%) of the confirmed listed species (Table 3). This listing does not include sal, which is protected in Bhutan and has limited distribution, and thus is afforded special status and consideration for critical habitat designation. A listing of all 30 confirmed species is provided in Table 4.

Table 3: Species Present at Phipsoo Wildlife Sanctuary

Tax[a]	IUCN Red List Status Species				FNCA Schedule I[a]	Total[b]
	CR	EN	VU	NT		
Mammals	1	6	5	6	11 (2)	20
Birds	1	0	1	0	1 (0)	2
Fish	0	1	1	2	1 (0)	4
Reptiles	0	0	2	0	0	2
Plants[c]	0	1	0	0	1 (0)	1
All	2	8	9	8	14 (2)	29

CR = critically endangered, EN = endangered, FNCA = Forest and Nature Conservation Act of Bhutan, IUCN = International Union for the Conservation of Nature, NT= near threatened, VU = vulnerable.

Note: Number of species confirmed as present, by taxa and IUCN Red Book category; as well as species listed only under the FNCA (not IUCN), and candidates for critical habitat designation.

[a] All Schedule I (those species not listed under IUCN in parentheses).

[b] Includes only those Schedule 1 species not listed under IUCN.

[c] Does not include sal, a Bhutan protected species with limited distribution.

Source: Asian Development Bank.

Table 4: Species Conferred with IUCN and/or Bhutan FNCA Status in Phipsoo Wildlife Sanctuary

Species (Scientific Name)	Listed Status		Confirmed at PWS		Critical[a] Habitat Candidate
	IUCN	Bhutan FNCA	Desktop Analysis	2015 BBA	
Mammals					
Chinese pangolin *(Manis pentadactyla)*	CR	–	✓	✓	Yes
Hog deer *(Axis porcinus)*	EN	–	✓		Yes
Asiatic water buffalo *(Bubalus bubalis)*	EN	Schedule I	✓		Yes
Dhole *(Cuon alpinus)*	EN	–	✓	✓	Yes
Asian elephant *(Elephas maximus)*	EN	Schedule I	✓	✓	Yes
Tiger *(Panthera tigris)*	EN	Schedule I	✓	✓	Yes
Golden langur *(Trachypithecus geei)*	EN	Schedule I	✓	✓	Yes
Gaur *(Bos gaurus)*	VU	Schedule I	✓	✓	Yes
Sambar *(Rusa unicolor)*	VU	–	✓	✓	
Asiatic black bear *(Ursus thibetanus)*	VU	Schedule I	✓	✓	Yes
Clouded leopard *(Neofelis nebulosa)*	VU	Schedule I	✓	✓	Yes

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Table 4 *continued*

Species (Scientific Name)	Listed Status		Confirmed at PWS		Critical[a] Habitat Candidate
	IUCN	Bhutan FNCA	Desktop Analysis	2015 BBA	
Marbled cat *(Pardofelis marmorata)*	VU	–	✓	✓	
Himalayan serow *(Capricornis thar)*	NT	Schedule I	✓	✓	Yes
Asiatic golden cat *(Felis chaus)*	NT	–	✓	✓	
Assamese macaque *(Macaca assamensis)*	NT	–	✓	✓	
Leopard *(Panthera pardus)*	NT	Schedule I	✓	✓	Yes
Black giant squirrel *(Ratufa bicolor)*	NT	–	✓	✓	
Large Indian civet *(Viverra zibetha)*	NT	–	✓	✓	
Chital (spotted) deer *(Axis axis)*	LC	Schedule I	✓	✓	Yes
Leopard cat *(Prionailurus bengalensis)*	LC	Schedule I	✓	✓	Yes
Birds					
White-bellied heron *(Ardea insignis)*	CR	–	✓	✓	Yes
Rufous-necked hornbill *(Aceros nipalensis)*	VU	Schedule I	✓	✓	Yes
Fish					
(Pterocryptis barakensis)	EN	–		✓	Yes
Giant danio *(Devario aquipimatus)*	VU	–		✓	
Katle *(Neolissochilus hexagonolepis)*	NT	–		✓	
Golden mahseer *(Tor tor)*	NT	Schedule I		✓	Yes
Reptiles					
King cobra *(Ophiophagus Hannah)*	VU	–	✓		
Burmese python *(Python bivittatus)*	VU	–	✓		
Plants					
Agar *(Aquilaria malaccensis)*	VU	Schedule I		✓	Yes
Sal *(Shorea robusta)*	LC	Protected	✓	✓	Yes

– = not listed, BBA = baseline biodiversity assessment, CR = critically endangered, EN = endangered, FNCA = Forest and Nature Conservation Act of Bhutan, IUCN = International Union for the Conservation of Nature, LC = least concern, PWS = Phipsoo Wildlife Sanctuary, NT= near threatened, VU = vulnerable .

[a] Candidate status based on threatened and/or endangered status, including FNCA.

Note: The listing includes species conferred with IUCN and/or Bhutan FNCA status per confirmed occurrence within PWS using desktop biodiversity analysis, or during the 2015 BBA; and species that are candidates for critical habitat designation under ADB's Safeguard Policy Statement (2009), requiring further assessment and study to confirm if critical habitat actually exists.

Source: Asian Development Bank.

B. FOREST PLANTATION INVENTORY

The PWS rangers provided a previously compiled inventory of approximately 50 forest plantation plots located in the southeast portion of the sanctuary (Map 4). Plantations dominated by teak were inventoried within four separate blocks encompassing the plots, ranging in size from 3.5 ha to 1,169 ha. These plantation blocks total 1,206.5 ha or 4.5% of PWS' area. Due to their lower tree and other species diversity, these plantation areas are considered modified habitat or degraded natural habitat under ADB's SPS.

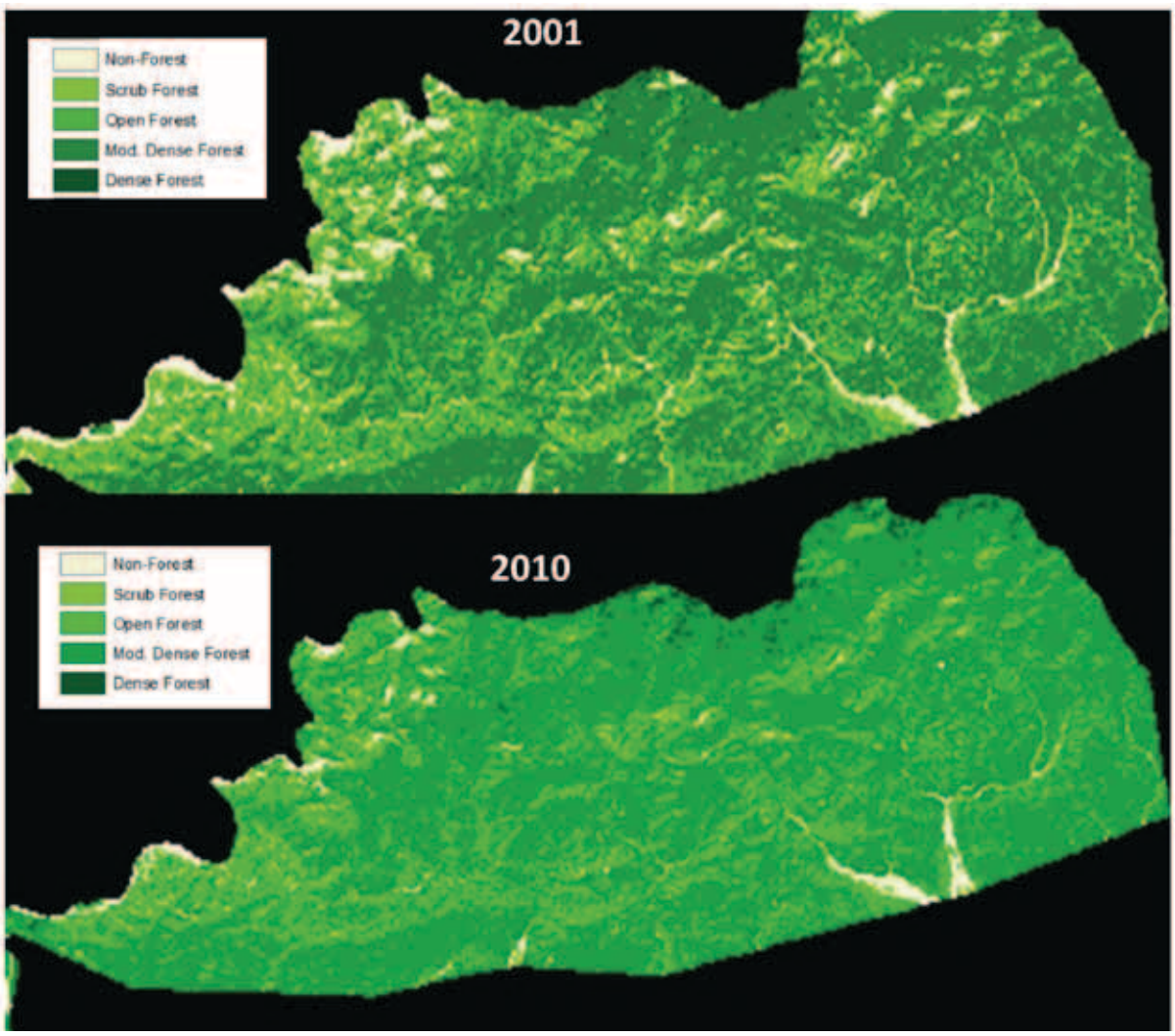
Map 4: Location of Plantation Blocks Inventoried by Phipsoo Wildlife Sanctuary Rangers

Source: Asian Development Bank.

C. NORMALIZED DIFFERENCE VEGETATION INDEX MODELING

Normalized difference vegetation index analysis comparing canopy density classification data provided by the WWF-Bhutan to assess changes from 2001 to 2010 (Map 5) was conducted with the help of a GIS analyst (Jenness Enterprises, Flagstaff, Arizona, United States). The 2001 raster data first needed to be spatially shifted approximately 100 m to the north to improve overlap with the 2010 data and to facilitate accurate comparison between years; this offset in registration between datasets likely was attributable to PWS' mountainous terrain.

Map 5: Classification of Phipsoo Wildlife Sanctuary Forest Canopy Density and Nonforest Habitats Using Normalized Difference Vegetation Index, 2001 and 2010



Source: Data provided by World Wildlife Fund for Nature-Bhutan.

The majority (71.9% of the 2010 classified rasters) of PWS' forests were classified as moderately dense forest, followed by open forest (21.1%; Table 5, Map 5). A negligible portion (0.7%) of PWS' forest was classified as dense forest. There were only modest net changes in the proportions of PWS falling into the density classes from 2001 to 2010 (Table 5), with the greatest change being a 7.2% increase in the area of moderately dense forest. Overall, 5.8% of the rasters realized a drop by one or more density class; 65.4% remained at the same canopy class level; and 28.8% saw an increase in density by one or more classes.

Table 5: Area Classification in Phipsoo Wildlife Sanctuary by Canopy Density Class Using Normalized Difference Vegetation Index (%)

Canopy Density Class	Percent of PWS Total, 2001	Percent of PWS Total, 2010	Percentage Change between Years
Nonforest	8.0	3.3	(4.8)
Scrub forest	8.0	6.3	(1.9)
Open forest	13.2	21.1	+7.2
Moderately dense forest	70.6	71.9	+1.3
Dense forest	0.3	0.7	+0.4

( ) = negative, PWS = Phipsoo Wildlife Sanctuary.

Source: Asian Development Bank.

The NDVI changes between 2001 and 2010 for each forest density class, either becoming more or less dense and shifting to other density classes, or exhibiting no change, are summarized in Table 6 and Map 6. Nearly three-quarters of nonforest became more dense by 2010, with >38% of the area increasing by two or more density classes. Similarly, 73% of scrub forest increased in canopy density between 2001 and 2010 by one or two classes. Over half (56%) of the open forest area increased in density over time, but by a single class, while nearly 40% remained unchanged. The vast majority (92%) of the predominant PWS moderately dense forest area exhibited no change in density class over time.

Table 6: Changes in Forest Density Class Distribution at Phipsoo Wildlife Sanctuary Using Normalized Difference Vegetation Index, 2001 and 2010

2001 Forest Density Class	Change to 2010 Forest Density Class	No. of Density Classes Changed	No. of Rasters	Share of Rasters in Density Class (%)[a]
Nonforest	No change	0	7,244	25.7
	To scrub forest	+1	10,023	35.5
	To open forest	+2	7,093	25.1
	To moderately dense forest	+3	3,847	13.6
Scrub forest	To nonforest	(1)	1,995	4.2
	No change	0	10,907	22.9
	To open forest	+1	23,169	48.5
	To moderately dense forest	+2	11,630	24.4
Open forest	To scrub forest	(1)	4,989	4.2
	No change	0	46,858	39.1
	To moderately dense forest	+1	67,705	56.6
	To dense forest	+2	153	0.1

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Table 6 *continued*

2001 Forest Density Class	Change to 2010 Forest Density Class	No. of Density Classes Changed	No. of Rasters	Share of Rasters in Density Class (%)[a]
Moderately dense forest	To scrub forest	(2)	1,066	0.4
	To open forest	(1)	16,938	6.6
	No change	0	236,392	92.0
	To dense forest	+1	2661	1.0
Dense forest	To moderately dense forest	(1)	618	64.5
	No change	0	340	35.5

( ) = negative.

[a] Percentage of area changed within each 2010 density class.

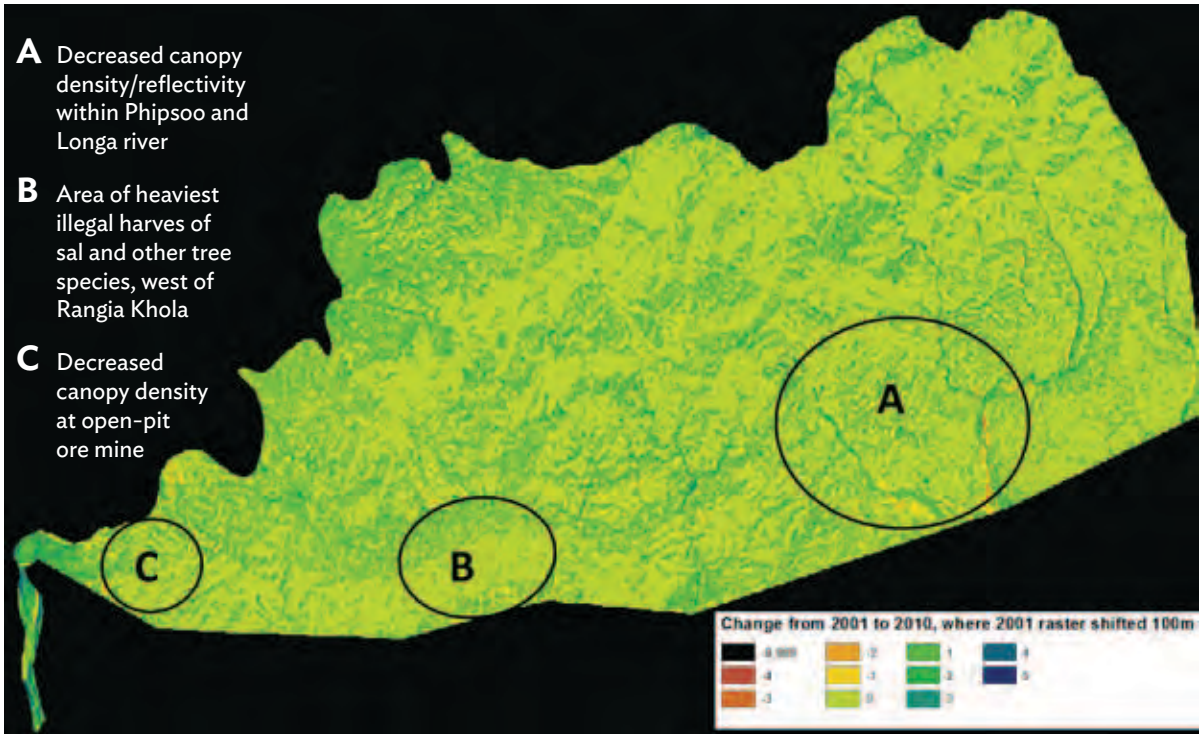
Source: Asian Development Bank.

Caution must be exercised in interpreting the spatial patterns of NDVI density class change at PWS, as many factors may contribute to the observed changes. However, there appear to be some likely explanations for some of the more dramatic changes, especially declines by two or more classes (Map 6). Most apparent is the decline in canopy density within grassland habitats along the Phipsoo and Longa river drainages (Map 6, Area A). These changes may reflect the impact of declining grassland health and vigor attributable to invasive species spread. Huang (2009) used NDVI in a similar manner to assess invasive species impact to grassland phenology in the United States. The PWS analysis points to the severity of this growing conservation issue for IUCN EN Asian elephants and other species. The inventoried area exhibiting some of the heaviest illegal sal harvest west of Ranga Kohala also reflects canopy density decline over time (Map 6, Area B), as does the area in the vicinity of the active open-pit ore mine located on an inholding in the far southwestern corner of PWS, where the forest canopy was eliminated altogether (Map 6, Area C).

D. 2014 MAMMALIAN CAMERA TRAPPING

A total of 8,322 individuals comprising 24 different mammalian species were camera trapped at PWS during 2014, including 15 IUCN-listed species (Table 7). The most photographed species was gaur (IUCN VU), which accounted for 55.6% of all recorded species, followed by Asian elephants (IUCN EN), which accounted for 18.7% of all recorded animals (Table 7). Six different species of cats, over half of the 11 known to occur in Bhutan (Wangchuk et al. 2004), were documented at the camera sites (Table 7). The common leopard (*Panthera pardus*; IUCN NT) was the most common cat species (105 records at 15 of the 29 sites), followed by the smaller leopard cat (*Prionailurus bengalensis*), an FNCA Schedule I species. Endangered tigers were camera trapped on 21 occasions at four sites. Two species of deer accounted for 9.2% of all animals, including the sambar (IUCN VU) and barking deer (Table 7).

Map 6: Changes in Forest Density Class Distribution at Phipsoo Wildlife Sanctuary between 2001 and 2010



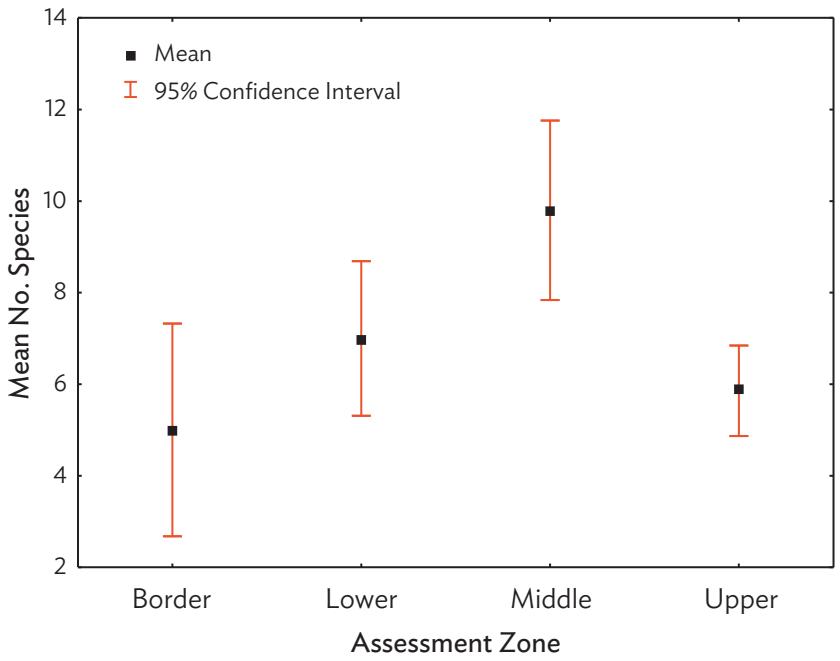
Note: Map shows the degree of change in forest canopy density as a function of the number classes that the vegetation changed: either denser (positive numbers), less dense (negative numbers), or no change (0) over time. The "–9,999" denotes unclassified rasters. Some interpretations of reductions in canopy density are provided (A, B, and C).

Source: Data provided by World Wildlife Fund for Nature-Bhutan.

After assigning the 29 PWS camera sites to one of four assessment zones, the biodiversity metrics for each camera site were calculated and then ANOVA was employed to compare means among the assessment zones, with post-hoc pairwise testing of between group (zones) comparisons when ANOVA yielded significant differences. Significant differences among the assessment zones for several of the mammalian camera trapping metrics (Table 8) were found.

Number of species per site. Significant differences were found to exist among the mean number of species camera trapped per site across assessment zones (Figure 1). The middle foothills mean was greater than that of the border lowlands and upper foothills zones (Table 7). Most notably, an average of nearly twice as many species were "trapped" at middle foothills camera sites (9.8 species) than border lowlands sites (5.0 species). The mean for the adjacent lower foothills zone (7.0 species) did not differ from the middle foothills zone.

Figure 1: Means and 95% Confidence Intervals for Different Species and Camera Sites



Source: Asian Development Bank.

Table 7: Number and Percentage for Each Mammalian Species in Phipsoo Wildlife Sanctuary

Species Common Name	IUCN Status	Camera Trapping Results by Terrain and Vegetative Assessment Zone								
		Border Lowlands		Lower Foothills		Middle Foothills		Upper Foothills		All
		No.	% of Total	No.	% of Total	No.	% of Total	No.	% of Total	No.
Asiatic brush-tailed porcupine	–	4	100.0	0	0.0	0	0.0	0	0.0	4
Asian elephant	EN	293	18.9	207	13.3	1,011	65.1	43	2.8	1,554
Asiatic golden cat	NT	0	0.0	0	0.0	0	0.0	6	100.0	6
Asiatic water buffalo	EN	8	100.0	0	0.0	0	0.0	0	0.0	8
Asiatic wild dog	EN	8	14.5	0	0.0	25	45.5	22	40.0	55
Assamese macaque	NT	82	16.9	4	0.8	399	82.1	1	0.2	486
Barking deer	–	53	16.5	39	12.1	107	33.2	123	38.2	322
Clouded leopard	VU	0	0.0	2	12.5	8	50.0	6	37.5	16

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Table 7 *continued*

Species Common Name	IUCN Status	Camera Trapping Results by Terrain and Vegetative Assessment Zone								
		Border Lowlands		Lower Foothills		Middle Foothills		Upper Foothills		All
		No.	% of Total	No.	% of Total	No.	% of Total	No.	% of Total	No.
Common leopard	NT	16	15.2	24	22.9	63	60.0	2	1.9	105
Crab-eating mongoose	–	3	1.7	6	3.4	149	86.1	15	8.7	173
Gaur	VU	341	7.4	296	6.4	1,809	39.1	2,178	47.1	4,624
Golden langur	EN	0	0.0	2	25.0	6	75.0	0	0.0	8
Himalayan black bear	VU	0	0.0	6	11.8	22	43.1	23	45.1	51
Himalayan crestless porcupine	–	0	0.0	4	22.2	0	0.0	14	77.8	18
Himalayan palm civet	–	0	0.0	6	75.0	0	0.0	2	25.0	8
Himalayan serow	NT	0	0.0	1	2.0	33	64.7	17	33.3	51
Large Indian civet	NT	5	16.1	0	0.0	26	83.9	0	0.0	31
Leopard cat	–	4	9.1	2	4.5	38	86.4	0	0.0	44
Marbled cat	VU	2	25.0	0	0.0	0	0.0	6	75.0	8
Sambar	VU	36	8.1	247	55.4	113	25.3	50	11.2	446
Small Indian civet	–	0	0.0	0	0.0	2	100.0	0	0.0	2
Squirrel	–	0	0.0	1	16.7	5	83.3	0	0.0	6
Tiger	EN	0	0.0	2	9.5	19	90.5	0	0.0	21
Wild pig	–	78	28.4	23	8.4	66	24.0	108	39.3	275
Zone totals and mean percent of total		**933**	**15.7**	**872**	**12.6**	**3,901**	**47.4**	**2,616**	**24.3**	**8,322**

– = no IUCN staus conferred, or not applicable, 0 = none of the species was recorded in that assessment zone, EN = endangered, IUCN = International Union for the Conservation of Nature, NT = near threatened, VU = vulnerable.

Note: Figures refer to camera trap during 2014, as well as totals and mean percentages by terrain and vegetation assessment zone.

Source: Asian Development Bank.

Table 8: Results of ANOVA Testing of Differences among Parameter and Metric Means, 2014

Parameter/ Metric	Means (±SE) by Assessment Zone				ANOVA Testing	
	Border Lowlands	Lower Foothills	Middle Foothills	Upper Foothills	Means Testing	Post-Hoc Tukey Test Group Mean Comparisons
Camera sites	5	7	10	7		
SDI	1.22 ±0.12	1.09 ±0.10	1.72 ±0.09	1.20 ±0.10	$F_{1,3}$=9.04 P<0.001	Middle Foothills > Border Lowlands; *P*=0.041 Lower Foothills; *P*=0.001 Upper Foothills; *P*=0.008
Species	5.0 ±0.9	7.0 ±0.8	9.8±0.7	5.9 ±0.8	$F_{1,3}$=8.00 P<0.001	Middle Foothills > Border Lowlands; *P*=0.006 Upper Foothills; *P*=0.008
No. of animals/site	186.6 ±188.3	113.0 ±159.11	390.2±133.12	402.3 ±159.1	NS *P*=0.471	No differences
Mean[a] proportion of total animals	0.16 ±0.06	0.13± 0.04	0.47±0.14	0.24 ±0.07	$F_{1,3}$=5.16 *P*=0.002	Middle Foothills > Border Lowlands; *P*=0.008 Lower Foothills; *P*=0.004

ANOVA = analysis of variance, SDI = Shannon–Weaver Diversity Indices, SE = standard error.

[a] ArcSin transformations used in testing.

Note: Results of ANOVA testing of differences among parameter and metric means (± standard error) including mean SDI, number of species, number of animals, and mean percentage of total animals camera trapped at 29 sites in 2014.

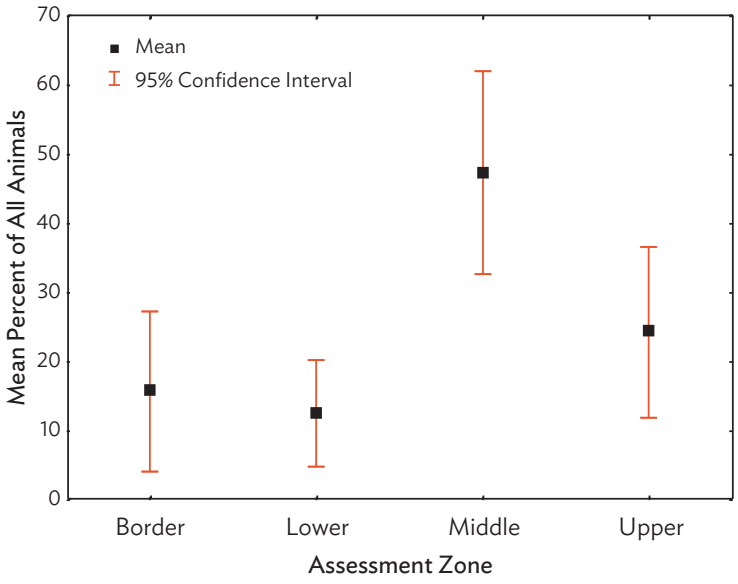
Source: Asian Development Bank.

Number of animals recorded per site. While the mean number of animals recorded at the middle and upper foothills camera sites was 2–3 times greater than that in the Border Lowlands and Lower Foothills sites (Tables 7 and 8), the difference among zones was not significant. There was considerable variation in the number of animals recorded among the sites for a few species, especially gaur records, which ranged from 0 to 1,898 animals across sites.

Proportion of total animals recorded per site. Whereas the mean total numbers of animals recorded at each camera site did not differ among assessment zones, the mean proportion (ArcSin transformed for ANOVA analysis) or percentage of total animals recorded at each site by species did differ significantly (Table 8 and Figure 2). Nearly half (47.4%) of all animals recorded by species were camera trapped at middle foothills sites, which was greater than the percentage recorded at border lowlands (15.7%) and lower foothills (12.6%) sites.

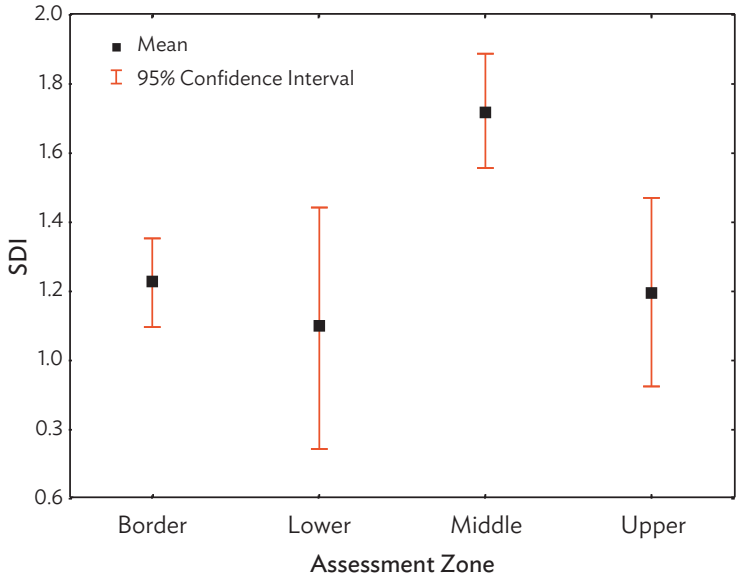
Of the PWS threatened and endangered species (Table 7), only one exhibited a substantial proportion of its camera trapping records within the border lowlands zone; the IUCN EN Asiatic water buffalo (*Bubalus bubalis*). All water buffalo records were made at a single border lowlands camera (and likely as part of a single occurrence) and PWS forest rangers seldom encounter the species at the sanctuary, which sits on the fringes of the species' range. Excluding the water buffalo, the border lowlands camera sites accounted for an average of less than 9% of all animals from 14 other listed species (Table 7).

Figure 2: Means and 95% Confidence Intervals for the Percentage of Total Animals in Assessment Zones



Source: Asian Development Bank.

Figure 3: Shannon–Weaver Diversity Indices Means and 95% Confidence Intervals among Assessment Zones



SDI = Shannon–Weaver Diversity Indices.

Source: Asian Development Bank.

Shannon–Weaver Diversity Indices. The mean SDI for the middle foothills camera sites (1.72) was substantially higher (≥40%) than those for the other three assessment zones, (1.09–1.22; Table 8 and Figure 3). As with mean species richness and the percentage of all animals recorded at sites across the assessment zones, the middle foothills zone reflects the zone with the highest mammalian biodiversity within PWS.

On the move. The survey team traversing the Upper Longa River in Phipsoo Wildlife Sanctuary (photo by ADB).

VI. BIODIVERSITY BASELINE ASSESSMENT RESULTS

This section presents the results of the BBA field assessment conducted in December 2014–February 2015. This includes data from the forest vegetation, bird, mammal, fish, and other animal surveys; as well as the inventory and assessment of special habitats such as khars and grasslands, and areas with illegal harvest of sal and other trees.

A. FOREST OVERSTORY TREE, ORCHID, AND SNAG INVENTORY

1. Overstory Tree Species Inventory

Forest overstory tree inventory was conducted at 33 PWS sampling sites (Table 9). 67 different overstory tree species were inventoried across all sites (Table 10 and Appendix 1), with an average of 5 species per site, which did not differ significantly among assessment zones (Table 9). An average of 11.7 trees per site were tallied using wedge prism sampling, which yielded an average basal area of 22.4 m^2/ha. The means did not differ among assessment zones, with the basal area being especially consistent across zones (Table 9).

Among assessment zone sites, none of the mean biodiversity metrics differed significantly, including number of trees tallied per site, SDI, number of species, basal area, and proportion of overstory tree composition for all species (Table 9).

Table 9: Results of ANOVA Testing of Differences among Overstory Tree Inventory Parameter or Metric Means

Parameter/Metric	Means (±SE) by Assessment Zone[a]				ANOVA Testing	
	All	Border Lowlands	Lower Foothills	Middle Foothills	Means Testing	Post-Hoc Tukey Test Group Mean Comparisons
No. of tree sample points	33	7	14	12		
No. of trees tallied	11.7 ±1.9	9.0 ±0.4	9.9 ±6.2	15.3 ±5.0	NS $P = 0.432$	No differences
SDI[b] – all species	1.38 ±007	1.52 ±0.12	1.27 ±0.12	1.41 ±0.91	NS $P = 0.350$	No differences

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Table 9 *continued*

Parameter/Metric	Means (±SE) by Assessment Zone[a]				ANOVA Testing	
	All	Border Lowlands	Lower Foothills	Middle Foothills	Means Testing	Post-Hoc Tukey Test Group Mean Comparisons
Species	5.0 ±0.3	5.45 ±0.6	4.9 ±0.5	5.0 ±0.4	NS P = 0.769	No differences
Basal area (m^2/ha)	22.4 ±1.2	20.7 ±0.9	22.8 ±2.2	23.0 ±2.1	NS P = 0.769	No differences
Proportion of total trees for all species	0.33 ±0.03	0.31 ±0.04	0.34 ±0.05	0.35 ±0.05	NS P = 0.785	No differences

ANOVA = analysis of variance, BBA = biodiversity baseline assessment, m^2/ha = square meter per hectare, NS = not significant, SDI = Shannon–Weaver Diversity Indices, SE = standard error.

Note: Includes number of trees tallied per site, SDI, number of species, *basal area*, and proportion of total trees per site for all species.

[a] BBA not conducted in the upper foothills zone.

Source: Asian Development Bank.

Table 10: Total Overstory Tree Composition for the 42 Most Common Overstory Tree Species, 2015 (%)

Common Name	Scientific Name	Percent of Total Overstory Tree Composition by Assessment Zone			
		All	BL	LF	MF
Sal	*Shorea robusta*	12.8	11.1	17.3	8.4
Phalamey/Phalami/Falami	*Walsura tubulata*	8.7	1.6	8.6	12.6
Chilaune	*Schima wallichii*	4.4	1.6	2.2	8.4
Myna	*Tertrameles nudiflora*	4.4	4.8	2.2	6.7
Rawa/Rawashing/Toon	*Toon ciliate*	4.0	4.8	3.6	4.2
Bara jhingni	*Eurrya cerasifolia*	3.7	–	2.9	6.7
Panasaj/Panisesag	*Terminalia myriocarpa*	3.1	4.8	1.4	4.2
Champ	*Michelia kisopa*	2.8	–	5.8	0.8
Gayo	*Bridelia retusa*	2.8	3.2	1.4	4.2
Amaki/Ambakay	*Syzygium formosum*	2.5	3.2	2.9	1.7
Lekchilaune	*Nyssa javanica*	2.5	–	–	6.7
Pararay/Parare	*Stereospermum chelonoides*	2.5	3.2	2.2	2.5
Shida	*Lagerstroemia parriflora*	2.5	4.8	2.2	1.7
Bar/Barahara/Fig	*Ficus bengalensis*	2.2	3.2	3.6	–
Kumbi	*Careya arborea*	2.2	4.8	1.4	1.7

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Table 10 *continued*

Common Name	Scientific Name	Percent of Total Overstory Tree Composition by Assessment Zone			
		All	BL	LF	MF
Phirpheray	*Acer oblongum*	2.2	–	2.9	2.5
Moorshing	*No scientic name found*	1.9	7.9	0.7	–
Ailanthus/Gokul	*Ailanthus gradis*	1.6	–	1.4	2.5
Kalaykat	*Miliusa macrocarpa*	1.6	–	2.9	0.8
Kawala/Kaula	*Cinnamomum glanduliferum*	1.6	–	2.9	0.8
Lampate	*Duabanga grandiflora*	1.6	–	3.6	–
Mulata/Malata	*Macaranga denticulata*	1.6	–	3.6	–
Chakrashi	*Chukrasia tabularis*	1.2	1.6	1.4	0.8
Hatipailay	*Pterospermum acerifolium*	1.2	–	1.4	1.7
Jumuna	*Syzygium cumini*	1.2	–	–	3.4%
Labchey	*Polyalithia simiarum*	1.2	–	2.9	–
Lasuni	*Aphanamixis polystachya*	1.2	6.3	–	–
Panchphaly	*Dillenia india*	1.2	–	1.4	1.7
Siris	*Albizia procera*	1.2	–	2.9	–
Wrightia	*Wrightia arborea-Khirra*	1.2	6.3	–	–
Gamari/Gemeray	*Gmelina arborea*	1.2	3.2	0.7	–
Prasea	*Prasea bootanica*	0.9	–	–	2.5
Satpate	*Aesculus assamica*	0.9	–	1.4	–
Amoora	*Spondias pinnata*	0.6	3.2	0.0	–
Castanopsis/Aule katus	*Castanopsis inidica*	0.6	–	–	1.7
Delfinia	*Delphinium spp.*	0.6	–	1.4	–
Hara/Harey	*Terminalia chebula*	0.6	–	–	1.7
Odal	*Sterculia villosa*	0.6	1.6	0.7	–
Sheti	*Altingia excelsa*	0.6	–	0.7	0.8
Shetikath	*Endospermum chinensis*	0.6	–	1.4	–
Simal	*Bombax ceiba*	0.6	1.6	0.7	–

– = not present, BL = border lowlands, LF = lower foothills, MF = middle foothills.

Note: Upper foothills not surveyed. Inventory was conducted at the end of 2015.

Source: Asian Development Bank.

Forest overstory. Myna *(Tertameles nudiflora)* is among common tree species in Phipsoo Wildlife Sanctuary (photo by ADB).

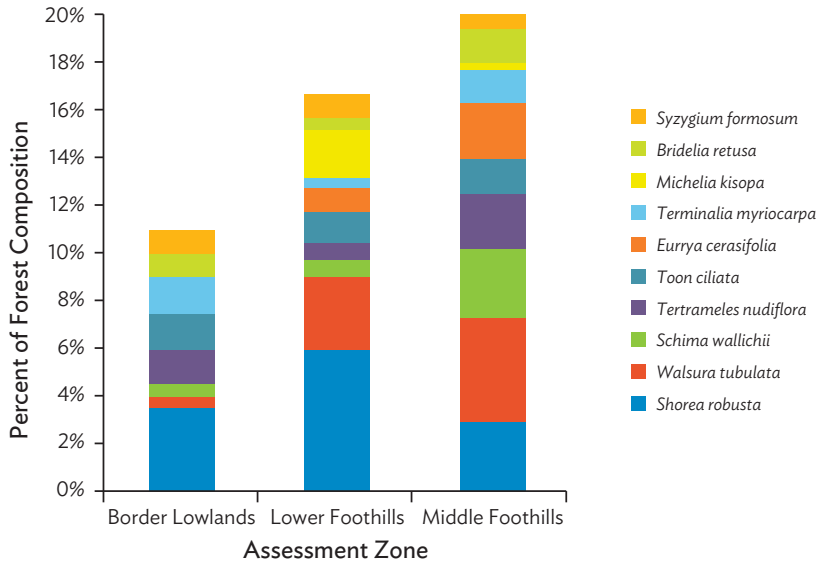
The number of species recorded during the sampling of PWS forests (67) was lower than those reported by Tripathi and Shankar (2014) in India, though their sampling plots were considerably larger, and thus likely captured more forest variability and species. The comparatively small sample effort under the BBA also probably affected the SDI values, which were relatively low compared to SDI reported by Tripathi and Shankar (2014), which exceeded 3.3. However, mean PWS forest basal area was actually somewhat higher than that reported for sal-dominated forests in India (15.6 m^2/ha).

Sal was the most common tree species in the inventory, accounting for 12.8% of total species composition across all PWS inventory sites. Sal was especially prevalent in the lower foothills zone, comprising 17.3% of the forest overstory composition (Table 10, 16). Phalamey *(Walsura tubulata)* was the next most common tree, comprising 8.7% of forest composition. Chilaune (*Schima wallichii*) and myna (*Tertrameles nudiflora*), each comprised 4.4% of the overall forest composition, though both were most prevalent in middle foothills sites (8.4% and 6.7% composition, respectively). Tripathi and Shankar (2014) noted similar overstory codominance between sal and other tree species, including chilaune in India, and regarded it as unusual since sal is typically solely dominant in forests in the region. In both PWS lower forest sites where it occurred, sal formed nearly pure overstories, comprising 78% of the tree composition. In the other two zones, it was more codominant with other species, averaging 27% and 33% composition in border lowlands and middle foothills zone sites, respectively.

Figure 4 shows the respective forest composition for the three assessment zones comprised by the 10 species contributing the highest composition across all sites. These 10 species made up 20% of the forest composition in the middle foothills, compared to 17% in the lower foothills, and only 11% in the border lowlands sites (with two species absent in the sampling there).

Forest tree composition comprised of the 10 most common PWS species (Figure 4) points to differences in species composition among assessment zones. The pair-wise comparisons of species composition overlap for all 67 species (Table 11) found that the composition similarity between the border lowlands and lower foothills zones was 11.3%, and similarity between the border lowlands and higher elevation middle foothills sites was even lower at 9.1%. Similarity between the lower and middle foothills zones were considerably higher,

Figure 4: Cumulative Percentage of Forest Overstory Tree Composition across Assessment Zones (%)



Note: The forest overstory tree composition is made up of the 10 most common tree species. See Table 10.

Source: Asian Development Bank.

19.4%. Across all three zones, similarity was quite low, only 8.8%. Thus, similarity between the border lowlands sites and the other two zones was about half that of the similarity in forest composition between the two higher-elevation zone sites.

Border lowlands species overlap with lower foothills forests was 35.5%, but dropped to 23.1% when compared with higher-elevation middle foothills forests species. Lower and middle foothills site species overlap was 37.5%. And across all zones, overlap in species occurrence was only 16.4% (Table 11).

Table 11: Overstory Tree Species Overlap and Species Composition Similarity: Pair-Wise Comparisons and across All Zones

Parameter/Metric	Overlap and Similarity			
Assessment zone	All zones	Border lowlands versus lower foothills	Border lowlands versus middle foothills	Lower foothills versus middle foothills
Species overlap	16.4% (11 of 67 species)	35.3% (18 of 51 species)	23.1% (12 of 52 species)	37.5% (21 of 56 species)
Similarity	8.8%	11.3%	9.1%	19.4%

Source: Asian Development Bank.

Interesting natural phenomenon. A ground fire captured in Middle Foothills Forest, Phipsoo Wildlife Sanctuary (photo by ADB).

One interesting phenomenon observed when analyzing the remote mammal trapping cameras was that low-intensity ground fires were recorded in the middle foothills sites on three separate occasions in March and April. These fires in remote areas of PWS, ostensibly caused by pre-monsoon lightening, burned for periods of up to 2 days, "creeping" along the forest floor. These records point to the role that fire plays in forest communities at PWS. Wildlife use at the sites resumed almost immediately after fires subsided.

2. Snag Inventory

Snags were counted at 29 PWS sites while inventorying forest overstory. Snag densities averaged between 2.2 snags/ha and 3.3 snags/ha across assessment zones, with large snags (>50 cm), which are generally most valuable to wildlife, averaging from 1.0/ha to 1.8/ha (Table 12). The total number of snags present on plots ranged from one to eight, and large snags ranged from one to four per site. At five of the 29 sites (17%), no snags occurred within sampling plots.

Table 12: Snag Densities by Size Class (numbers/hectare)

Assessment Zone	Mean No. of Snags per Hectare			
	Small (<20 cm)	Medium (21–50 cm)	Large (>50 cm)	Total
Border lowlands (*n* = 6)	0.3	0.9	1.5	2.5
Lower foothills (*n* = 12)	0.3	1.0	1.0	2.2
Middle foothills (*n* = 11)	0.3	1.4	1.8	3.3
All (*n* = 29)	0.2	1.1	1.4	2.7

cm = centimeter.

Note: Determined from an inventory of 29 forest sites during winter 2015.

Source: Asian Development Bank.

3. Orchid inventory

A total of 15 genera of orchids were inventoried during the winter 2015 BBA at 13 sampling sites (Table 13). The list of plant species compiled for the PWS CMP (Norbu and Tobgay 2012) included 11 genera of orchids. The BBA identified an additional 11 genera (Table 13), doubling the known genera to occur at PWS. Both the border lowlands and lower foothills plots supported a total of seven genera, while the middle foothills sites included nine (Table 13). Most of the inventoried orchids were epiphytic in their growth habit (11 genera), three were terrestrial, and one was lithophytic.

Epiphytic orchids. This species live on the surface of other plants (photo by ADB).

Table 13: Orchid Genera Inventoried across Assessment Zones

Orchid Genus	Growth Habit	Orchid Occurrence by Assessment Zone (no. of sampling sites)			Documentation in PWS Conservation Management Plan
		Border Lowlands (*n* = 3)	Lower Foothills (*n* = 6)	Middle Foothills (*n* = 4)	
Aerides	Epiphytic	X	X		X
Bulbophylum	Epiphytic			X	
Chuna	Terrestrial	X		X	
Cymbidium	Epiphytic		X	X	X
Dendrobium	Epiphytic	X	X	X	X
Denobium	Terrestrial	X		X	
Eria	Epiphytic		X		

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Table 13 *continued*

Orchid Genus	Growth Habit	Orchid Occurrence by Assessment Zone (no. of sampling sites)			Documentation in PWS Conservation Management Plan
		Border Lowlands (*n* = 3)	Lower Foothills (*n* = 6)	Middle Foothills (*n* = 4)	
Malaxis	Epiphytic	X	X	X	
Otochilus	Lithophytic	X			
Paphiopedilum	Epiphytic		X		
Pholidola	Epiphytic		X		
Pleone	Epiphytic			X	
Sunakhase	Terrestrial	X			
Tarwara	Epiphytic			X	
Vanda	Epiphytic			X	X
All (no. genera)		7	7	9	4

PWS = Phipsoo Wildlife Sanctuary.

Sources: Norbu and Tobgay. 2012 and Asian Development Bank.

B. AVIAN SPECIES INVENTORY

Sixteen separate winter avian surveys were conducted during the course of the BBA (Table 14). During these surveys, a total of 120 species of birds were observed and/or heard (Appendix 2). This total included 46 species that had not been previously documented as occurring at PWS (PWS CMP, Norbu and Tobgay 2012), representing a 35% increase in the number of known species, now at 177. Ten of the species documented were considered "abundant", while another 22 were considered "common" (Appendix 2). Combined, these species comprised 72% of all birds seen, and are listed in Table 15. One IUCN CR white-bellied heron and one IUCN VU rufous-necked hornbilll were recorded as part of the avian surveys, both within lower foothill zone sites (Appendix 2). Additional herons were observed at PWS during the BBA, outside of when formal avian surveys were being conducted (these observations are reported in Section VI. E.).

Of the 131 bird species previously known to occur at PWS (PWS CMP, Norbu and Tobgay 2012), 55 species (42%) were not detected during the winter BBA (Appendix 2). Their absence may reflect seasonal distribution shifts; some may have been wintering elsewhere in Asia.

The most common surveyed birds at PWS were the scarlet minivet (*Pericrocotus flammeus*), black stork (*Ciconia nigra*), and red-breasted parakeet (*Psittacula alexandri*), all greater than 5.5% of total avian composition (Table 15). The black stork was absent from border lowlands survey areas as no live, flowing rivers bisected this assessment zone.

Flying colors. Common surveyed birds at Phipsoo Wildlife Sanctuary include (i) the red-breasted parakeet and (ii) the minivet (photos from iStock.com).

In comparing avian survey results across assessment zones, the ANOVA yielded no significant comparisons among the mean number of bird detections, species, SDI, or proportion of birds per site (Table 14).

Table 14: Results of ANOVA Testing of Differences among Avian Species Surveyed

Parameter/Metric	Means (±SE) by Assessment Zone[a]				ANOVA Testing	
	All	Border Lowlands	Lower Foothills	Middle Foothills	Means Testing	Post-Hoc Tukey Test Group Mean Comparisons
No. of avian surveys	16	4	7	5		
No. of detections per site	58.7 ±4.5	56.0 ±11.1	55.9 ±6.2	65.0 ±7.9	NS P = 0.432	No differences
SDI - all species	2.61 ±0.10	2.50 ±0.20	2.77 ±0.13	2.47 ±0.24	NS P = 0.423	No differences
Species	19.3 ±0.4	17.5 ±3.8	20.4 ±2.7	19.0 ±0.4	NS P = 0.837	No differences
Proportion of total animals for all species	0.33 ±0.02	0.32 ±0.03	0.32 ±0.03	0.36 ±0.3	NS P = 0.346	No differences

ANOVA = analysis of variance, SDI = Shannon–Weaver Diversity Indices.

[a] Upper Foothills zone not surveyed.

Note: Also included in the survey were mean number of bird detections per site, SDI, number of species and richness, and proportion of total birds detected per site.

Source: Asian Development Bank.

Table 15: Composition of the 40 Most Common Bird Species Surveyed

Common Name	Scientific Name	Percent of Total Bird Detections by Assessment Zone			
		All	BL	LF	MF
Scarlet minivet	*Pericrocotus flammeus*	5.9	8.5	2.3	8.9
Black stork	*Ciconia nigra*	5.7	0.0	6.4	9.2
Red-breasted parakeet	*Psittacula alexandri*	5.7	8.0	5.1	5.2
Red-vented bulbul	*Pycnonotus cafer*	4.4	2.7	7.2	2.5
Great hornbill	*Buceros bicornis*	4.2	8.0	4.1	1.8
Black-crested bulbul	*Pycnonotus jocosus*	3.7	1.8	5.4	3.4
Oriental pied hornbill	*Anthracoceros albirostris*	3.1	0.0	6.9	0.9
White-throated bulbul	*Alophoixus flaveolus*	2.9	7.6	0.0	3.4
Crested serpent eagle	*Spilornis cheela*	2.4	0.4	3.1	3.1
Lineated barbet	*Megalaima lineate*	2.4	2.7	3.6	0.9
Black drongo	*Dicruus Macrocercus*	2.1	0.4	1.5	4.0
White-bellied yuhina	*Yuhina zantholeuca*	2.1	2.7	2.3	1.5
Black bulbul	*Hypsipetes leucocephalus*	1.8	3.6	0.0	2.2
Greater flameback	*Chrysocolaptes lucidus*	1.8	1.8	2.0	1.5
River lapwing	*Vanellus duvaucelii*	1.7	0.9	2.3	1.5
Great barbet	*Megalaima virens*	1.6	0.9	2.6	1.5
Spangled drongo	*Dicrurus hottentottus*	1.6	0.0	2.3	1.8
White-browed wagtail	*Motacilla maderaspatensis*	1.6	0.0	3.3	0.6
Indian pond heron	*Ardeola grayii*	1.5	0.0	3.3	0.3
Plumbeous water redstart	*Rhyacornis fuliginosus*	1.5	0.0	2.0	1.8
Green imperial pigeon	*Ducula aenea*	1.4	2.7	1.8	0.0
Grey-bellied tesia	*Tesia cyaniventer*	1.4	1.3	2.0	0.6
Rose-ringed parakeet	*Psittacula krameri*	1.4	0.0	0.0	0.0
White wagtail	*Motacilla alba*	1.4	0.0	2.8	0.6
Jungle myna	*Acridotheres fuscus*	1.2	2.7	1.5	0.0
Streaked spiderhunter	*Arachnothera magna*	1.2	1.3	1.8	0.6
Ashy bulbul	*Hemixos flavala*	1.1	0.0	0.0	3.4
Hill myna	*Gracula religiosa*	1.1	0.9	1.5	0.9
Pin-tailed green pigeon	*Treron apicauda*	1.1	0.0	0.0	3.4

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Table 15 *continued*

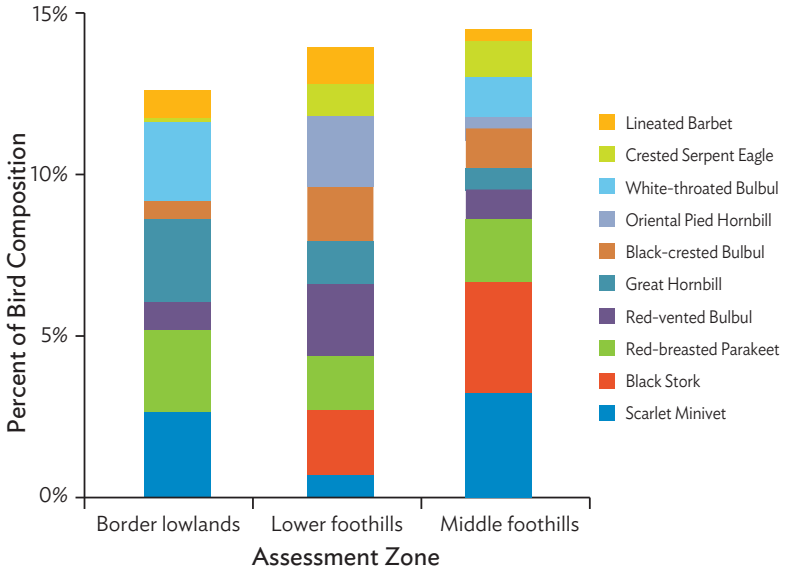
Common Name	Scientific Name	Percent of Total Bird Detections by Assessment Zone			
		All	BL	LF	MF
White-capped water redstart	*Chaimarrornis leucocephalus*	1.1	0.4	0.8	2.2
Wreathed hornbill	*Aceros undulates*	1.1	1.8	1.3	0.6
Red junglefowl	*Gallus gallus*	1.0	0.0	1.8	0.9
Slaty-backed forktail	*Enicurus schistaceus*	0.9	0.4	1.3	0.9
Golden-fronted leafbird	*Chloropsis aurifrons*	0.8	0.9	0.5	1.2
Rock pigeon	*Columba livia*	0.8	3.6	0.0	0.0
Silver-eared mesia	*Leiothrix argentauris*	0.8	0.0	0.0	2.5
Sultan tit	*Melanochlora sultanea*	0.8	2.7	0.0	0.6
Ashy drongo	*Dicrurus leucophaeus*	0.7	0.9	0.3	1.2
Asian pied starling	*Sturnus contra*	0.7	0.0	0.0	2.2
Great cormorant	*Phalacrocorax carbo*	0.7	3.1	0.0	0.0

BL = border lowlands, LF = lower foothills, MF = middle foothills.

Note: Survey conducted in winter 2015, with corrected total composition within assessment zones.

Source: Asian Development Bank.

Figure 5: Cumulative Percentage of Corrected (for Unequal Number of Sites) Avian Species Composition across Assessment Zones



Note: Avian species composition consists of the 10 most common bird species.

Source: Asian Development Bank.

Avian species overlap and similarity were consistent with the ANOVA results for biodiversity metrics (Tables 14 and 16). The 10 most common surveyed birds contributed to a very consistent cumulative species composition among zones ranging from 13% to 17%, though two species did not occur in all zones (Figure 5). Species overlap for all bird species was nearly identical between the border lowlands and both the lower and middle foothills zones (>29%; Table 16). Species composition similarity was also relatively low between the border lowlands and both the lower (12.2%) and middle (14.3%) foothills zones.

Table 16: Avian Species Overlap and Species Composition Similarity among Assessment Zone Pair-Wise Comparisons

Parameter/ Metric	Avian Species Overlap and Species Composition Similarity among Assessment Zones			
Assessment zone	All zones	Border lowlands versus lower foothills	Border lowlands versus middle foothills	Lower foothills versus middle foothills
Species overlap	17.3% (21 of 121 species)	29.2% (28 of 96 species)	27.0% (30 of 111 species)	37.4% (37 of 99 species)
Similarity	8.6%	12.2%	14.3%	16.9%

Note: Survey conducted in winter 2015.

Source: Asian Development Bank.

C. MAMMALIAN SPECIES INVENTORY

The winter mammalian species camera trapping provided a substantial amount of data to assess and compare biodiversity across PWS assessment zones, complemented the 2014 PWS camera trapping, and provided nearly a full year of monitoring data. The cameras recovered from PWS in May 2015 yielded a total of 17,857 images, of which 16,313 were mammals; 452 were birds; 652 were humans (including poachers); and 429 were livestock.

Of the 45 total cameras, two were stolen by poachers (both in border lowlands sites), two were destroyed by elephants, and two were tampered with by elephants but still yielded much usable data. Vegetation growth following installation constantly triggered camera sensors until batteries died, rendering two cameras unusable, pointing to the perils of installing cameras during the winter "dormant" season. Lastly, one camera was suspected of being taken by villagers as it was placed at a nearby khar and was visible to passersby. Thus, usable data was recovered from 38 cameras representing 33 discrete sites across PWS (Table 17, Appendix 3). The cameras were operational for an average of 110.7 days per site (±1.7 SE; 3.7 months) and recorded a mean of 496.6 images/site (±97.3 SE). Neither the mean days or images per site differed among assessment zones (ANOVA P = 0.160 and 0.129, respectively).

Photos of wildlife species shown in this section were taken by camera traps installed in the PWS and later recovered in 2015.

Table 17: Results of ANOVA Testing of Differences among Mammalian Species

Parameter/Metric	Site Means (±SE) by Assessment Zone[a]				ANOVA Testing	
	All	Border Lowlands	Lower Foothills	Middle Foothills	Means Testing	Post-Hoc Tukey Test Group Mean Comparisons
Camera sites	33	7	14	12		
No. of animals recorded per site	128.8 ±19.6	113.3 ±37.2	103.8 ±13.8	166.9 ±46.4	NS $P = 0.343$	No differences
SDI	1.39 ±0.08	1.03 ±0.20	1.46 ±0.13	1.53 ±0.09	$F_{2.30}=3.11$ $P = 0.050$	Border Lowlands < Lower Foothills; $P = 0.042$ Middle Foothills; $P = 0.024$
Species – all	8.1 ±0.4	5.4 ±0.7	9.4 ±0.6	8.5 ±0.4	$F_{2.30}=9.10$ $P < 0.001$	Border Lowlands < Lower Foothills; $P = 0.002$ Middle Foothills; $P = 0.033$
Species – T&E only	4.7 ±0.3	3.0 ±0.4	5.4 ±0.4	4.8 ±0.3	$F_{2.30}=9.50$ $P < 0.001$	Border Lowlands < Lower Foothills; $P = 0.002$ Middle Foothills; $P = 0.029$
Proportion of total animals for all species	0.33 ±0.04	0.15 ±0.04	0.40 ±0.06	0.45 ±0.07	$F_{2.81}=11.25$ $P < 0.001$	Border Lowlands < Lower Foothills; $P < 0.001$ Middle Foothills; $P = 0.001$

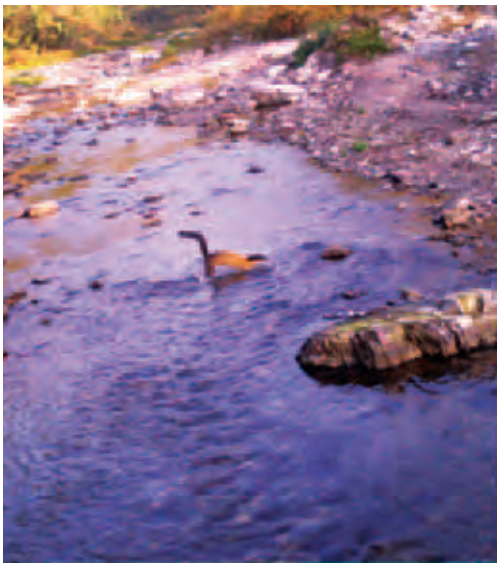
ANOVA = analysis of variance, IUCN = International Union for the Conservation of Nature, NS = not significant, T&E = threatened and endangered.

[a] Upper foothills zone not sampled.

Note: Survey includes number of species (all and IUCN-listed), and proportion of total animals per site derived during camera trapping in winter 2015.

Source: Asian Development Bank.

The analysis of camera data determined a total of 4,300 individual mammal images, within 2,227 separate groups, accounting for 28 different species (Table 18), four more than the 2014 PWS camera trapping. Fifteen of the species were IUCN-listed. Six species not camera trapped in 2014 were found in 2015: Bengal fox (*Vulpes bengalensis*), Indian hare (*Lepus nigricollis*), Chinese pangolin (*Manis pentadactyla*; IUCN CR), Himalayan yellow-throated marten (*Martes flavigula*), common palm civet (*Paradoxiurus hermaphroditus*), and spotted deer. The application of multiple cameras at some sites to target smaller mammals appeared to be productive. Conversely, efforts to target otter species along PWS' rivers were unsuccessful, and the presence of these species remains unconfirmed. The BBA camera trapping failed to document only one of the 24 species from the 2014 camera trapping: the Asiatic water buffalo.

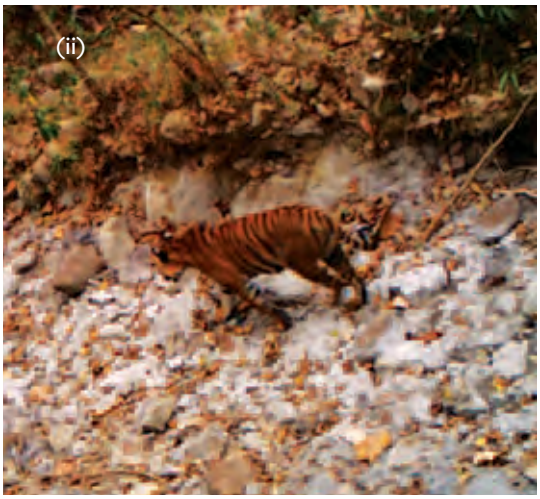


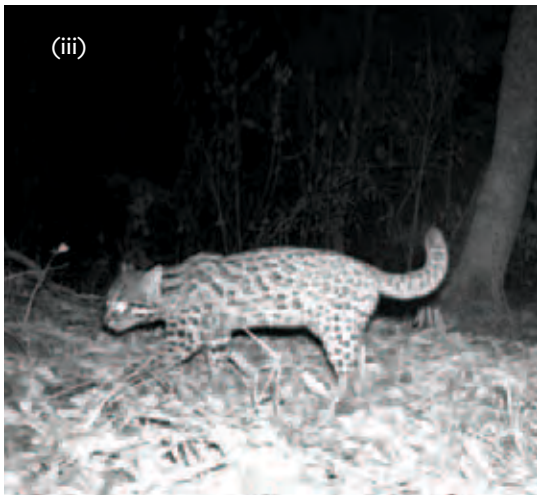
Strolling along. Camera traps capture a (i) Himalayan yellow-throated marten crossing Phipsoo River and (ii) Asian elephants passing along the Pingkha River (photos by ADB).

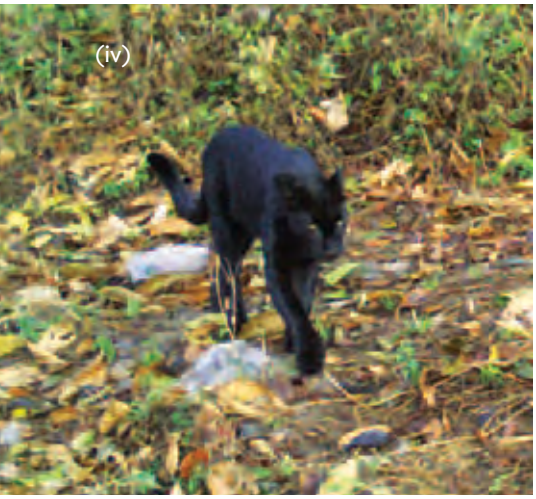
Asian elephants (IUCN EN) accounted for the majority (1,297) of mammals documented at PWS, recorded in 376 groups (3.4 per group). Elephants were documented at 29 camera sites (88%) spread evenly across assessment zones; in fact, they were the most evenly distributed of all mammal species (Table 18). One of the most dramatic differences exhibited by any species between the 2014 PWS and 2015 BBA camera trapping efforts was the over twofold increase in winter elephant use of the border lowlands and lower foothills zones in 2015 (there was minimal use of the upper foothills zone in 2014 by elephants, so data was comparable). It is suspected that this winter shift toward gentler terrain reflects increased use of lower grassland areas, and/or increased travel between PWS and the adjacent Ripu–Chirang Reserve Forest in neighboring India.

The second most common species recorded at PWS was gaur (IUCN VU), with 1,113 individuals classified within 381 groups (2.9 animals per group) at 24 different camera sites (73%). A large proportion of all gaur records (65.9%) occurred in middle foothills sites; similarly, the vast majority of 2014 PWS gaur camera trapping records also occurred at higher-elevation middle and upper foothills sites. Gaur had the greatest propensity to linger at the sites (for up to 8 hours).

Six species of felids (cats) were recorded (Table 18). Most common was the common leopard (IUCN NT), of which 50 were recorded (compared to 105 in 2014). Of the 19 sites where they were recorded, just 8% were in border lowlands sites; 62% were in middle foothills sites. Wangchuk et al. (2004) reported that half of Bhutan's leopards are melanistic "black panthers." The BBA recorded one of them. The next most common felid was the leopard cat, of which 33 animals were recorded at 12 sites. One site within the border lowlands accounted for 30% of all animals, while 75% of sites were in the lower foothills zone. Eleven clouded leopards (*Neofelis nebulosa*; IUCN VU) were recorded at seven sites; none occurred in the border lowlands and 64% occurred at middle foothills sites.







Roaming predators. Species of felids and other predator species spotted by camera traps in Phipsoo Wildlife Sanctuary include the (i) common leopard, (ii) tiger, (iii) leopard cat, (iv) panther, (v) clouded leopard, (vi) gaur, and (vii) the HImalayan black bear (photos by ADB).

Tigers (IUCN EN) were recorded on nine occasions at six sites, of which one was in the border lowlands zone, while two-thirds were recorded at lower foothills sites (Table 18). In 2014, 21 tigers were recorded during 8 months. PWS records reflect a minimum of two and possibly three unique adults, and up to two subadults; photographic records were provided to WCD for confirmation. Regardless, this points to the importance of PWS' tiger population to Bhutan's emerging role in the species' recovery.

Single Himalayan black bears (*Ursus thibetanus laniger*; IUCN VU) were camera trapped at 14 PWS sites during the BBA. Just one bear was recorded in the border lowlands zone and over two-thirds of bears were photographed in middle foothills zone sites (Table 18).

Table 18: Mammalian Species Camera Trapped at Phipsoo Wildlife Sanctuary

Mammalian Species	IUCN Status	Mammalian Camera Trapping Results by Terrain and Vegetative Assessment Zone										
		All Sites (n = 33)		Border Lowlands (n = 7)			Lower Foothills (n = 14)			Middle Foothills (n = 12)		
		Total	Mean No./ Site	Total	Mean No./ Site	% of Total	Total	Mean No./ Site	% of Total	No.	Mean No./ Site	% of Total
Asiatic brush-tailed porcupine	–	1	<0.1	–	–	–	–	–	–	1	0.1	100.0
Asian elephant	EN	1,297	39.3	425	60.7	32.8	455	32.5	35.1	417	34.8	32.2
Asiatic golden cat	NT	1	<0.1	–	–	–	–	–	–	1	0.1	100.0
Asiatic wild dog	EN	4	0.1	–	–	–	4	0.3	100.0	–	–	–
Assamese macaque	NT	15	0.5	6	0.9	40.0	7	0.5	46.7	2	0.2	13.3
Barking deer	–	700	21.2	56	8.0	8.0	342	24.4	48.9	302	25.2	43.1
Bengal fox	–	1	<0.1	–	–	–	–	–	–	1	0.1	100.0
Indian (black-naped) hare		1	<0.1	–	–	–	–	–	–	1	0.1	100.0
Chinese pangolin	CR	1	<0.1	–	–	–	1	0.1	100.0	–	–	–
Clouded leopard	VU	11	0.3	–	–	–	4	0.3	36.4	7	0.6	63.6
Common leopard	NT	50	1.5	4	0.6	8.0	15	1.1	30.0	31	2.6	62.0
Common palm civet	–	7	0.2	–	–	–	3	0.2	42.9	4	0.3	57.1
Crab-eating mongoose	–	6	0.2	1	0.1	16.7	5	0.4	83.3	–	–	–
Gaur	VU	1,113	33.7	154	22.0	13.8	226	16.1	20.3	733	61.1	65.9
Golden langur	EN	4	0.1	–	–	–	4	0.3	100.0	–	–	–
Himalayan black bear	VU	14	0.4	1	0.1	7.1	4	0.3	28.6	9	0.8	64.3
Himalayan crestless porcupine	–	66	2.0	–	–	–	24	1.7	36.4	42	3.5	63.6
Himalayan palm civet	–	7	0.2	–	–	–	3	0.2	42.9	4	0.3	57.1
Himalayan serow	NT	34	1.0	–	–	–	22	1.6	64.7	12	1.0	35.3
Yellow-throated marten	–	3	0.1	–	–	–	3	0.2	100.0	–	–	–
Large Indian civet	NT	41	1.2	1	0.1	2.4	31	2.2	75.6	9	0.8	22.0
Leopard cat	–	33	1.0	10	1.4	30.3	18	1.3	54.5	5	0.4	15.2
Marbled cat	VU	1	<0.1	–	–	–	–	–	–	1	0.1	100.0
Sambar	VU	376	11.4	58	8.3	15.4	155	11.1	41.2	163	13.6	43.4
Small Indian civet	–	3	0.1	–	–	–	2	0.1	66.7	1	0.1	33.3
Spotted deer	–	1	<0.1	1	0.1	100.0	–	–	–	–	–	–
Tiger	EN	9	0.3	1	0.1	11.1	6	0.4	66.7	2	0.2	22.2
Wild pig	–	449	13.6	75	10.7	16.7	119	8.5	26.5	255	21.3	56.8
All species		4,245	128.6	793	113.3	18.7%	1,453	103.8	34.2%	2,003	166.9	47.2%

– = not present, BBA = biodiversity baseline assessment, CR = critically endangered, EN = endangered, IUCN = International Union for the Conservation of Nature, NT= near threatened, VU = vulnerable.

Note: Camera trapping was done during the 2015 BBA.

Source: Asian Development Bank.

More mammal species. Camera traps take photos of a (i) male barking deer, (ii) female sambar and its fawn, and (iii) a female spotted deer roaming around during the day; and a (iv) large Indian civet sneaking through the night (photos by ADB).

Three species of deer were camera trapped at PWS during winter 2015; 700 barking deer (*Muntiacus mutjak*) were recorded at all but one of the 33 sites, making them the most widely distributed animal recorded, though 92% of all individual records occurred in the higher lower and middle foothills sites (Table 18). Sambar (IUCN VU) also were widely distributed across PWS, with 376 animals occurring at 26 sites (79%), but with 85% of all animals recorded at lowlands and middle foothills sites. Only one single spotted deer was recorded at a border lowlands site where they typically congregate in the vicinity of Phipsoo field station.

Four species of civets were camera trapped at PWS (Table 18); the most common was the large Indian civet (*Viverra zibetha*; IUCN NT), with over 97% of the 41 animals that were recorded occurring at lower and middle foothills camera sites.

Wild pigs. A common species found throughout Bhutan (photos by ADB).

The cameras recorded 34 Himalayan serow (*Capricornis sumatraensis*; IUCN NT) at 12 camera sites within the lower and middle foothills zones; none were recorded in the border lowlands zone. Four dhole (Asiatic wild dog; *Cuon alpinus*; IUCN EN) were also recorded at two lower foothills zone camera sites (Table 18).

Wild pig (*Sus scrofa*) observations were widespread at PWS, with 449 recorded at 31 sites (Table 18). Wild pigs were most plentiful in middle foothills sites, especially where prolific reproduction was noted. Though often regarded as an agricultural pest, wild pigs nonetheless represent an important prey for leopard, tiger, and dhole in addition to deer species, gaur, and serow.

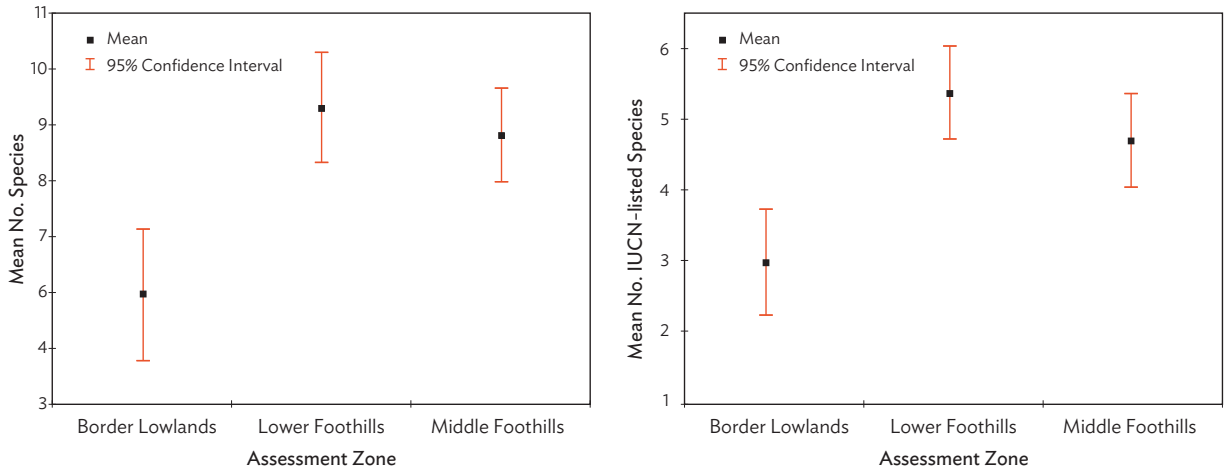
1. Mammalian Diversity Metrics

Camera trapping data was summarized both by the number of individuals and groups of animals recorded. There was a concern that the bias presented by herd species (e.g., elephant, gaur) could influence the outcome of the ANOVA and swamp out the influence of non-herd and/or rarer species. A strong association was found between individual and group animal numbers ($r = 0.947$), and the analyses using numbers of groups did not differ from testing using individual animals. As such, individual animal numbers were employed in the statistical testing; this also allowed direct comparison to the 2014 camera trapping results.

The ANOVA testing for differences among PWS assessment zone mammalian biodiversity metrics yielded significant results for all but one comparison (Table 17), most of which were highly significant ($P < 0.001$). There were no significant differences between the mean numbers of animals recorded per site; this was likely influenced by the large number of elephants recorded at border lowland sites during winter 2015.

Number of species per site. A highly significant difference was found among the mean number of species camera trapped per site across PWS assessment zones, for all species combined and IUCN-listed species only (Table 17 and Figure 6). The mean number of

Figure 6: Means and 95% Confidence Intervals for Species Recorded in the Assessment Zones, 2015



IUCN = International Union for the Conservation of Nature.

Source: Asian Development Bank.

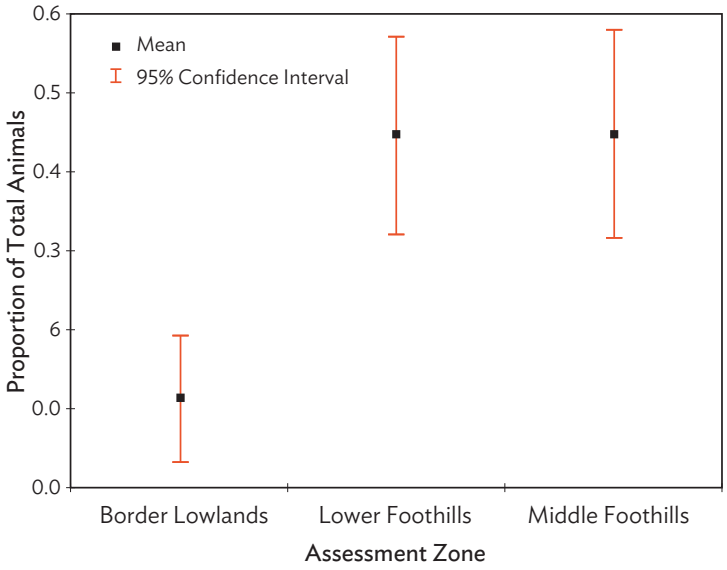
border lowlands zone species (all) was 36%–43% lower than the means for the lower and middle foothills zones, and differed significantly as determined by post-hoc pairwise comparisons (Table 17). Map 7 shows the location of PWS camera locations and the number of total species associated with the 2015 winter camera trapping at each site.

Proportion of animals per site. The difference among mean proportions of total animals for all species among PWS assessment zones was highly significant, with the border lowland mean proportion of animals being one-third less of the other zone means (Table 17 and Figure 7).

Shannon–Weaver Diversity Indices per site. The differences among the mean SDI per site differed by assessment zone (Table 17 and Figure 8), with the border lowlands mean being significantly lower than the means for the other two zones (Figure 8). The mean border lowlands zone SDI (1.03) was 29% lower than the lower foothills mean (1.46) and 32% lower than the middle foothills mean SDI (1.53). Map 8 shows the location of the PWS camera locations and their associated SDI; the sites with the highest SDI generally occur in PWS' interior north of the Indo–Bhutan border.

Species overlap and similarity. The five most common mammalian species recorded at PWS accounted for 93.3% of total composition by all species. There was considerable difference among assessment zones in the percentage that these species contributed to the total animals recorded (Figure 9). Within the border lowlands sites, these species constituted 28.6% of total recorded animals. Within the lower and middle foothills zones, they contributed 24.1% and 40.6% of the total number of recorded animals, respectively.

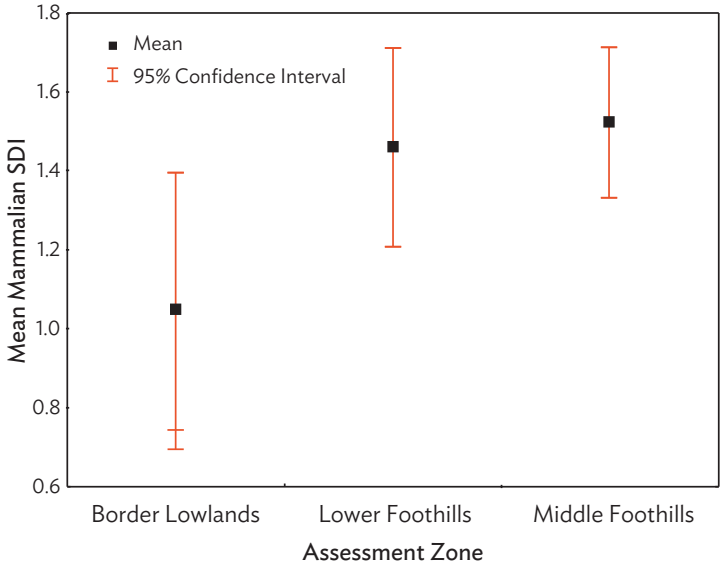
Figure 7: Means and 95% Confidence Intervals for the Proportion of Total Animals Recorded per Site



Note: The Border Lowlands zone mean was lower than those for the other two zones.

Source: Asian Development Bank.

Figure 8: Means and 95% Confidence Intervals for Shannon–Weaver Diversity Indices

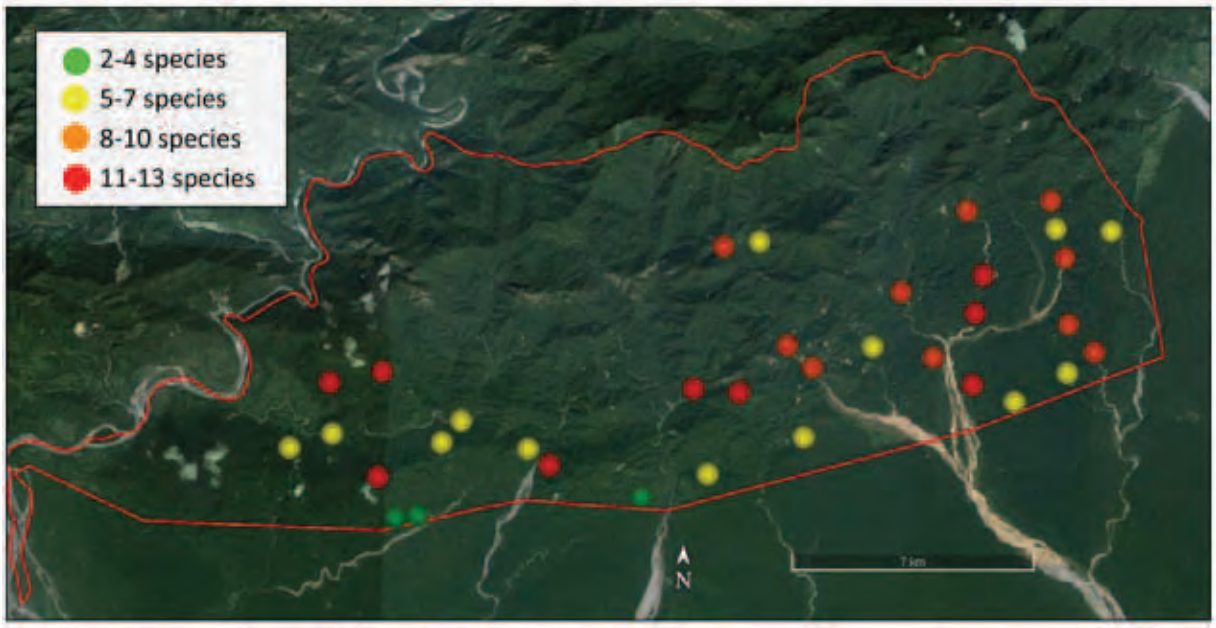


SDI = Shannon–Weaver Diversity Indices.

Note: The Border Lowlands zone mean was lower than those for the other two zones.

Source: Asian Development Bank.

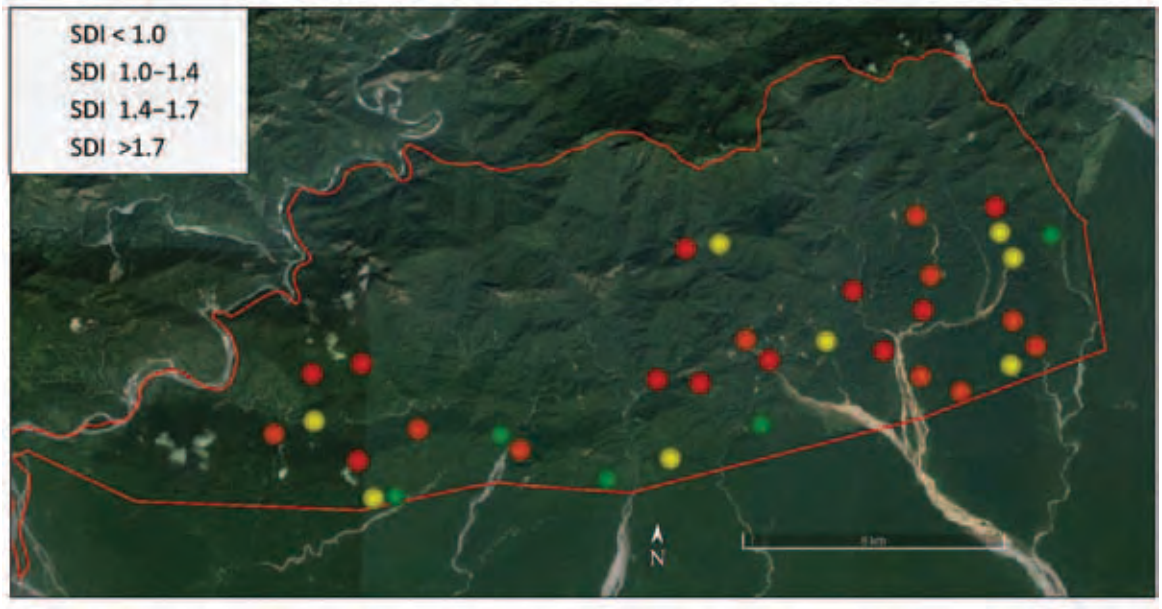
Map 7: Camera Trapping Locations and Associated Number of Mammal Species



Note: Recorded at each site during camera trapping in winter 2015.

Source: Asian Development Bank.

Map 8: Camera Locations and Associated Mammalian Species Shannon–Weaver Diversity Indices



SDI = Shannon–Weaver Diversity Indices.

Note: Results from camera trapping during winter 2015.

Source: Asian Development Bank.

Considering all 28 mammal species, the percentage overlap in species between the border lowlands and both the lower and middle foothills zones was comparable at 43.4% and 45.8%, respectively (Table 19). The overlap between the higher lower and middle foothills zones, however, was substantially higher at 66.6% (Table 19).

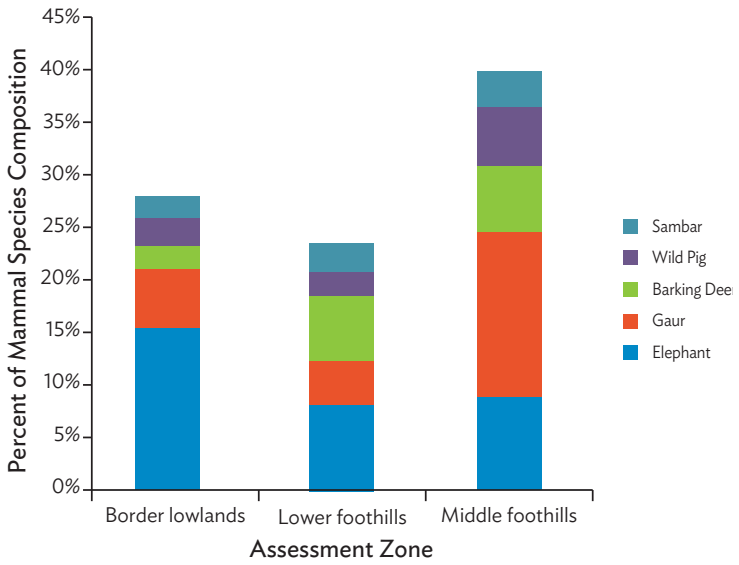
Table 19: Mammalian Species Overlap and Species Composition Similarity among Assessment Zones

Parameter/Metric	Mammalian Species Overlap and Species Composition Similarity among Assessment Zones			
Assessment zone	All zones	Border lowlands versus lower foothills	Border lowlands versus middle foothills	Lower foothills versus middle foothills
Species overlap	39.3% (11 of 28 species)	43.4% (10 of 23 species)	45.8% (11 of 24 species)	66.6% (18 of 27 species)
Similarity	19.5%	19.9%	22.2%	25.8%

Note: These are pair-wise comparisons and across all zones obtained from camera trapping in 2015.

Source: Asian Development Bank.

Figure 9: Cumulative Percentage of Mammalian Species Composition



Note: Comprised of the five most common species during camera trapping in winter 2015, with composition corrected for unequal sample sites (see Table 18).

Source: Asian Development Bank.

The border lowlands and lower foothills zones exhibited 18.7% similarity in species composition, similar to the similarity in species composition between border lowlands and middle foothills zone of 18.3% (Table 19). The similarity between the lower and middle foothills zones was considerably higher at 30.7%.

2. Comparing and Merging the 2014 and 2015 Mammalian Camera Trapping

The results for the 15 camera trapping sites at which monitoring was conducted during both the 2014 PWS and the winter 2015 BBA camera monitoring was compared. Similar results were found between years for SDI and the number of species per site (Table 20), where *t*-testing between years for each assessment zone did not differ (Table 20). Across all 15 sites, the difference in mean SDI between years was negligible: 1.40 in 2014 versus 1.47 in 2015, a difference of only 5.0%. This consistency between camera trapping efforts points to the utility of SDI as a metric in comparing biodiversity.

The difference between years was significant only for the proportion of total animals within the lower foothills zone, which increased 120% from 0.20 with the 2014 trapping to 0.44 in the BBA 2015 camera trapping effort. Commensurate with this increase between years was a decline in both the proportion of total animals in the border lowlands and middle foothills zones, though the differences were not significant (Table 20).

Table 20: Comparison of Mean Biodiversity Metrics among Assessment Zones

Metric	Year	Site Means by Assessment Zone and Year (±SE) (for 15 sites camera trapped in both years)		
		Border Lowlands (n = 4)	Lower Foothills (n = 8)	Middle Foothills (n = 3)
SDI	2014	1.17 (±0.16)	1.51 (±0.15)	1.44 (±0.13)
	2015	1.16 (±0.20)	1.52 (±0.18)	1.76 (±0.03)
	Merged	**1.16 (±0.12)**	**1.51 (±0.11)**	**1.60 (±0.08)**
	t-test for difference between years for each zone		Border lowlands: No difference (P = 0.993) Lower foothills: No difference (P = 0.962) Middle foothills: No difference (P = 0.166)	
	ANCOVA - merged year means		$F_{2,29}$ = 3.71 P = 0.359 Border Lowlands < Middle Foothills (P = 0.044)	
Species	2014	5.4 (±1.2)	7.9 (±0.9)	7.7 (±1.9)
	2015	6.2 (±0.8)	10.1 (±0.9)	9.7 ± (0.7)
	Merged	**5.6 (±0.6)**	**9.0 (±0.7)**	**9.1 (±1.0)**
	t-test for difference between years for each zone		Border lowlands: No difference (P = 0.779) Lower foothills: No difference (P = 0.115) Middle foothills: No difference (P = 0.707)	
	ANCOVA - merged year means		$F_{2,29}$ = 6.73 P = 0.003 Border lowlands < Lower foothills (P = 0.034) Border lowlands < Middle foothills (P = 0.013)	

continued on next page

Table 20 *continued*

Metric	Year	Site Means by Assessment Zone and Year (±SE) (for 15 sites camera trapped in both years)		
		Border Lowlands (n = 4)	Lower Foothills (n = 8)	Middle Foothills (n = 3)
Proportion of total animals	2014	0.21 (±0.07)	0.20 (±0.06)	0.59 (±0.08)
	2015	0.11 (±0.04)	0.44 (±0.06)	0.45 (±0.06)
	Merged	0.16 (±0.04)	0.33 (±0.05)	0.50 (±0.05)
	t-test for difference between years for each zone		Border lowlands: No difference (P = 0.189) Lower foothills: t = 7.22 (P = 0.010) Middle foothills: No difference (P = 0.249)	
	ANCOVA - merged year means		$F_{2,153}$ = 6.14 P = 0.003 Border lowlands < Lower foothills (P = 0.022) Border lowlands < Middle foothills (P = 0.003)	

ANCOVA = analysis of covariance, SDI = Shannon–Weaver Diversity Indices.

Note: Comparison of mean biodiversity metrics (mean SDI, number of species per site, and proportion of total animals) among assessment zones derived from camera trapping conducted in 2014 and 2015 at the same 15 camera sites. The t-test results represent differences between years. ANCOVA is used to assess differences in means among assessment zones for metrics when the 2014 and 2015 records were merged.

Source: Asian Development Bank.

Combined 2014–2015 camera trapping biodiversity metrics spanning 8 months (January–August) were derived; missing was data for the fall period (September–December). The merged mean SDI for the border lowlands zone was significantly lower than the mean for the middle foothills zone. Border lowlands means for both the number of species and proportion of total animals were lower than means for the lower and middle foothills zones (Table 20).

Number of species per site. Both the merged 2014 and 2015 lower and middle foothills means numbers of mammal species/site were >60% higher than the border lowlands mean (Table 20 and Figure 10).

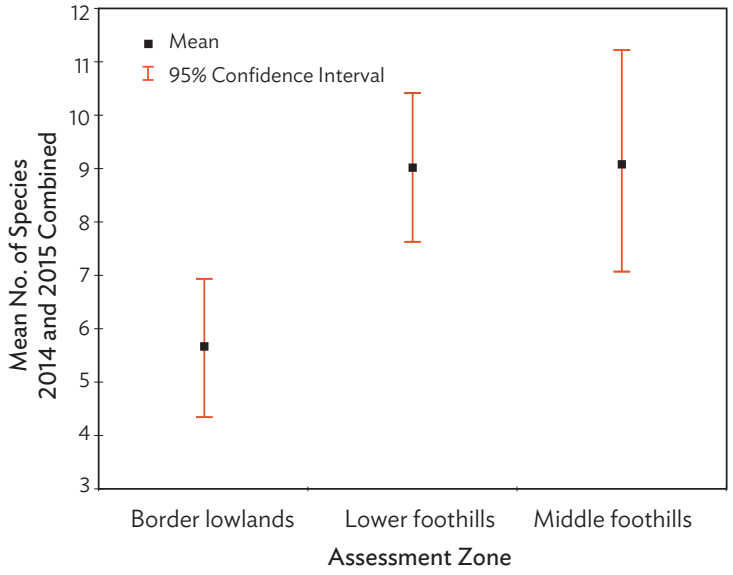
Proportion of animals per site. The mean proportion of total animals for all species recorded in the lower and middle foothills zones were 106% and 219% higher, respectively, than the border lowlands mean for 2014 and 2015 combined (Table 20 and Figure 11).

Shannon–Weaver Diversity Indices per site. The mean SDI for the middle foothills zone was 38% higher than the border lowlands zone mean for the merged 2014 and 2015 camera trapping records (Table 20 and Figure 12). And though the mean for the lower foothills zone was 30% higher than the border lowlands zone, it was not significantly different.

3. Temporal Relationships

Overall, 54.1% of the 4,300 individual mammals recorded during the 2015 PWS camera trapping were active during nighttime (dark) hours. By species, the percentage of records that occurred during nighttime ranged from 42.8% for the Himalayan black bear to 100% for four civet and two porcupine species (Table 18) documented at PWS (Table 21).

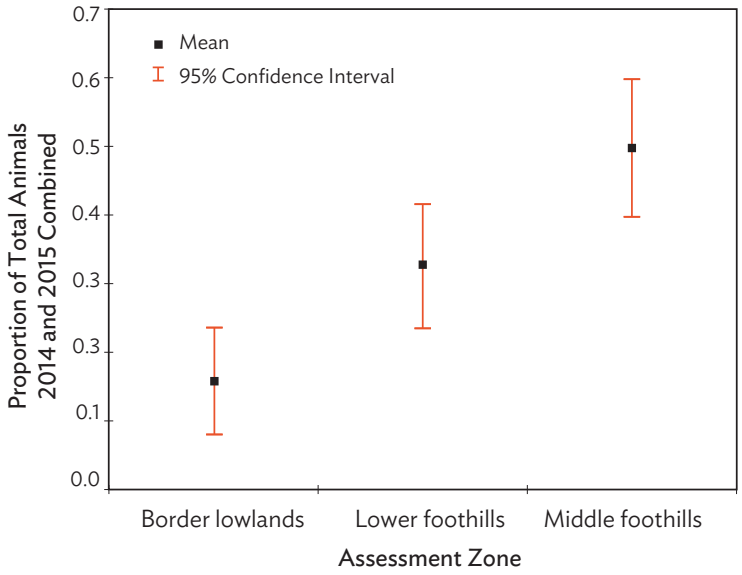
Figure 10: Means and 95% Confidence Intervals for the Number of Species Recorded per Site



Note: Species recorded per site are merged 2014 and 2015 camera trapping data. The Border Lowlands zones mean was lower than those for the other zones.

Source: Asian Development Bank.

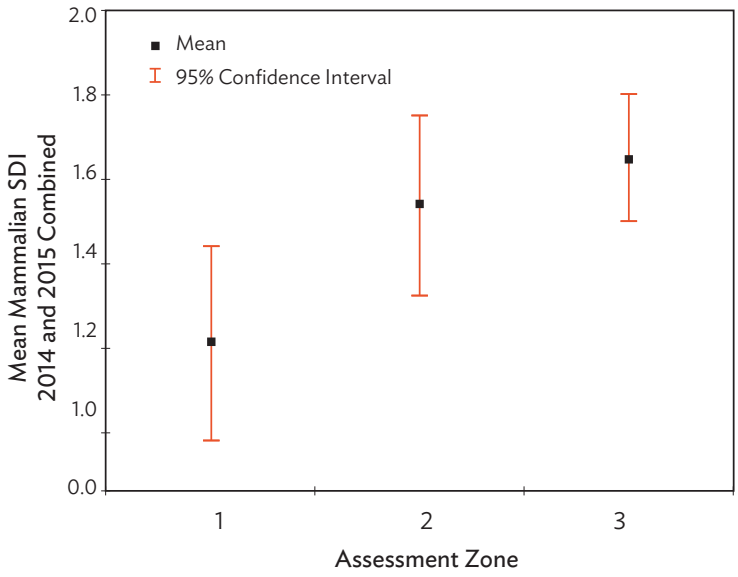
Figure 11: Means and 95% Confidence Intervals for the Proportion of Total Animals Recorded per Site



Note: Total animals recorded per site are merged 2014 and 2015 camera trapping data. The Border Lowlands zone mean was lower than those for the other zones.

Source: Asian Development Bank.

Figure 12: Means and 95% Confidence Intervals for Mammalian Shannon–Weaver Diversity Indices per Site



SDI = Shannon–Weaver Diversity Indices.

Note: Mammalian SDI per site are merged 2014 and 2015 camera trapping data. The Border Lowlands zone mean was lower than the Middle Foothills zone mean.

Source: Asian Development Bank.

Of the records for all IUCN-listed species combined, 60.0% occurred during nighttime hours (Table 22). For all the species and groups in Table 21, the Chi-square comparisons of observed versus expected (even) distributions of animal records by hour were highly significant ($P < 0.001$), indicating that activity patterns indeed exhibited an uneven distribution (e.g., nocturnal or crepuscular pattern).

The combined daily activity pattern for all 28 PWS species recorded exhibited three peaks across the day, with the largest occurring in the late afternoon and early evening, coinciding with dusk or sunset, between 1700 hours and 2000 hours, when many animals became active, travelling and feeding, after a midday period of relative inactivity from 1000 hours to 1500 hours (Figure 13). The second largest peak occurred during early morning between 0600 hours and 0800 hours, coinciding with dawn or sunrise, and likely reflected feeding and travel to cover for bedding during the day.

A third, smaller activity peak was evident between 0100 hours and 0200 hours, a bit unusual as most predominantly nocturnal animals exhibit a "classic" bimodal activity pattern. This three-peaked activity pattern was especially evident for elephant and gaur, which exhibited the greatest number of PWS camera records, and thus influenced the overall pattern for all species (Figure 14). However, a third early-morning peak (0100 hours) was evident in the combined activity patterns for all felid species, likely tied to the patterns of their prey species (Figure 13).

Table 21: Individual Camera Trapping Records where Animals were Active During Nighttime Hours, 2015

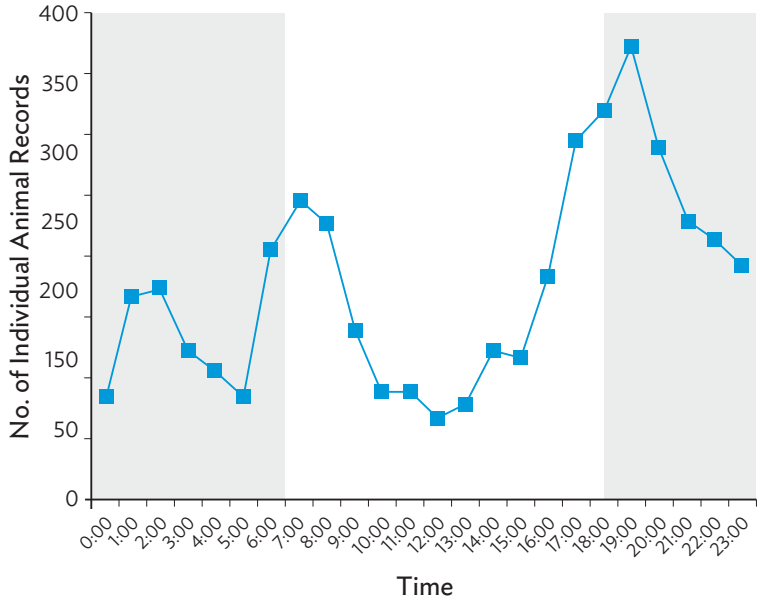
Species/Species Group	Total No. of Individual Records	Percentage of Nighttime Records
All species (*n* = 28)	4,300	54.1
Himalayan black bear	14	42.8
Barking deer	707	43.1
Gaur	1,125	51.2
Elephant	1.311	60.0
All T&E species (*n* = 12)	2,996	60.0
All felid (cat) species (*n* = 6)	109	67.9
Sambar	383	84.1
All civet species (*n* = 4)	59	100.0
All porcupine species (*n* = 2)	56	100.0

T&E = threatened and endangered.

Note: Nighttime hours refer to dark periods during camera recording.

Source: Asian Development Bank.

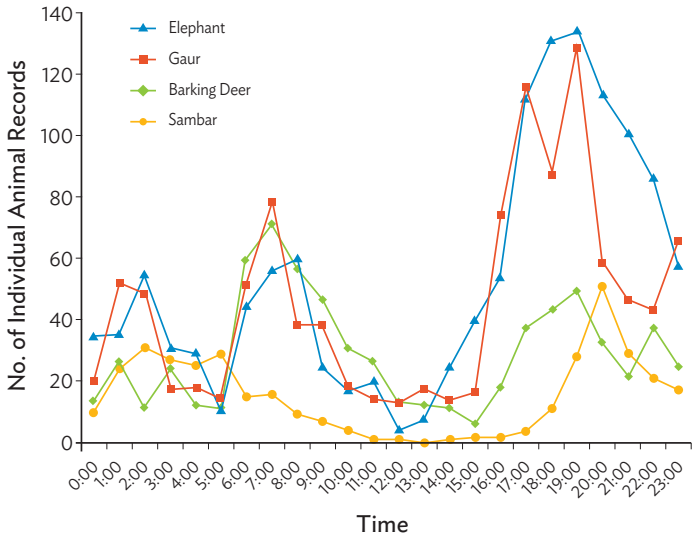
Figure 13: Daily Activity Pattern for 28 Species during Camera Trapping, 2015



Note: The daily activity pattern shows individuals recorded per hour for 28 species during camera trapping. Shading corresponds to approximate occurrence of nighttime hours.

Source: Asian Development Bank.

Figure 14: Activity Patterns for Select Animals, 2015



Note: Activity patterns correspond to individuals recorded per hour for Asian elephant, gaur, barking deer, and sambar, as determined from the camera trapping. Shading corresponds to approximately occurrence of nighttime hours.

Source: Asian Development Bank.

D. FISH SPECIES INVENTORY

The team sampled fish species at five sites spread along the length of the Nichula River (Map 9). Eight species of fish (Table 22) were documented, including one IUCN EN species (*Pterocryptis barakensis*) netted at a single site, one VU species (*Devario aquipimatus*) netted at all five sites, and one NT species (*Neolissochilus hexagonolepis*) netted at three sampling sites. The two middle and upper river sampling sites had higher fish species diversity (mean = 4.0 species/site) than the two lower river sites (mean = 2.5 species per site; Table 22). In addition to fish, freshwater crabs were netted.

Table 22: Number of Fish by Species Netted along the Nichula River

Fish Species (scientific and common names and family)	IUCN Status	Number of Fish Netted at Nichula River Sites				
		Confluence	Lower	Middle 1 site	Middle 2 site	Upper
Badis badis; Phag-nga Family Badidae	LC	–	–	1	–	–
Barilius barna; Barna baril Family Cyprinidae	LC	–	1	1	–	2
Channa stweartii; Borka Family Channidae	LC	1	–	4	3	5

continued on next page

Table 22 *continued*

Fish Species (scientific and common names and family)	IUCN Status	Number of Fish Netted at Nichula River Sites				
		Confluence	Lower	Middle 1 site	Middle 2 site	Upper
Danio dangile; Bhitte Family Cyprinidae	LC	–	–	1	–	2
Devario aquipimatus; Giant danio; Family Cyprinidae	VU	4	1	5	1	7
Garra lissorhynchus; Buduna Family Cyprinidae	LC	–	–	–	–	2
Neolissochilus hexagonolepis; Katle; Family Cyprinidae	NT	4	–	–	3	2
Pterocryptis barakensis; Family Siluridae	EN	–	–	–	1	–

– = not present, EN = endangered, LC = least concern, IUCN = International Union for the Conservation of Nature, NT= near threatened, VU = vulnerable.

Source: Asian Development Bank.

Map 9: Location of Fish Sampling Sites along the Nichula River

Note: The fish sampling sites are along the Nichula River stretching from the confluence with the Sunkosh River *(left)* to the upper river sampling site.

Source: Asian Development Bank.

Endangered fish species in the Nichula River. The fish *Pterocryptis barakensis* were measured and examined for the presence of diagnostic pores on the head that help identify the species. They are eventually returned to the river (photos by ADB).

E. OTHER IUCN-LISTED WILDLIFE SPECIES INVENTORY

Caught in the act. A golden languar is about to swing on a branch (photo by ADB).

1. White-Bellied Heron

At least three (and possibly four) different white-bellied herons were observed at three separate locations; two on the Longa River and one on the Phipsoo River (Map 10) within the lower foothills zone. Three of the herons were positively identified as subadults not engaged in breeding. Both Longa River observations occurred at or near a pool that appeared suitable for foraging, teeming with prey-sized fish. During the first observation when two herons were flushed, one left behind a fish it had just caught, a chepti (*Cyprinion semiplotus*). During the course of the BBA, numerous similar pools teeming with fish, including IUCN EN golden masheer (*Tor putitora*) were noted but not collected along the Longa and Phipsoo river drainages.

2. Golden Langur

During the winter 2015 BBA field activities, 16 different langur groups were surveyed (Map 11), accounting for a minimum of 136 individuals (8.5 per group), with a range of 4–15 langurs per group. A single group of langurs was sighted within the border lowlands zone, while all others were recorded within the higher lower and middle foothills zones (Table 23).

Map 10: White-Bellied Heron Sightings at Phipsoo Wildlife Sanctuary, 2015

Note: The white-bellied heron sightings were made during the biodiversity baseline assessment in January 2015, along the Longa and Phipsoo rivers.

Source: Asian Development Bank.

White-bellied heron and chepti sightings. The Longa River (left) is one of three locations where herons have been sighted; a chepti (right) left behind by herons (photos by ADB).

Map 11: Location of Golden Langur Observations at Phipsoo Wildlife Sanctuary

Note: Red triangles correspond to the observations made during the January and February 2015 field inventories.

Source: Asian Development Bank.

Table 23: Golden Langur Groups Surveyed

Assessment Zone	No. of Langur Groups Surveyed	Percent of Total Groups
Border lowlands	1	6.2
Lower foothills	7	43.8
Middle foothills	8	50.0
All	16	100.0

Note: Observations were made in January and February 2015.

Source: Asian Development Bank.

A male wreathed hornbill. One of four hornbill species found in Phipsoo Wildlife Sanctuary (photo by iStock.com).

3. Hornbills

During BBA field activities in January and February 2015, four species of hornbills were observed with 26 group or flock observations totaling 74 individual hornbills: (i) great, (ii) Oriental pied, (iii) wreathed, and (iv) rufous-necked hornbill (IUCN VU/FNCA Schedule I). Great hornbills are considered more widespread and adaptable to human disturbance than the other species and were regularly seen within modified habitats along the Indo–Bhutan border and in proximity to villages. 61.5% of great hornbill observations were within the border lowlands zone (Table 24). Similarly, the avian inventory recorded 40 great hornbills, of which 45% occurred in this assessment zone.

With the exception of a single Oriental pied hornbill observation within the border lowlands zone, all other Oriental pied and wreathed hornbill observations were made in the lower and middle foothills zones (Map 12 and Table 24). The avian inventory recorded 30 Oriental pied hornbills, with the vast majority (90%) occurring in the lower foothills zone and none in border lowlands. The survey recorded 11 wreathed hornbills spread among all three assessment zones. A single confirmed sighting of a rufous-necked hornbill was made during both the avian inventory and field assessment, within the lower foothills zone.

Table 24: Hornbill Groups Surveyed by Assessment Zone

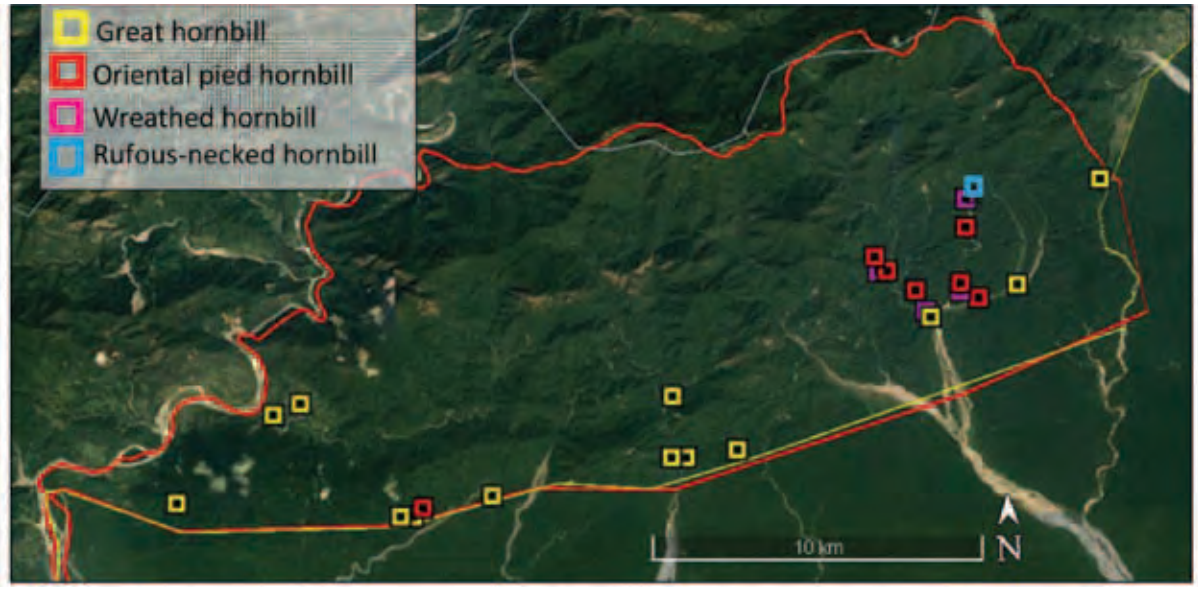
Hornbill Species	Total Groups	Number of Groups Inventoried by Assessment Zone (% of total)		
		Border Lowlands	Lower Foothills	Middle Foothills
Great	13	8 (61.5%)	4 (30.8%)	1 (7.7%)
Oriental pied	8	1 (12.4%)	4 (50.0%)	3 (37.5%)
Wreathed	4	–	2 (50.0%)	2 (50.0%)
Rufous-necked	1	–	1 (100.0%)	–
All	26	9 (34.6%)	11 (42.3%)	6 (23.1%)

– = not present.

Note: Observations were made in January and February 2015.

Source: Asian Development Bank.

Map 12: Locations of Four Species of Hornbill Group Observations in Phipsoo Wildlife Sanctuary, 2015



Source: Asian Development Bank.

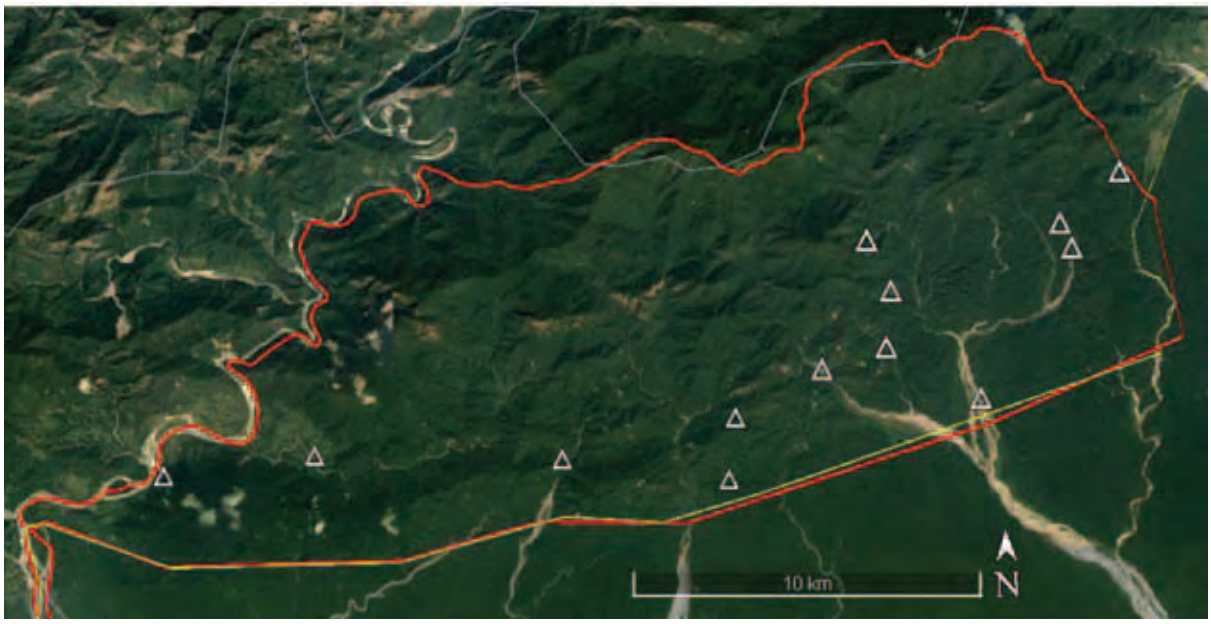
F. SPECIAL HABITAT INVENTORY AND ASSESSMENT

1. Khar Formations

Concentrated wildlife use around PWS khar (salt lick) formations were found, particularly by Asian elephants and gaur (Figure 30). Thirteen major khar formations were found across PWS, most within the lower and middle foothills zones (Map 13). Each khar was documented and GPS locations recorded. Predation on prey species (e.g., Himalayan serow) by leopard was observed in the vicinity of one khar. At Dangay Kali Khar northwest of Phipsoo field station, wildlife use was documented with a camera that recorded 32% of all gaur camera trapped at PWS as well as two tiger records. Conversely, the westernmost khar adjacent to the farm road southwest of Nichula exhibited considerably lower use by wildlife due to impacts associated with concentrated human use in the area.

Concentrations at Dangay Kali Khar. Camera trappings in 2015 show evidence of Asian elephants and gaurs concentrated in the northwest of Phipsoo field station (photos by ADB).

Map 13: Location of 13 Khar Formations across Phipsoo Wildlife Sanctuary



Note: Locations are marked with white triangles, and determined during the winter 2015 biodiversity baseline assessment.

Source: Asian Development Bank.

2. Grassland Health Assessment

Baseline inventory on the percentage of ground cover of native versus invasive species was conducted at two Longa River and one Phipsoo River grassland sites (Map 14). Vegetation was sampled along two to three transects at each site (Table 25).

The percentage of ground cover comprised of invasive species, primarily Siam weed (right), averaged 24.5% along the two Longa River grassland sampling sites and 43.5% at the Phipsoo River sampling site near Phipsoo field station (Table 25). Invasive species have become an established and substantial component of the PWS grassland habitats and are impacting productivity and native species health and vigor.

Invasive species. Siam weed (*Chromolaena* spp.) are abundant in grassland habitats of Phipsoo Wildlife Sanctuary (photo by ADB).

Table 25: Results of Line Intercept Transects Conducted on Grasslands along the Longa and Phipsoo River Drainages

River Drainage	Grassland Location	No. of Transects	Mean Invasive Species Cover (%)
Longa River	Upper drainage	2	25.1
	Middle drainage	2	24.0
Phipsoo River	Lower drainage	3	43.5

Note: The 30-meter line intercept transects were conducted to determine the baseline percentage of ground cover comprised of invasive plant species.

Source: Asian Development Bank.

Map 14: Location of Grassland Habitats and Assessment Transects along the Longa and Phipsoo River Drainages

Note: Dots represent approximate locations of grassland assessment transects.

Source: Asian Development Bank.

The PWS is the only place in Bhutan where the Chital (spotted) deer regularly occurs, particularly at the easternmost limit of its global range, and has been accorded FNCA Schedule I status. Its distribution is largely limited to the grassland or forest interface in and around the lower Phipsoo and Longa rivers. During the BBA, one group of 30+ Chital deer was seen southwest of Phipsoo field station within a modified teak plantation forest. In fact, Duckworth et al. (2008; IUCN status report) reported that this species thrives within teak forest habitats across its range. PWS' grasslands are also important because the species and efforts to restore and limit the impact of non-native invasive species will benefit the deer. Duckworth et al. (2008) reported that competition with cattle within such habitats may also pose a concern to Chital deer, and the ongoing grazing of cattle within the lower Phipsoo River grasslands of PWS could have a deleterious effect on the species, which is prey for tiger and leopard.

3. Illegal Tree Harvest Inventory

Along the Indian border west of the Ranga Kohala, a rapid inventory of tree stumps was conducted in an area representative of heavy illegal tree harvest. The illegal tree harvest has been so heavy that it has opened the native tree canopy to the point that many remaining trees have been subject to windfall due to lacking "wind firm" root systems. This area's forest canopy is now so open that the merits of future replanting of sal versus managing the area as created "grassland" for elephants to support recovery is debatable. The prime trees within the flattest areas adjacent to the border have largely already been cut, and illegal harvesting is now progressing upward on the slopes below Dude Ridge. Even the PWS forest rangers were surprised by the extent and number of large trees that had been cut and removed, many using small tractors.

Lost canopy in the forest. An area where heavy harvesting of trees occurred has left the forest canopy very open (photos by ADB).

From the GIS inventory, four 1 ha plots were superimposed onto the sampling area to determine that the average number of cut trees in this area was 20.5 per ha (Table 26 and Map 15). Most (73.2%) harvested trees were sal though three other species were measured; the average size of harvested sal tree stumps was 52.4 cm in diameter at the stump (Table 26).

Table 26: Results of Preliminary Illegal Tree Harvest and Stump Inventory

Tree Species (Scientific Name)	No. of Stumps (%)	Stump Diameter (cm)		Mean Stumps/ha
		Mean	Range	
Sal *(Shorea robusta)*	60 (73.2%)	52.4 cm	19–83 cm	15.0/ha
Shida *(Lagerstroemia parriflora)*	19 (23.2%)	55.8 cm	28–115 cm	4.7/ha
Jarul *(Lagerstroemia speciose)*	2 (2.4%)	50.0 cm	47–53 cm	0.5/ha
Chilaune *(Schima wallichii)*	1 (1.2%)	43.0 cm	–	0.2/ha
All trees	**82 (100%)**	**53.9 cm**	**19–115 cm**	**20.5/ha**

cm = centimeter, ha = hectare.

Note: Inventory was carried out west of Ranga Kohala along the Indo–Bhutan border. Four 1 ha plots were superimposed on the stump inventory geographic information system data to estimate the mean number of stumps per hectare.

Source: Asian Development Bank.

G. WILDLIFE AND FISH POACHING

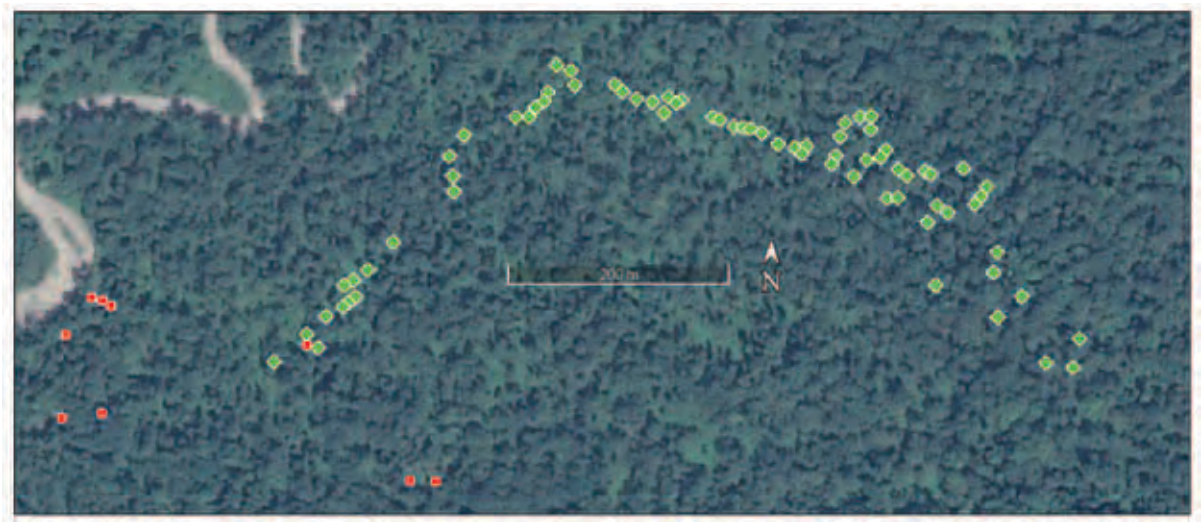
1. Wildlife Poaching

In addition to the illegal harvest of trees, poaching of PWS' diverse wildlife has long been recognized as a significant problem (PWS CMP, Norbu and Tobgay 2012). This is attributable to the "porous international border" (Norbu and Tobgay 2012) allowing entry by poachers (from neighboring India), PWS' proximity to regional wildlife trafficking routes, and a lucrative market for all or parts of some species (e.g., tiger).

Subsistence poaching for meat is further being exacerbated by population growth and decline of wildlife populations in India, as well as the challenge, difficulties, and security risks PWS forest rangers face in effectively patrolling and preventing such activities. Subsistence poaching is reported by rangers to focus on gaur, though other species such as sambar, barking deer, serow, and others may be taken if encountered. Poachers have been reported by rangers to occasionally kill elephants. The ever-present threat to tigers due to their high value (up to $50,000) on the Asian black market presents a risk to this species' recovery.

The 2014 camera trapping done at PWS recorded 457 humans (many villages working livestock), excluding PWS rangers and military. Of these, there were 26 clearly identifiable instances of "poachers" making incursions into PWS, such as the one captured on camera video (screengrab shown on p. 82). Five poachers were recorded at lower foothills zone camera sites and 21 occurred at middle slope zone sites. The number of poachers recorded

Map 15: Location of Sampled Illegally Harvested Tree Stumps Near the Indo–Bhutan Border West of Ranga Kohala



Note: Tree stumps (green dots) and other inventoried stumps (red dots).

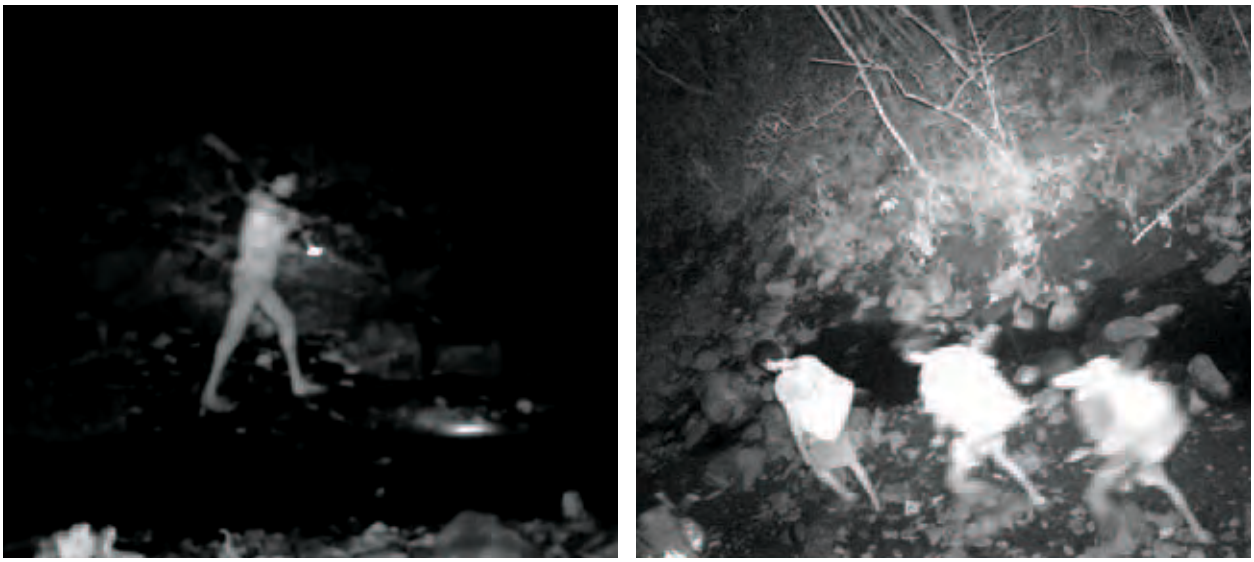
Source: Asian Development Bank.

in the middle foothills zone illustrates how far into PWS poachers make their illegal incursions in search of game; the substantially higher proportion of animals documented by camera trapping in this zone likely explains the disproportionate distribution of poachers this far into the sanctuary.

The 2015 BBA camera trapping yielded photos of 271 humans, most (236) being PWS rangers and military personnel. Of the other humans documented within PWS, most (31) appeared to be villagers working livestock and securing foods (e.g., mangos, forage for livestock) from the sanctuary, though some may have possibly been engaged in poaching. However, clearly just one group of four poachers was confirmed in the middle foothills zone (screengrab shown on p. 82). Overall, it would appear that incursions by poachers into PWS were dramatically lower in 2015 than during the 2014 camera trapping, especially given that it was the winter dry period. Ongoing Indian and Bhutanese military operations in the region targeting insurgents during the study no doubt had an impact in reducing poaching incursions and points to the potential benefit of increased patrols in protecting PWS' wildlife resources.

2. Fish Poaching

During field activities, several PWS rangers described an additional threat to the sanctuary's resources: the poaching of fish from some of PWS' perennial rivers, including with the use of poisons. The rangers described multiple incidents where poachers had employed nets to seine fish, as well as pesticides and herbicides ostensibly taken from neighboring tea plantations to mass-poison entire stretches of the river during low flow periods. These poached fish are subsequently dried and transported to Indian markets for sale (Figure 33).



Caught on camera. Screengrabs from video footages of camera trappings show (i) a poacher carrying a rifle to which a flashlight was attached for hunting in 2014 (photo by PWS) and (ii) a group of three poachers also armed with rifles in 2015 (photo by ADB).

In one instance in 2015, rangers found a dead poacher who had succumbed to the effects of the poisons he was releasing into the river. The latest incident occurred along the Longa River in February 2016, where PWS rangers apprehended 23 poachers with rifles, leg-hold traps, fish cast nets, and poisons (as shown on p. 83). These poachers also had substantial amounts of dried fish in their possession, which they likely were transporting to markets in India (as shown on p. 83).

The environmental impact from the application of poisons to kill PWS' fish is potentially tremendous to the entire aquatic ecosystem food chain—from macro-invertebrates to storks, herons, and other predatory birds such as kingfishers. In particular, with the apparent increasing use of PWS by white-bellied herons during winter as observed during the study when low flows occur, such poisoning of fish has the potential to kill herons and significantly impact heron recovery. This poisoning has not been documented in the past along the Phipsoo River, due likely to the presence of the existing field station and its rangers. As such, establishment of an anti-poaching outpost along the Longa and Pingkhua river drainages could likewise provide substantial resource protection benefit to their aquatic resources and dependent species such as herons and a multitude of other PWS resources.

The PWS CMP (Norbu and Tobgay 2012) devoted considerable attention to developing a highly trained ranger force along with acquiring equipment and infrastructure to support anti-poaching efforts. A well-trained and dedicated force of rangers is now in place at PWS, and strides have been made to equip them with support equipment including radios and a limited fleet of vehicles. However, rangers are hampered by limited road access, and even foot access during the monsoon period, making patrol difficult and logistically challenging as well as dangerous. The CMP indeed identifies the construction of new anti-poaching outposts near the Longa and Pingkhua rivers, as well as at Nichula and remote Dhaneshri as a priority objective. And while the CMP only addresses upgrading the Phipsoo field station

Poachers apprehended. In February 2016, rangers aprehended 23 poachers with rifles, traps, and fish seine nets, as well as sacks containing poison for mass killing fish (photos by PWS).

road to improve year-round travel there, PWS and WCD staffs viewed a potential future road as a resource protection asset if balanced against minimizing impact to the sanctuary's resources and ensuring a commitment is made to manage the road appropriately.

H. BIODIVERSITY INDICES AND SUMMARY

Compilation of the scaled values for 10 biodiversity metrics measured as part of the BBA is summarized in Table 27. Biodiversity indices differed among assessment zones (ANOVA $F_{2,27} = 5.97$, $P = 0.007$). The lower and middle foothills zones exhibited comparable overall biodiversity indices, 0.42 and 0.38, respectively, twice that exhibited by the border lowlands zone (0.20); the border lowlands index was significantly lower than those for the lower (Tukey test $P = 0.019$) and middle ($P = 0.013$) foothills zones.

As described in Section VII. A. much of the border lowlands zone has been modified or degraded by a variety of human-induced impacts that have likely contributed to the zone's lower overall biodiversity. Further, this zone lacks the proximity to PWS' perennial river ecosystems (at least during the dry winter period when the BBA was conducted) that bisect the higher elevation lower and middle foothills zones and contribute to their higher biodiversity. These biodiversity indices are meant for comparative and summary purposes only relative to the metrics we measured, and are not intended to oversimplify PWS' complex biodiversity and ecological processes. Nonetheless, they do point to the higher overall biodiversity found within PWS' interior core compared to the zone along much of the Indo–Bhutan border.

Table 27: Biodiversity Indices for Assessment Zones

Biodiversity Metric	Assessment Zone[a]		
	Border Lowlands	Lower Foothills	Middle Foothills
Mean overstory tree SDI/site	0.39	0.32	0.36
No. of orchid species/zone	0.30	0.30	0.39
Mean avian SDI/site	0.32	0.36	0.32
Mean mammal SDI/site	0.26	0.34	0.36
Mean proportion of total mammals/site	0.16	0.33	0.51
No. of white-bellied heron observations	0.00	1.00	0.00
No. of golden langur group observations	0.06	0.44	0.51
No. of hornbill group observations	0.35	0.42	0.23
No. of khar formation locations	0.15	0.46	0.39
No. of tiger camera trapping records	0.03	0.27	0.70
Biodiversity Index (average of 10 metrics)[b]	0.20	0.42	0.38

BBA = biodiversity baseline assessment, SDI = Shannon–Weaver Diversity Indices.

[a] Biodiversity indices differed among assessment zones (analysis of variance $F_{2,27} = 5.97$, $P = 0.007$)

[b] Border Lowlands < Lower Foothills ($P = 0.019$); Border Lowlands < Middle Foothills ($P = 0.013$).

Note: Based on scaled values for 10 biodiversity metrics measured during the 2015 BBA and 2014 camera trapping.

Source: Asian Development Bank.

VII. HABITAT CLASSIFICATION

ADB's SPS provides guidance for classification of habitats within project areas and the respective limits for habitat degradation associated with ADB-funded projects. The two primary classifications include natural and modified habitats. For both habitats, ADB's SPS provides the framework for the determination of critical habitat for endangered, limited distribution and/or endemic, and migratory and/or congregatory species, as well as other factors.

A. MODIFIED AND DEGRADED NATURAL HABITATS

As described earlier, much of the southern portion of PWS constitutes modified habitat impacted by a host of human activities ranging from plantations to illegal tree harvest, livestock grazing, and human development associated with villages, and even an operating open-pit ore mine within PWS.

Plantations. Much of the eastern half of PWS up to the Pingkhua River drainage exhibits evidence of past harvest of native forest species and subsequent replanting of teak and sal in plantation plots dating back to the 1950s and 1960s. These areas constitute modified habitat. Such plantation forests have considerably lower plant species diversity than natural habitats remaining in the area, and occur in four separate blocks encompassing approximately 50 plots. The blocks range in size from 3.5 ha to 1,169 ha (Map 16), and total 1,206 ha (Table 28).

Villages. The area surrounding the abandoned village of Pingkhua near the center of PWS reflects past modification of native habitats associated with human habitation, including removal of native forest. The area at the far west side of PWS adjacent to the Sunkosh River and extending north to both sides of the lower Nichula River reflects human settlement in the village of Nichula, including homes, farms, and livestock grazing (Map 16). These areas of past and present village habitation constitute a modified habitat within PWS (Table 28).

Modified habitat. Remnants of a train track used for logging at plantations near the Longa River (photo by ADB).

Illegal tree harvest. Tree stumps show evidence of illegally harvested sal trees in Phipsoo Wildlife Sanctuary (photo by ADB).

Illegal tree harvest. As described in Section VI. F., the area abutting the Indian border west of the Pingkhua River to the far western side of PWS has been affected by varying levels of illegal harvest of trees, primarily protected sal (Map 16). Illegal tree harvest spans an approximately 15 km band along the Indo–Bhutan border, though the extent and severity of harvest across this entire band were not determined due to the suspension of BBA field activities. These habitats may constitute natural but degraded versus modified habitats, where the heaviest cutover areas likely meet the modified criterion.

Map 16: Modified or Degraded Natural Habitats at Phipsoo Wildlife Sanctuary

Note: Map shows plantation plots (orange), illegal tree harvests (blue), villages (yellow), and open-pit ore mines (red).

Source: Asian Development Bank.

Table 28: Predominant Human Activities within Phipsoo Wildlife Sanctuary that Have Contributed to Modification of Natural Habitats

Human Activity	Area (hectare)	Area of Sanctuary (%)
Plantation plots (four blocks)	1,206	4.5
Villages (Pingkhua and Nichula)	503	1.9
Illegal tree harvest	890	3.3
Open-pit ore mine	5	<0.1
Total	**2,604**	**9.7**

Note: See also Map 16.

Source: Asian Development Bank.

The stump inventory conducted west of Ranga Kohala points to the potential severity and impact of illegal tree harvest. Assuming that only half of the documented level of poaching (22.6 trees per ha) occurs elsewhere along the 15 km band, and within a conservative 150 m wide band, illegal tree poaching to date could easily have resulted in as many as 2,500 trees being cut. And not only does such harvest eliminate the trees themselves, it reduces canopy density and integrity, alters site microclimates, promotes windfall of remaining trees, and promotes establishment of invasive species associated with plant community and soil disruption.

Additional illegal tree harvest or stump inventory is a priority need along the Indo–Bhutan border. The 10-year Normalized Difference Vegetation Index comparative analysis presented in Section V. C. (Map 5) shows areas of reduced canopy density; however, ground truthing or validation of this data is necessary to make an accurate interpretation for utility in delineating areas of illegal tree harvest.

When considering all human-impacted habitats along PWS' southern border with India (Table 28), modified and/or degraded habitat encompasses 2,604 ha and accounts for a total of 9.7% of the sanctuary's total acreage.

B. NATURAL HABITAT

With the 9.7% of PWS determined to be modified or degraded habitat, it was found that the remaining 90.3% of PWS' habitat remains as intact, or natural habitat.

Comparison of mammalian diversity in modified and/or degraded versus natural habitats. It is typically assumed that modified habitats reflect lower biodiversity and, in the case of PWS' modified habitats, there has indeed been reduced canopy density from illegal tree harvest and reduced species diversity from logging and/or replanting of plantations. The 2015 BBA mammalian biodiversity metrics for camera trapping sites within PWS modified and/or degraded habitats associated with plantations (n = 6) and adjacent camera sites (n = 7) were compared within natural habitats of the border lowlands, and lower foothills zones to obtain empirical insights. The natural habitat camera sites were at comparable elevations located near the modified habitat sites.

Table 29: Comparison of 2015 Mammalian SDI and Number of Species

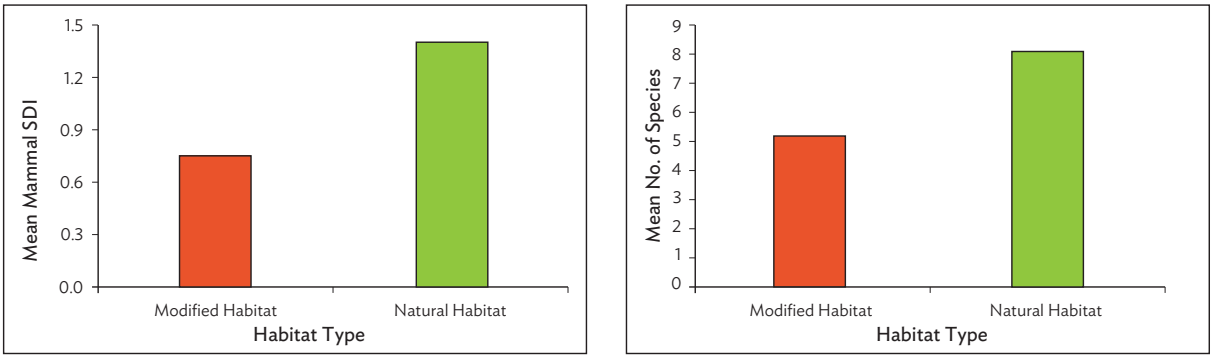
Parameter/Metric	Modified Habitat Mean (±SE)	Natural Habitat Mean (±SE)	Student's t-test Results for Differences between Means
No. of Camera Sites	6	7	
SDI	0.76 (±0.15)	1.40 (±0.17)	t_{11} = 2.80** P = 0.017
Species	5.2 (±0.8)	8.1 (±0.8)	t_{11} = 2.64** P = 0.023

** = significant statistical test results, SDI = Shannon–Weaver Diversity Indices.

Source: Asian Development Bank.

The t-testing for differences between the means derived from camera sites in modified habitats versus adjacent natural habitats yielded significant results for both metrics (Table 29 and Figure 15). Modified and/or degraded habitat SDI were about half that of the adjacent natural habitat sites, and the number of species was 36% lower in modified habitats (Figure 15). This provides some empirical insight to the impact of habitat modification/degradation on mammalian biodiversity, as well as the degree to which protected area habitats have already been impacted by human activities.

Figure 15: Comparison of the Mean Mammalian Shannon–Weaver Diversity Indices and Number of Mammal Species from Camera Monitoring, 2015



SDI = Shannon–Weaver Diversity Indices.

Source: Asian Development Bank.

C. CRITICAL HABITAT

With the plethora of IUCN-listed, FNCA-protected, and limited-distribution and/or restricted-range species at PWS, many of these species (Table 4) were considered candidates for critical habitat designation within natural and modified and/or degraded habitats. The proposed road through PWS was originally designated an ADB environmental category A project due to its high environmental sensitivity tied to the protected area status of PWS and the many IUCN-listed species that occur there. As such, ADB's SPS and its Environmental Safeguards Good Practice Sourcebook (2012, p. 44) provide the framework for consideration of the potential for projects to be considered within a critical habitat, defined as follows:

Critical habitat is an area that has high biodiversity value and may include sites that are legally protected or officially proposed for protection (e.g., areas that meet the IUCN classification criteria, etc.). Critical habitat includes the following:

- habitat required for the survival of critically endangered or endangered species;
- areas with special significance for endemic or restricted-range species;
- sites that are critical for the survival of migratory species;
- areas supporting globally significant concentrations or numbers of individuals of congregatory species;
- areas with unique assemblages of species that are associated with key evolutionary processes or provide key ecosystem services; and
- areas with biodiversity that has significant social, cultural, or economic importance to local communities.

Based on limited field studies and without consultation with species experts, a preliminary determination if PWS' habitats potentially constitute critical habitat for endangered and other species was conducted. Screening was carried out using the Integrated Biodiversity Assessment Tool (IBAT) and other desktop analyses, including consideration of IUCN species profiles and BBA information. This collective information was used to identify 20 critical habitat candidate species: 2 IUCN-CR species, 7 IUCN-EN species, 10 Bhutan FNCA Schedule I-listed species, and 1 limited-distribution species (Table 4). For these 20 species, the criteria and thresholds (Table 30) described in the International Finance Corporation (IFC) Performance Standard 6 Guidance Note (2012) to guide potential critical habitat determination were applied, which include the following:

- Criterion 1: Critically endangered and/or endangered species
- Criterion 2: Endemic and/or restricted-range species
- Criterion 3: Migratory and/or congregatory species
- Criterion 4: Highly threatened and/or unique ecosystems
- Criterion 5: Key evolutionary processes

Table 30: International Finance Corporation Performance Standard 6 Guidance Note (2012) Criteria 1–3 and Their Associated Thresholds as Applied in Phipsoo Wildlife Sanctuary

Criterion 1: Critically Endangered (CR) and/or Endangered (EN) Species
Tier 1 Subcriterion
(i) Habitat required to sustain ≥ 10% of the global population of CR or EN species where there are known, regular occurrences of the species, and where that habitat could be considered a discrete management unit.
(ii) Habitat with known, regular occurrences of CR or EN species where that habitat is 1 of 10 or fewer discrete management sites globally.
Tier 2 Subcriterion
(i) Habitat that supports the regular occurrence of a single individual of a CR species, and/or habitat containing regionally important concentrations of a Red List EN species where that habitat could be considered a discrete management unit.
(ii) Habitat of significant importance to CR or EN species that are wide-ranging and/or whose population distribution is not well understood, and where the loss of such a habitat could potentially impact the long-term survivability .
(iii) As appropriate, habitat containing nationally or regionally important concentrations of an EN, CR, or equivalent national or regional listing.
Criterion 2: Endemic or Restricted Range Species
Tier 1 Subcriterion
(i) Habitat known to sustain ≥ 95% of the global population of an endemic or restricted-range species where that habitat could be considered a discrete management unit for that species (e.g., a single-site endemic).
Tier 2 Subcriterion
(i) Habitat known to sustain ≥ 1% but < 95% of the global population of an endemic or restricted-range species where that habitat could be considered a discrete management unit, and where data are available and/or based on expert judgment

continued on next page

Table 30 *continued*

Criterion 3: Migratory or Congregatory Species
Tier 1 Subcriterion
(i) Habitat known to sustain, on a cyclical or otherwise regular basis, ≥ 95% of the global population of migratory or congregatory species at any point of the species' lifecycle where that habitat could be considered a discrete management unit.
Tier 2 Subcriterion
(i) Habitat known to sustain, on a cyclical or otherwise regular basis, ≥ 1% but < 95% of the global population of migratory or congregatory species at any point of the species' lifecycle and where that habitat could be considered a discrete management unit, where adequate data are available and/or based on expert judgment.
(ii) For birds, habitat that meets BirdLife International's Criterion A4 for congregations and/or Ramsar Criteria 5 or 6 for Identifying Wetlands of International Importance.
(iii) For species with large but clumped distributions, a provisional threshold is set at ≥5% of the global population for both terrestrial and marine species.
(iv) Source sites that contribute ≥ 1% of the global population of recruits.

PWS = Phipsoo Wildlife Sanctuary.

Note: The note was used to guide the determination of critical habitat for PWS candidate species. PWS was considered as a discrete management unit with its clear borders and management regime, though it was also considered as part of a larger landscape-scale discrete management unit within Bhutan's (and India's) networks of protected areas.

Source: Asian Development Bank, based on International Finance Corporation Performance Standard 6 Guidance Note. 2012.

The assessment of the 20 candidate species for potential critical habitat designation (Table 31) found that most (12) likely do not merit such designation largely due to PWS' relatively small size and, thus, low level of overlap with global ranges or relatively small contribution toward global population levels that did not meet IFC threshold criteria. Several candidate species exhibited low densities at PWS as well (Table 31).

Four candidate species, Chinese pangolin (IUCN-CR), Asian elephant (IUCN-EN), golden langur (IUCN-EN), and gaur (IUCN-VU) were found to merit further evaluation and consultation in the context of PWS being part of a larger, regional discrete management unit that encompasses the Himalayan foothills to and beyond RMNP. The two candidate fish species also merit further consideration and consultation, as well as additional survey within PWS, to determine their importance to the recovery of these species, especially if they exhibit continued regional declines. Critical habitat designation for these five species was identified as possibly dependent on additional surveys, insights, and consultation (Table 31).

Based on the preliminary assessment, it was found that PWS likely constitutes critical habitat for two candidate species based on the IFC criteria for endangered species (IFC Criterion 1); the EN tiger and CR white-bellied heron (Table 31). In addition, likely critical habitat designation for the white-bellied heron reflects the species' apparent congregatory use by dispersing subadult birds that may be of increasing importance to recovery (IFC Criterion 3).

Table 31: Assessment of 20 Candidate Species for Potential Critical Habitat Designation

Critical Habitat Candidate Species	IUCN/ FNCA Status	Endenic/ Restricted Range/ Congregatory	PWS Habitat Type	PWS Range Overlap	Regional/PWS Threats	Assessment Outcome	Critical Habitat at PWS
Mammals							
Chinese pangolin *(Manis pentadactyla)*	CR	Potentially a restricted range species	Subtropical forests	0.01%	Hunting/poaching; forest habitat fragmentation outside PWS/ Bhutan	Fringe of global range distribution and uncommon at PWS; a single camera record during 2015 camera trapping. Does not meet IFC critera thresholds.	Possible
Hog deer *(Axis porcinus)*	EN	No	Grasslands River floodplains	0.07%	Hunting/poaching Grassland habitat degradation from invasive species; regional habitat fragmentation	Rare at PWS; not seen during BBA. Recovery of grassland for Asian elephants will also benefit hog deer. Does not meet IFC criteria thresholds.	Not likely
Asiatic water buffalo *(Bubalus bubalis)*	EN Bhutan Sch. I	No	Wet grasslands	No IUCN data to assess overlap	Hunting/ poaching; habitat degradation and fragmentation	Fringe of range; not documented during 2015 BBA; recorded at single camera in 2014 along border with India. Would benefit from grassland restoration along with Asian elephant. Does not meet IFC criteria thresholds.	Not likely
Dhole (Asiatic wild dog) *(Cuon alpinus)*	EN	No	Subtropical forests River floodplains	No IUCN data to assess overlap	Forest habitat fragmentation and degradation; decline of prey species numbers	Outside known range; not common at PWS; recorded at a limited number of Lower Foothills camera sites in 2014 and 2015; sign noted in several areas along border with India during BBA. PWS offers excellent prey base, including deer species and wild pig. Does not meet IFC criteria thresholds.	Not likely
Asian elephant *(Elephas maximus)*	EN Bhutan Sch. I	No	Subtropical forests Grasslands Rivers as travel corridors	0.04%	Grassland habitat degradation from invasive species; fragmentation of habitats in India; poaching; conflict with humans and farms; highway and road barrier effect	Habitat fragmentation is a regional, landscape-scale concern; PWS provides quality, intact habitat with corridors across southern Bhutan. Bhutan accounts for <1% of global population, but together with the Ripu–Chirang Reserve and the entire Sarpang–Gelephu Foothills Key Biodiversity Area could constitute a discrete management unit; PWS population likely 75–150 animals. Otherwise, does not meet IFC criteria. Conservation offset restore grasslands for elephants and other dependent species needed. Needs consultation.	Possible

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Table 31 *continued*

Critical Habitat Candidate Species	IUCN/ FNCA Status	Endenic/ Restricted Range/ Congregatory	PWS Habitat Type	PWS Range Overlap	Regional/PWS Threats	Assessment Outcome	Critical Habitat at PWS
Tiger *(Panthera tigris)*	EN Bhutan Sch. I	No	Subtropical forests	0.02%	Poaching for Asian black market; habitat loss and fragmentation, especially in neighboring India; potential conflict with humans and their livestock	Habitat fragmentation is a regional, landscape-scale concern. PWS provides quality, intact habitat with corridors across Bhutan. PWS offers excellent prey base. Tigers recorded at numerous camera sites in PWS' interior forests. Recovery focus on source sites with >25 breeding females, legal protection, and landscape potential to support >50 breeding females makes Bhutan likely candidate as a source site (42 to date); PWS supports 2–3 adults and is important nationally to achieving source status. Marginally meets IFC criterion 1.	Likley
Golden langur *(Trachypithecus geei)*	EN Bhutan Sch. I	No	Subtropical forests	4.20%	Limited to Bhutan and India; Indian habitat highly fragmented Poaching of forests, including at PWS; highway and road barriers	PWS accounts for the largest percentage of range overlap for this species of all candidate species; PWS offers quality, intact forest habitats and connectivity with other intact habitats. Good population documented at PWS during BBA largely in interior forests; might pass threshold for IFC criterion 1. Needs more evaluation/ consultation.	Possible
Gaur *(Bos gaurus)*	VU Bhutan Sch. I	No	Subtropical forests Grasslands	0.01%	Hunting/poaching for meat at PWS Habitat loss and fragmentation in India; grassland degradation at PWS	PWS supports substantial, widespread population of gaur, mostly in the interior of the sanctuary. Together with the Ripu-Chirang Reserve and the Sarpang-Gelephu Foothills Key Biodiversity Area stretching to Royal Manas National Park, could constitute a discrete management unit of intact, connected habitat; however, does not appear to meet IFC criteria. Needs more evaluation /consultation.	Possible
Asiatic black bear *(Ursus thibetanus)*	VU Bhutan Sch. I	No	Subtropical forests	0.01%	Hunting/ poaching for Asian black market; habitat loss and fragmentation	Species has wide global range. PWS supports modest bear densities in its interior forests, but its quality habitat represents a very small portion of the range. Fails to meet IFC thresholds.	Not likely

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Table 31 *continued*

Critical Habitat Candidate Species	IUCN/ FNCA Status	Endenic/ Restricted Range/ Congregatory	PWS Habitat Type	PWS Range Overlap	Regional/PWS Threats	Assessment Outcome	Critical Habitat at PWS
Clouded leopard *(Neofelis nebulosa)*	VU Bhutan Sch. I	No	Subtropical forests	0.01%	Poaching for trade of animal parts and hides; forest fragmentation elsewhere	PWS supports modest clouded leopard densities in interior forests, but its quality habitat is a very small portion of the global range. PWS population secure. Fails to meet IFC thresholds.	Not likely
Himalayan serow *(Capricornis thar)*	NT Bhutan Sch. I	No	Rugged and hilly forested terrain	No IUCN data to assess overlap	Hunting/poaching for meat; habitat loss and fragmentation elsewhere	Serow occur in modest numbers at PWS. Due to small contribution of PWS toward the global range and fairly small population. Does not meet IFC thresholds.	Not likely
Leopard *(Panthera pardus)*	NT Bhutan Sch. I	No	Highly adaptable Forests Grasslands	<0.01%	Hunting/poaching for part and skins; habitat loss and fragmentation elsewhere	Very widespread global range and common species (except some subspecies), including at PWS with its excellent prey base; likely help control wild pig numbers. Common at PWS. Does not meet IFC thresholds.	Not likely
Chital (spotted) deer *(Axis axis)*	LC Bhutan Sch. I	Restricted range in Bhutan (does not meet IFC threshold)	Subtropical forests and grassland interface	0.01%	Limited threats from poaching for meat, habitat loss and degradation Grassland impact from livestock	Very widespread global range and common species; Bhutan lies at eastern fringe of range. Deer confined to relatively small area of PWS; would benefit from grassland restoration. Does not meet IFC thresholds.	Not likely
Leopard cat *(Prionailurus bengalensis)*	LC Bhutan Sch. I	No	Subtropical forests	<0.01%	Limited threats, primarily from hunting in some areas	Widespread global range and common species, including at PWS, with stable global population. Does not meet IFC thresholds.	Not likely
Birds							
White-bellied heron *(Ardea insignis)*	CR	Congregatory (tier 2); PWS potentially important as juvenile dispersal habitat	Rivers	0.33%	Hydroelectric power projects, increased use and recreation along rivers; poisoning of streams by fish poachers at PWS	Herons, mostly subadults appear to be using Phipsoo and Longa rivers in interior of PWS for dispersal and feeding on plentiful fish. PWS may be of growing importance to recovery. Much of global range outside Bhutan not protected. Meets IFC criterion 1 threshold in spite of low range overlap.	Likely

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Table 31 *continued*

Critical Habitat Candidate Species	IUCN/ FNCA Status	Endenic/ Restricted Range/ Congregatory	PWS Habitat Type	PWS Range Overlap	Regional/PWS Threats	Assessment Outcome	Critical Habitat at PWS
Rufous-necked hornbill *(Aceros nipalensis)*	VU Bhutan Sch. I	No	Subtropical forests with mature trees	0.09%	Habitat loss and fragmentation outside Bhutan	Few hornbills documented during BBA; may reflect limited survey of upper foothills. PWS and surrounding areas (e.g., Sarpang–Gelephu Foothills) could be important to species recovery; PWS accounts for small portion of range. Does not meet IFC thresholds.	Not likely
Fish							
Pterocryptis barakensis	EN	Unknown	Rivers	No IUCN data to assess overlap	Loss of river habitats from dams in India	Little known about the species; reported for a single location by IUCN but documented at Royal Manas National Park and Nichula River at PWS. More evaluation needed.	Possible
Golden mahseer *(Tor tor)*	NT Bhutan Sch. I	Unknown	Rivers	No IUCN data to assess overlap	Overfishing of populations, especially in India; poisoning of PWS rivers by fish poachers	Widespread species, but in rapid decline over range. PWS, especially upper Phipsoo River, harbors good population; could be important to future recovery. Further survey and consultation needed; not enough information to evaluate.	Possible
Plants							
Agar *(Aquilaria malaccensis)*	VU Bhutan Sch. I	No	Subtropical Forests	No IUCN data to assess overlap	Overharvest and/ or destruction of native forests	Appears to be rare at PWS, as a single specimen was noted during BBA in the Lower Foothills. CR in India. Does not meet IFC thresholds.	Not likely
Sal *(Shorea robusta)*	LC	Restricted range in Bhutan (does not meet IFC threshold)	Subtropical Forests	No IUCN data to assess overlap	Overharvest and destruction of native forests; poaching within PWS along Indian border	Limited distribution species; Bhutan at the eastern fringe of range. Widespread in region; dominant species in lower PWS forests; poaching impacting borer forests. Does not meet IFC thresholds; protected elsewhere.	Not likely

BBA = biodiversity baseline assessment, CR = critically endangered, EN = endangered, FNCA = Forest and Nature Conservation Act of Bhutan (1999), IBAT = Integrated Biodiversity Assessment Tool, IFC = International Finance Corporation, IUCN = International Union for the Conservation of Nature, LC = least concern, NT= near threatened, PWS = Phipsoo Wildlife Sanctuary, VU = vulnerable.

Note: Assessment applied the IBAT, IUCN species profiles, BBA results, and other information to address the IFC threshold criteria (see Table Table 4).

Source: Asian Development Bank, based on International Finance Corporation Performance Standard 6 Guidance Note. 2012.

Regardless of the limited number of species for which a preliminary critical habitat determination for PWS was made, majority of the species will largely fall under the "umbrella" of protection provided by likely critical habitat designation for the tiger. This species' potential critical habitat delineation overlaps the habitat for nearly all the other candidate species and, thus, softens the uncertainty of whether more might merit critical habitat designation.

1. White-Bellied Heron Potential Critical Habitat

BirdLife International (2013) reports that as few as 70 total individual white-bellied herons may exist across the species' range. Thus, the sighting of four herons within a week at PWS represents a substantial proportion (6%) of the extant population. Further, it indicates that PWS and its excellent foraging habitat with plentiful fish may be important in promoting the survival and eventual recruitment of young, subadult herons into the breeding population. Potential PWS critical habitat for the heron was delineated along the Longa and Phipsoo rivers encompassing approximately 1,000 ha (Map 17), though this may be conservative.

The single greatest threat to white-bellied herons at PWS is the potential for continued fish poisoning that has been documented by PWS forest rangers in the past, primarily within the Longa River drainage (Section VI. G.). Such poisoning has not been documented along the Phipsoo River, which is likely protected by the presence of the existing field station and its rangers. As such, the construction of other anti-poaching outposts identified in the PWS CMP (Norbu and Tobgay 2012) offer substantial resource protection benefit to herons that appear to be increasingly using the area, as well as a multitude of other PWS resources.

Map 17: Critical Habitat Designation for the White-Bellied Heron at Phipsoo Wildlife Sanctuary

Note: The orange-shaded critical habitat areas are found along the Longa and Phipsoo river drainages.

Source: Asian Development Bank.

The Longa and Phipsoo rivers may constitute increasingly important habitat for the heron, especially for dispersing immature and subadult birds. Here, foraging rates may be substantially higher than along faster-flowing major rivers where fishing success is relatively low (Pradhan et al. 2011) and where hydroelectric power plant construction may be causing herons to disperse away, at least seasonally. Much of the habitat adjacent to the Phipsoo and Longa rivers is open and accessible to herons, and exhibits excellent site and approach visibility (Pradhan et al. 2011)—though this could be limited by further invasive species expansion within adjacent grassland habitats. Forest habitats adjacent to PWS' rivers afford suitable perching or roosting habitat, where herons were observed. Most importantly, numerous pools along PWS' rivers teem with prey-sized fish that are relatively easy for herons to catch during low flows.

Teeming with fish. The Longa River is home to plenty of fish, making it an attractive foraging habitat to white-bellied herons (photo by ADB).

2. Tiger Potential Critical Habitat

The other species for which PWS critical habitat appears warranted is the tiger. During the course of the field activities, three tiger tracks were recorded, including two very fresh tracks that were distinctly different in size and whose locations were separated by >15 km. This tracking data, along with the mammalian camera trapping results, suggest that at least two and perhaps three adult tigers inhabit PWS, which PWS and WCD staff indicate is indeed plausible.



Protection from poaching. (i) Field activities have recorded Bengal tigers in the middle and lower foothills of Phipsoo Wildlife Sanctuary (photo by iStock.com). (ii) Tiger tracks were also seen along the banks of the Longa River (photo by ADB). (iii) However, poaching continuous to be a serious threat as parts are sold in the black market (photo from Wildlife Conservation Society).

According to the IUCN (Chundawat et al. 2011), a 2009 assessment of the global tiger population found that dramatic declines in habitat occupancy and populations had occurred since the previous status assessment; vast areas of Asia once thought to support tigers were devoid of tigers (Walston et al. 2010). Employing a new recovery approach and methodology to identify source sites, defined as areas with >25 breeding females, legal protection, and landscape potential to support >50 breeding females, just 42 sites encompassing 90,000 km^2 were identified as source sites across Asia. Many countries once considered tiger range now have no healthy breeding populations, and several including Bhutan have no confirmed source sites (Walston et al. 2010). However, Bhutan's ongoing national tiger survey has increased awareness of its suitability for a source site population supported by its network of protected areas and corridors. Thus, every tiger is integral to supporting the larger discrete management unit in Bhutan and neighboring India, and in attaining future source site status.

With Bhutan's network of protected areas and corridors, its tiger habitat is relatively safe from habitat fragmentation that plagues other areas of Asia. The tiger's greatest threat here is opportunistic take by poachers for sale on the Asian black market. In fact, while field activities were being conducted in January 2015, an adult tiger was poached at RMNP. Anti-poaching field stations within both the Longa and Pingkhua river drainages would significantly reduce the risk for illegal take of tigers and many other species of wildlife. A future well-designed and managed road could be a protection asset to enhance patrolling and be a deterrent to poaching, though it could also impact tigers from potential vehicle-related mortality if it is not managed properly to limit access by poachers.

The 2014 camera trapping conducted by PWS rangers recorded 21 tiger observations at four (of 29) camera sites; the 2015 BBA camera trapping recorded another nine tiger records at six sites, including at least one subadult tiger. Seventy percent of records occurred at camera sites in the middle foothills zone, and 27% in the lower foothills zone. Just a single record (3%) was made in the border lowlands zone (natural habitat) near the Indian border. In the 2014 camera trapping, no records were made in the upper foothills zone at PWS northern border. Thus, PWS' middle and lower foothills zones appear to constitute a critical habitat "core" for tigers (Map 18), an area of approximately 16,000 ha.

D. ECOSYSTEM SERVICES AND SUSTAINABLE NATURAL RESOURCE MANAGEMENT

Along with other requirements of ADB's SPS, there is a requirement to address the current and continued management of ecosystem services associated with PWS and its impact to affected communities. Since PWS is a legally protected area, there is no authorized timber harvest or large-scale agriculture or plantation activities that support local, affected

Map 18: Critical Habitat Designation for the Tiger within the Phipsoo Wildlife Sanctuary

km^2 = square kilometer, PWS = Phipsoo Wildlife Sanctuary.

Note: The red shaded area is the PWS "core" constituting 160 km^2 (60% of PWS).

Source: Asian Development Bank.

communities other than the farming that is ongoing on the fringes of the development in and south of the community of Nichula. There is currently a largely unregulated grazing of livestock, primarily cattle, along the Nichula and Phipsoo rivers, as well as the eastern fringe of PWS near the community of Senge. The PWS management plan sets goals to develop sustainable grazing and livestock management practices that improve ecological integrity of PWS' habitats, while yielding continued benefits to local communities and their residents.

The most significant ecosystem services provided by PWS to affected communities are the rivers with water of outstanding quality that flows from the sanctuary southward into Assam and West Bengal, India, as well as the village of Nichula within PWS. This water is vital to human populations in these areas for drinking, agriculture, and other uses, as well as supporting fish populations that provide food. Thus, it is critical that steps be taken to ensure the continued flows of high water quality into the future.

During the course of the BBA and subsequent analysis of field data, the notion that the middle foothills assessment zone sits at the center of PWS' biodiversity "core" with its critical habitat values for the while-bellied heron, tiger, potentially other endangered species, and many other habitat values became increasingly evident. Equally evident is the vital role that PWS' river systems play in promoting and sustaining the sanctuary's high biodiversity and serving as invaluable wildlife connectivity conduits and travel corridors.

VIII. FUTURE MANAGEMENT CONSIDERATIONS

Though the BBA was not conducted over a year as originally planned, the findings added substantially to the biological baseline knowledge regarding PWS. As mentioned earlier, much more inventory and assessment are needed. Hence, priorities for future consideration have been identified.

A potential road alignment near the Indo–Bhutan border within the border lowlands assessment zone would pass through modified and degraded natural habitats and would impact no critical habitats. Such a project could yield net benefits to biodiversity provided that it includes conservation offset and aggressive management programs. The identified conservation offset programs are still very much needed even without a road project and for which alternative (to a road project) funding vehicles (e.g., grants) should be pursued for implementation. A well-designed road along the PWS border with India could yield considerable resource and border protection benefits if managed properly.

A. ADDITIONAL INVENTORY PRIORITIES

A preliminary inventory and assessment of the following resources were conducted under the BBA. These resources remain priorities for continued inventory and assessment by WCD PWS, along with its partners WWF-Bhutan and RSPN.

1. White-Bellied Heron

The winter presence of subadult herons was documented along PWS' main riverine systems, the Longa and Phipsoo rivers. Additional surveys, including during other seasons, are needed to further understand the role that PWS may play in the preservation and recovery of this species. While PWS does not constitute heron breeding habitat, the BBA points to the potentially crucial role that it may play in promoting population recruitment of young and subadult birds.

2. Illegal Tree Harvest

During the preliminary BBA field excursion, significant scale and intensity of illegal tree harvest were found on the west half of PWS along the Indo–Bhutan border. The initial inventory effort to quantify illegal harvest was admittedly limited in nature, though thorough enough to raise serious concerns about the growing impact to PWS' border forest integrity. Further sampling effort is a priority need to quantify the extent and understand the impact of illegal tree harvest. Further, such inventory will inform the strategies for remediating the impact, whether it be replanting native tree species such as

sal, or managing these now-open habitats as created grasslands for the benefit of Asian elephants and other grassland-dependent species.

3. Fisheries Inventory

The fisheries inventory was limited to just one of PWS' five perennial rivers. Even still, a rich fish species diversity was documented, including IUCN-listed species for which PWS could play an important recovery role. Further, PWS' fisheries may be important to other mammal and bird species, including the white-bellied heron. Further sampling is recommended on the other four rives, particularly the Longa and Phipsoo rivers using a methodology similar to the one under the BBA.

B. CONSERVATION PROGRAMS

1. Antipoaching Outposts

The BBA documented the impact of poaching on PWS' wildlife and trees, particularly the species for which critical habitat exists: the tiger and white-bellied heron. The single greatest threat to PWS' biodiversity is the potential devastating impact to the critically endangered white-bellied heron from the poisoning of entire river reaches. Such poisoning could have a huge impact to herons and the entire aquatic ecosystems. The potential poaching of a tiger within PWS could have a similarly devastating impact and jeopardize the ability of Bhutan's tiger population to attain source site status and help meet global recovery goals. Current PWS patrol efforts are having only limited success in deterring the ongoing poaching of trees and other species of wildlife.

The PWS management plan details the need for additional infrastructure to support patrol efforts and deter poaching via improved road access and new anti-poaching outposts. The Phipsoo River drainage is relatively free of the same type of wildlife, tree, and fish poaching that is occurring along the Longa and Pingkhua rivers largely due to the presence of the

Phipsoo Field Station. Phipsoo Wildlife Sanctuary rangers reside here (photo by ADB).

strategically located Phipsoo field station and its deterrent effect on these illegal activities. Objective 2 of the PWS management plan calls for the construction of anti-poaching outposts at four sites to enhance patrol efforts. The proposed outposts in the Longa and Pingkhua river vicinities will be vital to resource protection, especially the one along the Longa River with its while-bellied heron critical habitat. These outposts could be small compared to the Phipsoo field station with facilities to support a team of rangers and visiting researchers.

2. Grassland Restoration

Invasive species have become established and spread into the grassland habitats adjacent to the large riverine habitats of PWS, affecting the plant composition, vigor, and biodiversity and productivity (McFadyen 2004) of these areas important for elephant, Chital deer, and numerous other species. In fact, degraded grasslands invaded by shrubs such as *Chromolaena* spp. may even impact habitat for the critically endangered white-bellied heron due to reduced site visibility adjacent to rivers and on larger sandbars, thus affecting heron security and response to disturbances, such as encounters with predators (Pradhan et al. 2011).

Tripathi et al. (2012) detail various strategies to control *Chromolaena*, including the following:

- **Manual removal:** typically appropriate only for small areas, especially agricultural lands. Stem cutting or digging plants out is very labor-intensive and requires repeated treatments.
- **Cultural practices:** mulching or planting cover crops after plant removal have been successful in plantations, but may not be appropriate for native grasslands.
- **Herbicides and chemical control:** can be effective but are expensive, and may create other environmental issues, including adverse impact to nontarget, desired grassland species.
- **Biological control:** This may be considered the *only* viable solution, especially from an economic standpoint (McFadyen 2004) for control of *Chromolaena* spp.; several species of insects have proven useful, though there has been mixed results attained worldwide.

PWS has already employed mechanical control treatments of *Chromolaena* near Phipsoo field station. Interestingly, Tripathi et al. (2012) did not list this approach as a control technique; nor did they list burning as a viable treatment. Due to the uncertainties in achieving large-scale control, PWS should pursue a cautious and well-documented and evaluated adaptive management approach to restoring its grasslands. An expert on *Chromolaena* ecology and control is recommended to be engaged to assist in the development of a sound control strategy. This strategy must utilize and rigorously evaluate multiple control treatments under a sound experimental design with adequate controls to assess effectiveness for wider application. Once a viable treatment strategy is developed, it should be sustained over a multiyear period with follow-up monitoring to evaluate success.

C. CONSIDERATION OF A FUTURE ROAD AS A RESOURCE PROTECTION ASSET

Illegal and regular incursions into PWS continue to occur even though the sanctuary has been operationalized and has increased its law enforcement presence. These illegal incursions, especially illegal timber harvest, appear to occur to a higher degree on the western half of PWS where there is no road with regular sanctuary staff traffic; as such, even the unimproved dirt Phipsoo road appears to be a deterrent to illegal entry into PWS. Thus, rather than being a liability with unwanted lateral access and impact to resources (Maisels et al. 2013), a future road could present an opportunity to enhance resource protection and ecosystem integrity over current levels, and be a vehicle to enhance management and facilitate implementation of PWS' CMP. The key, however, to such a road remaining a resource protection asset into the future lies in aggressive and committed long-term management of the road.

With the construction of a road, PWS rangers would be able to conduct intensified patrol of the entire sanctuary and dramatically reduce illegal incursions for poaching and damage to PWS resources. Enhanced infrastructure (e.g., observation towers, anti-poaching outposts) to support law enforcement would further enhance resource protection, as well as ranger safety. Over time, once greater stability and security in the area is attained, a road can facilitate ecotourism within PWS that would provide a sustainable source of revenue for park operations.

D. EDUCATION, INTERPRETATION, AND WILDLIFE-BASED ECOTOURISM

The PWS has tremendous potential for public education, interpretation, and ultimately ecotourism programs, currently undeveloped due to its remote location, poor access, and security/safety issues. The pursuit of education and interpretation could help create and elevate public awareness of PWS, which will ultimately increase appreciation, understanding, and support for its programs. These education pursuits should be pursued incrementally, starting with passive programs involving interpretative signages at key pullouts along a future road if one is built, and then developing observation infrastructure (e.g., viewing towers and platforms) to support wildlife viewing and education at key locations.

Longer-range opportunities to pursue limited, high-quality, wildlife-based ecotourism with guided operations for birdwatching and other wildlife viewing would bring increased awareness and prestige to PWS. Further, such ecotourism programs could present a significant and sustainable funding vehicle to implement PWS CMP goals and maintenance of infrastructure. It would also foster diversified economic development in the region. The potential long-range development of limited tourist lodging and other infrastructure within PWS could further help accomplish these objectives.

PWS Opportunities. Phipsoo Wildlife Sanctuary (PWS) has potential for integrating passive education and interpretation of resources. (Clockwise from L–R) signages about biodiversity information, road improvement and/or conservation (photo by Oregon State University), and wildlife infrastructure development at key locations (photo by United States Fish and Wildlife Service).

Potential for ecotourism. A future road across the Phipsoo Wildlife Sanctuary presents considerable potential to foster high-quality wildlife-based ecotourism that could also fund sanctuary management and conservation, including travel to remote yet secure overnight tree houses such as the one shown above in western Bhutan. Such tree houses would be ideal for birdwatching, animal observation activities, and even lodging (photo by ADB).

Soaring high. A flock of black storks over Phipsoo Wildlife Sanctuary (photo by ADB).

APPENDIX 1: Phipsoo Wildlife Sanctuary 2015 Biodiversity Baseline Assessment Overstory Tree Inventory Summary

Local Name	Scientific Name	Border Lowlands (*n* = 7)		Lower Foothills (*n* = 14)		Middle Foothills (*n* = 12)		All Sites (*n* = 33) % Total
		% Total	No. of Sites	% Total	No. of Sites	% Total	No. of Sites	
Sal	*Shorea robusta*	11.1	3	17.3	2	8.4	3	12.8
Phalamey/ Phalami	*Walsura tubulata*	1.6	0	8.6	3	12.6	4	8.7
Chilaune	*Schima wallichii*	1.6	1	2.2	3	8.4	2	4.4
Myna	*Tertrameles nudiflora*	4.8	2	2.2	1	6.7	4	4.4
Rawa/Rawashing/ Toon	*Toon ciliata*	4.8	0	3.6	1	4.2	1	4.0
Bara jhingni	*Eurrya cerasifolia*	0.0	0	2.9	2	6.7	1	3.7
Panasaj/Panisesag	*Terminalia myriocarpa*	4.8	0	1.4	0	4.2	3	3.1
Champ	*Michelia kisopa*	0.0	0	5.8	2	0.8	1	2.8
Gayo	*Bridelia retusa*	3.2	1	1.4	2	4.2	2	2.8
Amaki/Ambakay	*Syzygium formosum*	3.2	1	2.9	1	1.7	1	2.5
Lekchilaune	*Nyssa javanica*	0.0	0	0.0	0	6.7	1	2.5
Pararay/Parare	*Stereospermum chelonoides*	3.2	2	2.2	1	2.5	0	2.5
Shida	*Lagerstroemia parriflora*	4.8	3	2.2	2	1.7	1	2.5
Bar/Barahara/Fig	*Ficus bengalensis*	3.2	0	3.6	1	0.0	0	2.2
Kumbi	*Careya arborea*	4.8	1	1.4	2	1.7	2	2.2
Phirpheray	*Acer oblongum*	0.0	0	2.9	1	2.5	1	2.2
Moorshing	*No Scientic name found*	7.9	2	0.7	1	0.0	0	1.9
Ailanthus/Gokul	*Ailanthus gradis*	0.0	0	1.4	1	2.5	1	1.6
Kalaykat	*Miliusa macrocarpa*	0.0	0	2.9	3	0.8	1	1.6
Kawala/Kaula	*Cinnamomum glanduliferum*	0.0	0	2.9	1	0.8	0	1.6
Lampate	*Duabanga grandiflora*	0.0	0	3.6	2	0.0	0	1.6

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Appendix 1 *continued*

Local Name	Scientific Name	Border Lowlands (*n* = 7)		Lower Foothills (*n* = 14)		Middle Foothills (*n* = 12)		All Sites (*n* = 33)
		% Total	No. of Sites	% Total	No. of Sites	% Total	No. of Sites	% Total
Mulata/Malata	*Macaranga denticulata*	0.0	0	3.6	1	0.0	0	1.6
Chakrashi	*Chukrasia tabularis*	1.6	0	1.4	2	0.8	0	1.2
Hatipailay	*Pterospermum acerifolium*	0.0	0	1.4	2	1.7	2	1.2
Jumuna	*Syzygium cumini*	0.0	0	0.0	0	3.4	1	1.2
Labchey	*Polyalithia simiarum*	0.0	0	2.9	1	0.0	0	1.2
Lasuni	*Aphanamixis polystachya*	6.3	2	0.0	0	0.0	0	1.2
Panchphaly	*Dillenia india*	0.0	0	1.4	2	1.7	1	1.2
Siris	*Albizia procera*	0.0	0	2.9	2	0.0	0	1.2
Wrightia	*Wrightia arborea-Khirra*	6.3	1	0.0	0	0.0	0	1.2
Gamari/Gemeray	*Gmelina arborea*	3.2	2	0.7	0	0.0	0	0.9
Prasea	*Prasea bootanica*	0.0	0	0.0	0	2.5	1	0.9
Satpate	*Aesculus assamica*	0.0	0	1.4	2	0.0	0	0.6
Amoora	*Spondias pinnata*	3.2	1	0.0	0	0.0	0	0.6
Castanopsis/Aule katus	*Castanopsis inidica*	0.0	0	0.0	0	1.7	1	0.6
Delfinia	*Delphinium spp.*	0.0	0	1.4	1	0.0	0	0.6
Hara/Harey	*Terminalia chebula*	0.0	0	0.0	0	1.7	1	0.6
Odal	*Sterculia villosa*	1.6	1	0.7	1	0.0	0	0.6
Shelphusrey	*No Scientic name found*	1.6	1	0.7	1	0.0	0	0.6
Sheti	*Altingia excelsa*	0.0	0	0.7	1	0.8	1	0.6
Shetikath	*Endospermum chinensis*	0.0	0	1.4	1	0.0	0	0.6
Simal	*Bombax ceiba*	1.6	2	0.7	1	0.0	0	0.6
Tamki/Tanki	*Bauhinia purpurea*	0.0	0	1.4	1	0.0	0	0.6
Balaykahre	*Ficus spp.*	0.0	0	0.0	0	0.8	1	0.3
Bandargayray	*Gynocardia odorata*	0.0	0	0.7	1	0.0	0	0.3
Baru/Barro	*Terminalia belliria*	1.6	1	0.0	0	0.0	0	0.3
Chopshing	*No scientific name found*	0.0	0	0.0	0	0.8	1	0.3
Kali lahara	*Artabotrys caudatus*	1.6	1	0.0	0	0.0	0	0.3
Katus	*Castanopsis hystrix*	1.6	1	0.0	0	0.0	0	0.3

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Appendix 1 *continued*

Local Name	Scientific Name	Border Lowlands (*n* = 7)		Lower Foothills (*n* = 14)		Middle Foothills (*n* = 12)		All Sites (*n* = 33)
		% Total	No. of Sites	% Total	No. of Sites	% Total	No. of Sites	% Total
Lakbamary	*No Scientic name found*	0.0	0	0.0	0	0.8	1	0.3
Lali/Amari	*Aglaia spectabilis*	0.0	0	0.0	0	0.8	1	0.3
Lapchikawla	*Persea fructifera*	0.0	0	0.0	0	0.8	1	0.3
Lida	*No scientific name found*	0.0	0	0.7	1	0.0	0	0.3
Lipay/Lipe	*Oreocnide rubescens*	0.0	0	0.0	0	0.8	1	0.3
Bonsum	*Litsea monopetala*	0.0	0	0.0	0	0.8	1	0.3
Panchpati	*Vitex quinata*	0.0	0	0.7	1	0.0	0	0.3
Pipalpate	*Populas glauca*	0.0	0	0.7	1	0.0	0	0.3
Poinle	*Neonauclea griffithii*	0.0	0	0.0	0	0.8	1	0.3
Rate kath	*Calophyllum polyanthum*	0.0	0	0.0	0	0.8	1	0.3
Ritha	*Sapindus rarak*	1.6	1	0.0	0	0.0	3	0.3
Shetikawla	*Persea kurzii*	0.0	0	0.0	0	0.8	1	0.3
Sinduri	*Mallotus philippensis*	1.6	1	0.0	0	0.0	0	0.3
Tartary	*Dillenia pentagyna*	0.0	0	0.7	1	0.0	0	0.3
Terminilia	*Terminilia bellirica*	0.0	0	0.7	1	0.0	0	0.3
Totola	*Oroxylum indica*	1.6	1	0.0	0	0.0	0	0.3
Iron wood	*Mesua ferrea*	0.0	0	0.0	0	0.8	1	0.3

Source: Asian Development Bank.

Passersby. Elephant tracks left on the banks of the Longa River seen at dawn (photo by ADB).

APPENDIX 2: Phipsoo Wildlife Sanctuary 2015 Biodiversity Baseline Assessment Avian Survey Summary

Common Name	Scientific Name	Abundance[a]	Status[b]	Percent of Zone Total			All Zones (% of total)
				Border Lowlands	Lower Foothills	Middle Foothills	
Abbot's babbler	*Malacocincla abbotti*	Incidental	BBA only	0.0	0.0	0.3	0.1
Aberrant bush warbler	*Cettia flavolivacea*	Absent	CMP only	0.0	0.0	0.0	0.0
Ashy bulbul	*Hemixos flavala*	Common	CMP and BBA	0.0	0.0	3.4	1.1
Ashy drongo	*Dicrurus leucophaeus*	Uncommon	CMP and BBA	0.9	0.3	1.2	0.7
Ashy woodswallow	*Artamus fuscus*	Incidental	BBA only	0.0	0.0	0.6	0.2
Asian barred owlet	*Gluacidium brodiei*	Incidental	CMP and BBA	0.4	0.0	0.0	0.1
Asian fairy bluebird	*Irena puella*	Uncommon	CMP and BBA	0.9	0.0	0.3	0.3
Asian palm swift	*Cypsiurus balasiensis*	Absent	CMP only	0.0	0.0	0.0	0.0
Asian pied starling	*Sturnus contra*	Uncommon	CMP and BBA	0.0	0.0	2.2	0.7
Barred cuckoo dove	*Macropygia unchall*	Uncommon	CMP and BBA	0.0	0.0	0.9	0.3
Bar-winged flycatcher-shrike	*Hemipus picatus*	Absent	CMP only	0.0	0.0	0.0	0.0
Bay woodpecker	*Blythipicus pyrrhotis*	Absent	CMP only	0.0	0.0	0.0	0.0
Black bulbul	*Hypsipetes leucocephalus*	Common	CMP and BBA	3.6	0.0	2.2	1.8
Black drongo	*Dicruus Macrocercus*	Common	BBA only	0.4	1.5	4.0	2.1
Black eagle	*Ictinaetus malayensis*	Incidental	CMP and BBA	0.4	0.3	0.0	0.2
Black stork	*Ciconia nigra*	Abundant	CMP and BBA	0.0	6.4	9.2	5.7
Black-backed forktail	*Enicurus immaculatus*	Uncommon	CMP and BBA	0.0	0.8	0.0	0.3

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Appendix 2 *continued*

Common Name	Scientific Name	Abundance[a]	Status[b]	Percent of Zone Total			All Zones (% of total)
				Border Lowlands	Lower Foothills	Middle Foothills	
Black-crested bulbul	*Pycnonotus jocosus*	Abundant	CMP and BBA	1.8	5.4	3.4	3.7
Black-crowned night heron	*Nycticorax nycticorax*	Uncommon	BBA only	0.0	0.3	1.5	0.6
Black-hooded oriole	*Oriolus tenuirostris*	Uncommon	CMP and BBA	0.4	0.0	0.6	0.3
Black-naped monarch	*Hypothymis azurea*	Absent	CMP only	0.0	0.0	0.0	0.0
Black-throated sunbird	*Aethopyga saturate*	Incidental	CMP and BBA	0.0	0.0	0.6	0.2
Blue rock thrush	*Monticola solitaries*	Incidental	CMP and BBA	0.4	0.3	0.0	0.2
Blue whistling thrush	*Myophonus caeruleus*	Incidental	BBA only	0.4	0.3	0.0	0.2
Blue-bearded bee-eater	*Nyctyornis athertoni*	Incidental	CMP and BBA	0.4	0.3	0.0	0.2
Blue-eared barbet	*Megalaima australis*	Incidental	BBA only	0.0	0.0	0.0	0.1
Blue-throated barbet	*Megalaima asiatica*	Incidental	CMP and BBA	0.0	0.0	0.3	0.1
Blue-throated flycatcher	*Cyornis rubeculoides*	Absent	CMP only	0.0	0.0	0.0	0.0
Blue-winged minla	*Minla cyanouroptera*	Absent	CMP only	0.0	0.0	0.0	0.0
Blyth's kingfisher	*Alcedo Hercules*	Incidental	CMP and BBA	0.0	0.3	0.0	0.1
Blyth's leaf warbler	*Phylloscopus reguloides*	Incidental	CMP and BBA	0.9	0.0	0.0	0.2
Bronzed drongo	*Dicrurus aeneus*	Uncommon	CMP and BBA	1.3	0.3	0.0	0.4
Brown dipper	*Cinclus pallasii*	Absent	CMP only	0.0	0.0	0.0	0.0
Brownish-flanked bush warbler	*Horornis fortipes*	Incidental	BBA only	0.0	0.0	0.6	0.2
Buff-barred warbler	*Phylloscopus pulcher*	Absent	CMP only	0.0	0.0	0.0	0.0
Cattle egret	*Bubulcus ibis*	Uncommon	BBA only	0.0	0.0	1.8	0.6
Cested kingfisher	*Megaceryle lugubris*	Incidental	BBA only	0.0	0.3	0.0	0.1
Chestnut-headed bee-eater	*Merops leschenaulti*	Incidental	BBA only	0.0	0.3	0.0	0.1

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Appendix 2 *continued*

Common Name	Scientific Name	Abundance[a]	Status[b]	Percent of Zone Total			All Zones (% of total)
				Border Lowlands	Lower Foothills	Middle Foothills	
Chestnut-headed tesia	*Tesia castaneocoronata*	Incidental	CMP and BBA	0.4	0.0	0.3	0.2
Chestnut-tailed starling	*Sturnus malabaricus*	Absent	CMP only	0.0	0.0	0.0	0.0
Citrine wagtail	*Motacilla citreola*	Absent	CMP only	0.0	0.0	0.0	0.0
Collared falconet	*Microhierax caerulescens*	Uncommon	CMP and BBA	0.0	0.5	0.3	0.3
Common buzzard	*Buteo buteo*	Absent	CMP only	0.0	0.0	0.0	0.0
Common green magpie	*Cissa chinensis*	Uncommon	CMP and BBA	0.0	0.0	0.9	0.3
Common hawk cuckoo	*Hierococcyx varius*	Absent	CMP only	0.0	0.0	0.0	0.0
Common hoopoe	*Upupa epops*	Absent	CMP only	0.0	0.0	0.0	0.0
Common iora	*Aegithina tiphia*	Absent	CMP only	0.0	0.0	0.0	0.0
Common kestrel	*Falco tinnunculus*	Incidental	BBA only	0.0	0.3	0.0	0.1
Common kingfisher	*Alcedo atthis*	Uncommon	CMP and BBA	0.0	1.0	0.3	0.5
Common myna	*Acridotheres tristis*	Absent	CMP only	0.0	0.0	0.0	0.0
Common sandpiper	*Actitis hypoleucos*	Absent	CMP only	0.0	0.0	0.0	0.0
Common stonechat	*Saxicola torquata*	Absent	CMP only	0.0	0.0	0.0	0.0
Common tailorbird	*Orthotomus sutorius*	Absent	CMP only	0.0	0.0	0.0	0.0
Crested bunting	*Melophus lathami*	Absent	CMP only	0.0	0.0	0.0	0.0
Crested kingfisher	*Megaceryle lugubris*	Incidental	CMP and BBA	0.0	0.3	0.0	0.1
Crested serpent eagle	*Spilornis cheela*	Abundant	CMP and BBA	0.4	3.1	3.1	2.4
Crimson sunbird	*Aethopyga siparaja*	Uncommon	CMP and BBA	0.0	0.3	0.6	0.3
Crow-billed drongo	*Dicrurus annectans*	Incidental	CMP and BBA	0.0	0.0	0.3	0.1
Fire-breasted flowerpecker	*Dicaeum ignipectus*	Absent	CMP only	0.0	0.0	0.0	0.0
Golden babbler	*Stachyris chrysaea*	Absent	CMP only	0.0	0.0	0.0	0.0

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Appendix 2 *continued*

Common Name	Scientific Name	Abundance[a]	Status[b]	Percent of Zone Total			All Zones (% of total)
				Border Lowlands	Lower Foothills	Middle Foothills	
Golden-fronted leafbird	*Chloropsis aurifrons*	Uncommon	CMP and BBA	0.9	0.5	1.2	0.8
Golden-spectacled warbler	*Seicercus burkii*	Absent	CMP only	0.0	0.0	0.0	0.0
Great barbet	*Megalaima virens*	Common	CMP and BBA	0.9	2.6	1.5	1.6
Great cormorant	*Phalacrocorax carbo*	Uncommon	BBA only	3.1	0.0	0.0	0.7
Great hornbill	*Buceros bicornis*	Abundant	CMP and BBA	8.0	4.1	1.8	4.2
Greater flameback	*Chrysocolaptes lucidus*	Common	CMP and BBA	1.8	2.0	1.5	1.8
Greater necklaced laughingthrush	*Garrulax pectoralis*	Uncommon	BBA only	2.7	0.0	0.0	0.6
Greater racket-tailed drongo	*Dicrurus paradiseus*	Uncommon	CMP and BBA	0.9	0.3	0.6	0.5
Greater yellownape	*Picus flavinucha*	Incidental	CMP and BBA	0.0	0.3	0.0	0.1
Green bee-eater	*Merops orientalis*	Incidental	BBA only	0.9	0.0	0.0	0.2
Green imperial pigeon	*Ducula aenea*	Common	CMP and BBA	2.7	1.8	0.0	1.4
Green sandpiper	*Tringa ochropus*	Absent	CMP only	0.0	0.0	0.0	0.0
Green-bellied malkoha	*Phaenicophaeus tristis*	Uncommon	BBA only	0.0	0.3	0.6	0.3
Grey bushchat	*Saxicola ferrea*	Absent	CMP only	0.0	0.0	0.0	0.0
Grey peacock pheasant	*Polyplectron bicalcaratum*	Absent	CMP only	0.0	0.0	0.0	0.0
Grey treepie	*Dendrocitta formosae*	Incidental	CMP and BBA	0.0	0.3	0.3	0.2
Grey wagtail	*Motacilla cinerea*	Incidental	BBA only	0.0	0.3	0.0	0.1
Grey-backed shrike	*Lanius tephronotus*	Uncommon	CMP and BBA	0.4	0.0	0.9	0.4
Grey-bellied tesia	*Tesia cyaniventer*	Common	BBA only	1.3	2.0	0.6	1.4
Grey-capped pygmy woodpecker	*Picoides canicapillus*	Incidental	BBA only	0.4	0.0	0.0	0.1
Grey-cheeked warbler	*Seicercus poliogenys*	Absent	CMP only	0.0	0.0	0.0	0.0

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Appendix 2 *continued*

Common Name	Scientific Name	Abundance[a]	Status[b]	Percent of Zone Total			All Zones (% of total)
				Border Lowlands	Lower Foothills	Middle Foothills	
Grey-chinned minivet	*Pericrocotus solaris*	Uncommon	BBA only	2.7	0.0	0.0	0.6
Grey-headed bush shrike	*Malaconotus blanchoti*	Incidental	BBA only	0.0	0.3	0.0	0.1
Grey-headed canary flycatcher	*Culicicapa ceylonensis*	Absent	CMP only	0.0	0.0	0.0	0.0
Grey-headed woodpecker	*Picus canus*	Uncommon	BBA only	0.0	0.0	1.2	0.4
Hill myna	*Gracula religiosa*	Common	CMP and BBA	0.9	1.5	0.9	1.1
Hill prinia	*Prinia atrogularis*	Absent	CMP only	0.0	0.0	0.0	0.0
Indian cuckoo	*Cuculus micropterus*	Incidental	BBA only	0.0	0.3	0.0	0.1
Indian peafowl	*Pavo cristatus*	Uncommon	CMP and BBA	0.0	0.0	1.5	0.5
Indian pond heron	*Ardeola grayii*	Common	BBA only	0.0	3.3	0.3	1.5
Indian roller	*Coracias benghalensis*	Incidental	CMP and BBA	0.9	0.0	0.0	0.2
Jungle myna	*Acridotheres fuscus*	Common	BBA only	2.7	1.5	0.0	1.2
Large niltava	*Niltava grandis*	Absent	CMP only	0.0	0.0	0.0	0.0
Large woodshrike	*Tephrodornis gularis*	Incidental	CMP and BBA	0.0	0.0	0.6	0.2
Large-billed crow	*Corvus macrorhynchos*	Absent	CMP only	0.0	0.0	0.0	0.0
Lemon-rumped warbler	*Phylloscopus chloronotus*	Absent	CMP only	0.0	0.0	0.0	0.0
Lesser racket-tailed drongo	*Dicrurus remifer*	Uncommon	CMP and BBA	0.0	0.5	0.3	0.3
Lesser yellownape	*Picus chlorophus*	Uncommon	BBA only	1.3	0.0	0.0	0.3
Lineated barbet	*Megalaima lineate*	Abundant	CMP and BBA	2.7	3.6	0.9	2.4
Little comorant	*Microcarbo niger*	Incidental	BBA only	0.9	0.0	0.0	0.2
Little forktail	*Enicurus scouleri*	Incidental	CMP and BBA	0.0	0.3	0.0	0.1
Little heron	*Butorides striatus*	Uncommon	CMP and BBA	0.0	1.3	0.0	0.5
Little pied flycatcher	*Ficedula westermanni*	Absent	CMP only	0.0	0.0	0.0	0.0

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Appendix 2 *continued*

Common Name	Scientific Name	Abundance[a]	Status[b]	Percent of Zone Total			All Zones (% of total)
				Border Lowlands	Lower Foothills	Middle Foothills	
Little spiderhunter	*Arachnothera longirostra*	Absent	CMP only	0.0	0.0	0.0	0.0
Long-tailed broadbill	*Psarisomus dalhousiae*	Uncommon	BBA only	0.0	1.8	0.0	0.7
Long-tailed minivet	*Pericrocotus ethologus*	Uncommon	BBA only	0.0	1.0	0.0	0.4
Maroon oriole	*Oriolus traillii*	Uncommon	CMP and BBA	0.9	0.0	0.3	0.3
Mountain bulbul	*Hypsipetes mcclellandii*	Absent	CMP only	0.0	0.0	0.0	0.0
Mountain hawk eagle	*Spizaetus nipalensis*	Absent	CMP only	0.0	0.0	0.0	0.0
Mountain imperial pigeon	*Ducula badia*	Uncommon	CMP and BBA	0.0	1.3	0.6	0.7
Olive-backed pipit	*Anthus hodgsoni*	Incidental	CMP and BBA	0.0	0.0	0.6	0.2
Orange-bellied leafbird	*Chloropsis hardwickii*	Incidental	CMP and BBA	0.0	0.0	0.3	0.1
Oriental magpie robin	*Copsychus saularis*	Absent	CMP only	0.0	0.0	0.0	0.0
Oriental pied hornbill	*Anthracoceros albirostris*	Abundant	CMP and BBA	0.0	6.9	0.9	3.1
Oriental turtle dove	*Streptopelia orientalis*	Incidental	CMP and BBA	0.0	0.3	0.0	0.1
Oriental white-eye	*Zosterops palpebrosus*	Absent	CMP only	0.0	0.0	0.0	0.0
Paddyfield pipit	*Anthus rufulus*	Absent	CMP only	0.0	0.0	0.0	0.0
Pale-chinned flycatcher	*Cyornis poliogenys*	Incidental	BBA only	0.4	0.0	0.3	0.2
Pied kingfisher	*Ceryle rudis*	Incidental	BBA only	0.4	0.0	0.0	0.1
Pin-tailed green pigeon	*Treron apicauda*	Common	CMP and BBA	0.0	0.0	3.4	1.1
Plain flowerpecker	*Dicaeum minullum*	Incidental	BBA only	0.0	0.3	0.0	0.1
Plumbeous water redstart	*Rhyacornis fuliginosus*	Common	CMP and BBA	0.0	2.0	1.8	1.5
Puff-throated babbler	*Pellorneum ruficeps*	Absent	CMP only	0.0	0.0	0.0	0.0

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Appendix 2 *continued*

Common Name	Scientific Name	Abundance[a]	Status[b]	Percent of Zone Total			All Zones (% of total)
				Border Lowlands	Lower Foothills	Middle Foothills	
Red collared dove	*Streptopelia tranquebarica*	Uncommon	CMP and BBA	1.3	0.0	0.0	0.3
Red junglefowl	*Gallus gallus*	Common	CMP and BBA	0.0	1.8	0.9	1.0
Red-breasted parakeet	*Psittacula alexandri*	Abundant	BBA only	8.0	5.1	5.2	5.7
Red-headed trogon	*Harpactes erythrocephalus*	Absent	CMP only	0.0	0.0	0.0	0.0
Red-tailed minla	*Minla ignotincta*	Absent	CMP only	0.0	0.0	0.0	0.0
Red-vented bulbul	*Pycnonotus cafer*	Abundant	CMP and BBA	2.7	7.2	2.5	4.4
Red-wattled lapwing	*Vanellus indicus*	Incidental	CMP and BBA	0.0	0.0	0.6	0.2
Red-whiskered bulbul	*Pycnonotus jocosus*	Absent	CMP only	0.0	0.0	0.0	0.0
River lapwing	*Vanellus duvaucelii*	Common	CMP and BBA	0.9	2.3	1.5	1.7
Rock pigeon	*Columba livia*	Uncommon	CMP and BBA	3.6	0.0	0.0	0.8
Rose-ringed parakeet	*Psittacula krameri*	Common	CMP and BBA	0.0	0.0	0.0	1.4
Ruddy kingfisher	*Halcyon coromanda*	Incidental	BBA only	0.0	0.0	0.3	0.1
Rufous treepie	*Dendrocitta vagabunda*	Incidental	BBA only	0.9	0.0	0.0	0.2
Rufous-bellied niltava	*Niltava sundara*	Absent	CMP only	0.0	0.0	0.0	0.0
Rufous-fronted babbler	*Stachyris rufifrons*	Absent	CMP only	0.0	0.0	0.0	0.0
Rufous-necked hornbill	*Aceros nipalensis*	Incidental	CMP and BBA	0.0	0.3	0.0	0.1
Rufous-necked laughingthrush	*Garrulax ruficollis*	Absent	CMP only	0.0	0.0	0.0	0.0
Scarlet minivet	*Pericrocotus flammeus*	Abundant	CMP and BBA	8.5	2.3	8.9	5.9
Scarlet-backed flowerpecker	*Dicaeum cruentatum*	Incidental	BBA only	0.4	0.0	0.0	0.1
Shikra	*Accipiter badius*	Absent	CMP only	0.0	0.0	0.0	0.0

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Appendix 2 *continued*

Common Name	Scientific Name	Abundance[a]	Status[b]	Percent of Zone Total			All Zones (% of total)
				Border Lowlands	Lower Foothills	Middle Foothills	
Silver-breasted broadbill	*Serilophus lunatus*	Uncommon	BBA only	0.0	0.0	1.2	0.4
Silver-eared mesia	*Leiothrix argentauris*	Uncommon	CMP and BBA	0.0	0.0	2.5	0.8
Slaty-backed forktail	*Enicurus schistaceus*	Uncommon	CMP and BBA	0.4	1.3	0.9	0.9
Small niltava	*Niltava macgrigoriae*	Incidental	CMP and BBA	0.9	0.0	0.0	0.2
Smoky warbler	*Phylloscopus fuligiventer*	Absent	CMP only	0.0	0.0	0.0	0.0
Spangled drongo	*Dicrurus hottentottus*	Common	CMP and BBA	0.0	2.3	1.8	1.6
Speckled piculet	*Picumnus innominatus*	Absent	CMP only	0.0	0.0	0.0	0.0
Spotted dove	*Streptopelia chinensis*	Uncommon	CMP and BBA	0.0	0.0	2.2	0.7
Spotted forktail	*Enicurus maculates*	Absent	CMP only	0.0	0.0	0.0	0.0
Streaked spiderhunter	*Arachnothera magna*	Common	CMP and BBA	1.3	1.8	0.6	1.2
Streaked spiderhunter	*Arachnothera magna*	Incidental	BBA only	0.9	0.0	0.0	0.2
Striped tit babbler	*Macronous gularis*	Absent	CMP only	0.0	0.0	0.0	0.0
Sultan tit	*Melanochlora sultanea*	Uncommon	CMP and BBA	2.7	0.0	0.6	0.8
Tawny fish owl	*ketupa flavipes*	Incidental	BBA only	0.4	0.0	0.0	0.1
Wedge-tailed green pigeon	*Treron sphenura*	Absent	CMP only	0.0	0.0	0.0	0.0
Whiskered yuhina	*Yuhina flavicollis*	Absent	CMP only	0.0	0.0	0.0	0.0
White wagtail	*Motacilla alba*	Common	BBA only	0.0	2.8	0.6	1.4
White-bellied heron	*Ardea insignis*	Incidental	BBA only	0.0	0.3	0.0	0.1
White-bellied yuhina	*Yuhina zantholeuca*	Common	CMP and BBA	2.7	2.3	1.5	2.1
White-browed piculet	*Sasia ochracea*	Incidental	BBA only	0.0	0.0	0.3	0.1
White-browed wagtail	*Motacilla maderaspatensis*	Common	BBA only	0.0	3.3	0.6	1.6

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Appendix 2 *continued*

Common Name	Scientific Name	Abundance[a]	Status[b]	Percent of Zone Total			All Zones (% of total)
				Border Lowlands	Lower Foothills	Middle Foothills	
White-capped water redstart	*Chaimarrornis leucocephalus*	Common	CMP and BBA	0.4	0.8	2.2	1.1
White-crested laughingthrush	*Garrulax leucolophus*	Absent	CMP only	0.0	0.0	0.0	0.0
White-rumped shama	*Copsychus malabaricus*	Incidental	BBA only	0.4	0.0	0.0	0.1
White-throated bulbul	*Alophoixus flaveolus*	Abundant	BBA only	7.6	0.0	3.4	2.9
White-throated fantail	*Rhipidura albicollis*	Uncommon	CMP and BBA	0.0	1.0	0.3	0.5
White-throated kingfisher	*Halcyon smyrnensis*	Incidental	CMP and BBA	0.0	0.5	0.0	0.2
White-vented myna	*Acridotheres cinereus*	Absent	CMP only	0.0	0.0	0.0	0.0
Wreathed hornbill	*Aceros undulates*	Common	CMP and BBA	1.8	1.3	0.6	1.1
Yellow-bellied fantail	*Rhipidura hypoxantha*	Incidental	CMP and BBA	0.4	0.0	0.3	0.2
Yellow-bellied warbler	*Abroscopus superciliaris*	Incidental	BBA only	0.4	0.0	0.3	0.2
Yellow-vented flowerpecker	*Dicaeum chrysorrheum*	Incidental	BBA only	0.4	0.0	0.0	0.1
Yellow-vented warbler	*Phylloscopus cantator*	Uncommon	CMP and BBA	1.3	1.0	0.0	0.7

CMP = conservation management plan.

[a] Abundance categories:
Absent = not noted during BBA surveys (only CMP)
Incidental = 1–2 records/<2 surveys (of 16 total)
Uncommon = 3–9 records/<4 surveys (of 16 total)
Common = 10–20 records/<9 surveys (of 16 total)
Abundant = >20 records/up to 10 surveys (of 16 total)

[b] Status categories:
CMP only = birds documented in the PWS CMP but absent during the BBA (55 species)
BBA only = new bird species recorded during BBA but not documented in the CMP (46 species)
CMP and BBA = species noted during both CMP and BBA surveys (74 species)

Source: Asian Development Bank.

High contrast. Fungi with bright orange hue grow on a decaying log (photo by ADB).

APPENDIX 3: Phipsoo Wildlife Sanctuary 2015 Biodiversity Baseline Assessment Remote Camera Trapping Locations And Recovery Status

Site No.	Date Installed	Recovery Date	Days Operated	Elevation (masl)	Assessment Zone	N. GPS Coords.	X	E. GPS Coords.	Recovery Status	Used in 2014
C-6 R	2-Feb-15	23-May-15	111	527	Middle foothills	26°45'44.1"	X	89°57'51.0"	Successfully recovered	Yes
C-11	3-Feb-15	21-May-15	108	501	Middle foothills	26°44'09.2"	X	89°58'08.4"	Successfully recovered	Yes
C-12L	3-Feb-15	21-May-15	108	182	Border lowlands	26°43'32.4"	X	89°58'25.3"	Successfully recovered	Yes
C-13	22-Jan-15	11-May-15	109	199	Lower foothills	26°44'55.7"	X	90°05'30.5"	Successfully recovered	Yes
C-14	20-Jan-15	11-May-15	111	231	Lower foothills	26°44'19.8"	X	90°03'51.2"	Successfully recovered	Yes
C-16	4-Feb-15	21-May-15	107	171	Border lowlands	26°44'32.6"	X	90°00'55.3"	Successfully recovered	Yes
C-17L	20-Jan-15	5-Feb-15	15	235	Lower foothills	26°45'33.2"	X	90°03'35.3"	Vegetation failure	Yes
C-17R	20-Jan-15	11-May-15	111	282	Middle foothills	26°45'30.4"	X	90°03'41.1"	Successfully recovered	Yes
C-18	21-Jan-15	11-May-15	110	222	Lower foothills	26°45'59.3"	X	90°05'37.5"	Successfully recovered	Yes
C-24	19-Jan-15	13-May-15	114	242	Lower foothills	26°47'10.4"	X	90°07'09.0"	Successfully recovered	Yes
C-26 L1	16-Jan-15	13-May-15	117	208	Lower foothills	26°46'53.0"	X	90°08'27.4"	Successfully recovered	Yes
C-26 R	18-Jan-15	13-May-15	115	233	Lower foothills	26°47'27.6"	X	90°08'35.0"	Successfully recovered	Yes
C-26-L	17-Jan-15	N/A	N/A	208	Lower foothills	26°46'53.0"	X	90°08'27.4"	Removed by elephants	Yes
C-27 L	16-Jan-15	12-May-15	116	179	Lower foothills	26°45'31.4"	X	90°08'19.7"	Successfully recovered	Yes
C-27 R	16-Jan-15	7-Mar-15	51	179	Lower foothills	26°45'31.4"	X	90°08'19.7"	Successfully recovered	Yes

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Appendix 3 *continued*

Site No.	Date Installed	Recovery Date	Days Operated	Elevation (masl)	Assessment Zone	N. GPS Coords.	X	E. GPS Coords.	Recovery Status	Used in 2014
C-28 L	16-Jan-15	12-May-15	116	218	Border lowlands	26°46'00.8"	X	90°10'05.8"	Successfully recovered	Yes
C-28 R	16-Jan-15	28-Mar-15	72	230	Border lowlands	26°46'00.8"	X	90°10'05.8"	Damaged by elephant	Yes
C-29	17-Jan-15	14-May-15	117	251	Lower foothills	26°47'45.8"	X	90°10'01.1"	Successfully recovered	Yes
N-BL-1	16-Jan-15	12-May-15	116	222	Border lowlands	26°45'33.0"	X	90°09'10.6"	Successfully recovered	No
N-BL-2	22-Jan-15	N/A	N/A	253	Border lowlands	26°44'56.5"	X	90°06'01.5"	Poachers stole camera	No
N-BL-3	20-Jan-15	11-May-15	111	192	Border lowlands	26°44'16.8"	X	90°03'06.9"	Successfully recovered	No
N-BL-4	6-Feb-15	10-Feb-15	4	210	Border lowlands	26°43'46.5"	X	89°53'29.0"	Elephant moved camera	No
N-IF-1 L	17-Jan-15	15-May-15	118	358	Middle foothills	26°48'37.5"	X	90°09'44.9"	Successfully recovered	No
N-IF-1 R	17-Jan-15	15-May-15	118	358	Middle foothills	26°48'37.5"	X	90°09'44.9"	Successfully recovered	No
N-IF-2 L	18-Jan-15	13-May-15	115	437	Middle foothills	26°48'26.3"	X	90°08'16.7"	Successfully recovered	No
N-IF-2 R	18-Jan-15	13-May-15	115	437	Middle foothills	26°48'26.3"	X	90°08'16.7"	Successfully recovered	No
N-IF-3 L	21-Jan-15	10-May-15	109	508	Middle foothills	26°47'46.9"	X	90°04'17.4"	Successfully recovered	No
N-IF-3 R	21-Jan-15	10-May-15	109	508	Middle foothills	26°47'46.9"	X	90°04'17.4"	Successfully recovered	No
N-IF-4	5-Feb-15	23-May-15	108	489	Middle foothills	26°44'41.8"	X	89°59'13.3"	Successfully recovered	No
N-IF-6	2-Feb-15	23-May-15	111	392	Middle foothills	26°45'33.1"	X	89°57'13.6"	Successfully recovered	No
N-IF-7	20-Jan-15	11-May-15	111	435	Middle foothills	26°45'34.6"	X	90°04'21.7"	Successfully recovered	No
N-IF-8	3-Feb-15	22-May-15	109	526	Middle foothills	26°44'00.6"	X	89°56'54.2"	Successfully recovered	No
N-LF-1	28-Dec-14	15-May-15	137	287	Lower foothills	26°48'11.1"	X	90°10'48.2"	Successfully recovered	No
N-LF-2	17-Jan-15	14-May-15	117	356	Lower foothills	26°46'44.8"	X	90°10'06.2"	Successfully recovered	No
N-LF-3	19-Jan-15	12-May-15	113	244	Lower foothills	26°46'11.6"	X	90°07'44.4"	Successfully recovered	No

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Appendix 3 *continued*

Site No.	Date Installed	Recovery Date	Days Operated	Elevation (masl)	Assessment Zone	N. GPS Coords.	X	E. GPS Coords.	Recovery Status	Used in 2014
N-LF-6	6-Feb-15	23-May-15	107	220	Lower foothills	26°44'46.6"	X	89°57'16.9"	Successfully recovered	No
N-LF-7	4-Feb-15	21-May-15	107	341	Lower foothills	26°44'28.9"	X	90°01'01.5"	Successfully recovered	No
N-LF-8	5-Feb-15	21-May-15	106	329	Lower foothills	26°44'55.3"	X	89°59'12.6"	Destroyed by elephants	No
SC-1	17-Jan-15	14-May-15	117	282	Middle foothills	26°48'12.1"	X	90°09'50.8"	Successfully recovered	No
SC-2	19-Jan-15	18-Apr-15	89	238	Middle foothills	26°47'19.6"	X	90°06'40.2"	Successfully recovered	No
SC-4	21-Jan-15	N/A	N/A	368	Middle foothills	26°47'24.5"	X	90°04'32.3"	Vegetation failure	No
SC-5	21-Jan-15	10-May-15	109	235	Lower foothills	26°46'18.7"	X	90°05'11.2"	Successfully recovered	No
SC-6	22-Jan-15	N/A	N/A	193	Border lowlands	26°46'13.9"	X	90°08'02.2"	Poachers stole camera	No
SC-7	4-Feb-15	21-May-15	107	158	Border lowlands	26°43'35.2"	X	89°58'49.1"	Successfully recovered	No
SC-8	6-Feb-15	N/A	N/A	180	Lower foothills	26°44'40.5"	X	89°57'11.3"	Villagers stole camera	No

GPS Coords. = GPS coordinates (north and east), masl = meters above sea level, = N/A = not applicable.

Source: Asian Development Bank.

Early morning fog. A hazy view of the Longa River (photo by ADB).

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Biodiversity Baseline Assessment

Phipsoo Wildlife Sanctuary in Bhutan

This report presents a biodiversity baseline assessment that was conducted in 2014–2015 at the Phipsoo Wildlife Sanctuary in southern Bhutan. Inventory and sampling of tree, avian, mammal, and fish species was accomplished in three areas. Grassland conditions and illegal tree harvesting were quantified. The assessment confirmed the presence of 27 protected species. Mammals accounted for the majority at 74%. Camera trapping over 5 months yielded 4,300 individual mammals and 28 species. Mammalian biodiversity metrics differed significantly among assessment zones. The elephant was the species most documented. The sanctuary was found to be a critical habitat for the endangered tiger and the critically endangered white bellied heron.

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