The inter-linking of rivers and biodiversity conservation: a study of Panna Tiger Reserve, Madhya Pradesh, India

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The Panna tiger reserve is one of the best examples of the most successful tiger re-introduction programme from zero tiger in 2009 to 54 in 2019. The Government of India has approved the proposal of interlinking of the two rivers, viz. Ken in Madhya Pradesh and Betwa in Uttar Pradesh, to provide surplus water to the local population of drought prone areas of Bundelkhand, UP. This river interlinking will be submerging around 58.03 sq. km of the Critical Tiger Habitat. Our study on vegetation and major prey species of tiger shows higher densities in submerged areas. The NITI Ayog report of 2019 provided one of the best example of the locals of Jakhni village of Banda district of Bundelkhand which managed the severe water crisis. The sensitivity of tiger reserve that project involves need a close attention, which this essay attempts at arguing.

Keywords: River linking, submerged area, tiger reserve, ungulates density, water crises.

CONSTRUCTION of large dams for the interlinking of rivers to solve the irrigation and drinking water problems has created potential threats to faunal as well as floral diversity. The interlinking of Ken and Betwa rivers has been proposed by the Government of India (GoI) considering that it would minimize water problems in the drought-prone Bundelkhand area, Uttar Pradesh (UP). No doubt this project may bring some relief to the local people, but it is expected that a large chunk of the Critical Tiger Habitat (CTH) of Panna Tiger Reserve (PTR) in Madhya Pradesh (MP) would be submerged. The proposed project may also have impact on the existing biodiversity and habitats. Considering this, the present study was conducted to evaluate the expected loss in PTR (24°15′–24°20′N and 80°00′–80°15′0E). This is one of the important and successful Tiger Recovery Reserves in the country. A species recovery plan was developed to reinforce the tiger population[1]. As a result the tiger population has successfully increased from nil in 2009 to 54 in 2019 (ref. 2). However, GoI has already started the river interlinking project, viz. Ken–Betwa River Interlinking (KBRIL) Project, to provide surplus water from the Ken river in MP to Betwa in UP to irrigate the drought-prone Bundelkhand region. This spreads across the districts of two states, mainly Jhansi, Banda, Lalitpur, and Mahoba districts of UP, and Tikamgarh, Panna and Chhatarpur districts of MP through a 230 km long canal. This will result in the irrigation of 127,000 ha of land in Bundelkhand, as it is the most drought-affected area.

Apart from successful tiger translocation, PTR is rich in prey species such as sambar *Rusa unicolor*, chital *Axis axis*, blue bull *Boselaphus tragocamelus*, chinkara *Gazella bennettii*, chausingha *Tetracerus quadricornis*, etc. All the species are protected under the Wildlife Protection Act, 1972 and are also listed in CITES. Our surveys revealed that the submerged area is teak-dominated and has good and thick understorey[3]. However due to this river interlinking, a major portion of the core area of PTR will be submerged under water, with a direct estimated loss of 58.03 sq. km (10.07%) of CTH in the Reserve. Due to submergence, there will be an indirect loss of 105.23 sq. km of CTH because of habitat fragmentation and loss of connectivity[4]. The submergence of CTH will involve the major loss of the tiger and its major prey species, such as chital, sambar. Also, there will be a loss of two million trees[5]. The National Tiger Conservation Authority (NTCA) and Central Empowered Committee (CEC) appointed by the Supreme Court of India have already expressed concerns about the loss of 105 sq. km of the tiger habitat because of submergence and habitat fragmentation. The KBRIL Project will destroy the most successful tiger reintroduction programme launched in PTR[6].

The present study considers two issues. One, the water needs of the people of Bundelkhand region, for which the river-linking project is underway. Second is the threat to PTR due to this project. Nowhere in the world, to the best of our knowledge, do two such significant ecological and biodiversity problems exist simultaneously. Given the fact that both issues are equally vital and that the river-linking project has become a settled matter, ideally, the Reserve should have not been put under such a threat. Now that the project is already a fait accompli and we are now looking at the issue solely as post-facto environmental

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scientists, we can only propose a workable or easy solution to address both the issues of biodiversity as well as water scarcity.

The river interlinking in other parts of the world was mainly for the navigation of goods, mostly agricultural produce ores and fertilizers. For example, the Panama and Suez canals, Rhine–Main–Danube Canal, etc. However, to the best of our knowledge, no such work has been published or publicized adequately where a tiger reserve is involved. Despite the existence of explicit operational benefits, the Sardar Sarovar Project (SSP) has been the most contentious in modern India and around the world. It gradually devolved into a legal issue and a major source of concern for environmentalists. No other river project in the world has ever been stalled for decades and been the subject of such vehement debate as the Narmada. After the 1980s, the project was widely opposed. The submergence due to consideration of the dam has several direct and negative consequences. The eviction of thousands of people will also have negative impact. The most fundamental issue, the number of people displaced by the dam, is still a point of contention. Around 6147 families were estimated to have been displaced in the 1990s. SSP had affected 40,245 families by the early 1990s, according to a report issued by the five-member group.

The Bundelkhand project is unique and sensitive as well. The construction of a dam in the Bundelkhand region is a settled matter now, but its impact on the tiger reserve as well as the people living and dependent on the natural resources needs to be considered, which this study attempts to underline and argue. The need for natural resources, including drinking and irrigation water by the increasing human population has left the entire world in an uncertain state. PTR is one of the areas under threat due to growing water demand; and Ken river flows through PTR. The loss of the core zone will not only decrease the rich forest cover, but may affect the population of herbivores as well as carnivores. Hence, this study was initiated to understand the loss of forest resources. The study aims to understand the loss of flora and fauna due to implementation of the KBRIL Project.

Study area

Non-submerged area

PTR is situated in the Vindhaya mountain range in the northern part of MP, spread over the Panna and Chhatarpur districts (24°15′–24°20′N and 80°00′–80°15′E) and dominated by dry deciduous forest. It has an area of around 576 sq. km and the Panna National Park was set-up in 1981. It was declared a PTR by GoI in 1994. The National Park consists of areas falling under former Gangau Wildlife Sanctuary set-up in 1975. The UNESCO declared it as a Biosphere Reserve in 2020. The KBRIL project was conceptualized in the 1980s, but water-sharing agreement could not be reached between the two states. Work on the project was originally slated to begin in 2015, but only got a fresh push last year with GoI making a revised deal with the two states. Initially, the Agricultural Finance Corporation Limited (AFC) carried out EIA study of the project according to the Terms of Reference (ToR) approved by the Ministry of Environment and Forests (MoEF), GoI, for the EIA chapter in a Detailed Project Report (DPR)[3].

The terrain consists of extensive plateau and gorges. About 35 species of mammals are observed in PTR, a sizeable number of which is of endangered status. The carnivore fauna is represented by the tiger (*Panthera tigris*), leopard (*Panthera pardus*), dhole (*Cuon alpinus*), jungle cat (*Felis chaus*), Asiatic wildcat (*Felis silvestris* orneta) and Indian fox (*Vulpes benghalensis*). Wolves (*Canis lupus*) occur on the fringes and outside the Reserve limits. Striped hyena (*Hyaena hyaena*), sloth bear (*Melursus ursinus*) and Jackal (*Canis aureus*) make up the rest of the carnivore fauna of the Reserve. Chital (*Axis axis*), sambar (*Cervus unicolor*), nilgai (*Boselaphus tragocamelus*), wild pig (*Sus scrofa*), chinkara (*Gazella bennetti*) and Chowsingha (*Tetraceros quadricornis*) are the wild ungulate species found in the study area. The common langur (*Semnopithecus entellus*) and rhesus macaque (*Macaca mulatta*) represent the primate fauna of the area. The Indian porcupine (*Hystrix indica*), honey badger (*Mellivora capensis*) and black-naped hare (*Lepus nigricollis nigricollis*) also occur in PTR. The protected Area (PA) supports over 10 species of reptiles, some have an endangered status, e.g. Indian cobra (*Naja naja*), Indian rock python (*Python molurus*), rat snake (*Ptyas mucosus*) and common monitor lizard (*Varanus bengalensis*). The Ken river provides shelter to a variety of aquatic fauna, and a total of 14 species of fish are found in the PA. The species like tengra (*Mystus tengara*), catfish (*Wallago attu*), mahseer (*Tor tor*), katai (*Mistris singhala*) and hilsa (*Hilsa ilisha*) are of rare/endangered status. Avifauna diversity in the Reserve supports several species of vultures, including white-rumped vulture (*Gyps bengalensis*), red-headed vulture (*Sarcogpys calvus*) and Indian vulture (*Gyps indicus*).

Submerged area

The total area of submergence is estimated as 86.50 sq. km, of which 57.21 sq. km lies within PTR (Figures 1 and 2). This accounts for 65.50% of total submergence. The LANDSAT 8 data with 30 m spatial resolution and Projection data WGS84 were acquired on 24 April 2017 (path 144, row 043). The satellite imagery was used for the preparation of land use/land cover map (LULC). The map was classified into 24 different micro-level categories (Table 1 and Figure 3).

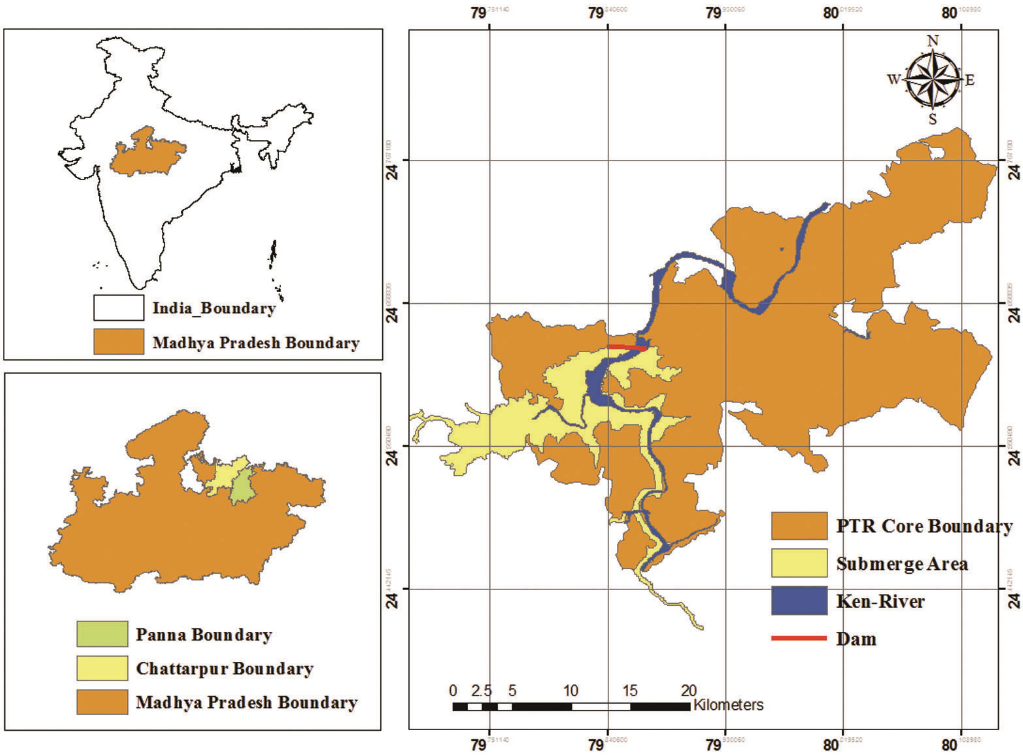

Figure 1. Panna Tiger Reserve, Madhya Pradesh, India with submerged area.

Table 1. Area and their percentage of different land-use categories of submerged and non-submerged areas of Panna Tiger Reserve, Madhya Pradesh, India

Land use category	Submerged area (sq. km)	Submerged area (%)	Non-submerged area (sq. km)	Non-submerged area (%)
Barren land	6.18	7.998	21.530	3.582
Agriculture	13.96	16.139	13.239	2.203
Water	6.749	7.803	12.138	2.019
Dense mixed	4.854	5.612	38.252	6.363
Dense mixed, mainly Tendu	0.509	0.589	19.159	3.187
Sagon mixed, mainly Dhaba	0.909	1.050	16.940	2.818
Mixed with dense understorey	5.335	6.168	76.575	12.738
Kardhai mixed	1.339	1.548	8.024	1.335
Open Salai mixed	0.423	0.489	8.727	1.452
Only Sagon	0.215	0.249	9.125	1.518
Sagon mixed	9.39	10.856	8.839	1.470
Savanna	10.05	11.619	44.940	7.476
Sagon mixed, mainly Khair, Ghont	1.709	1.976	21.266	3.538
Sagon mixed, mainly Tendu, Saj	1.400	1.619	96.254	16.010
Sagon mixed, mainly Palas	2.058	2.379	7.046	1.173
Open mixed	3.635	4.203	30.787	5.122
Mixed thorn	7.125	8.237	57.839	9.620
Grassland	0.057	0.066	5.747	0.956
Open mixed, mainly Seja	0.587	0.679	11.660	1.939
Sagon mixed, mainly Seja	1.609	1.860	24.515	4.078
Open mixed, mainly Khair	2.128	2.460	27.456	4.568
Open mixed, mainly Dhaba	0.964	1.115	22.539	3.749
Sagon mixed, mainly Bel	4.075	4.71	16.233	2.700
Bamboo	0.412	0.477	2.350	0.390
Total	86.50	100	601.18	100

Tendu, *Diospyros melanoxylon*; Dhaba, *Anogeissus latifolia*; Kardhai, *Anogeissus pendula*; Salai, *Boswellia serrata*; Sagon, *Tectona grandis*; Khair, *Acacia catechu*; Ghont, *Zizyphus xylopyra*; Saj, *Terminalia tomentosa*; Palas, *Butea monosperma*; Seja, *Lagerstroemia parviflora*; Bel, *Aegle marmelos*.

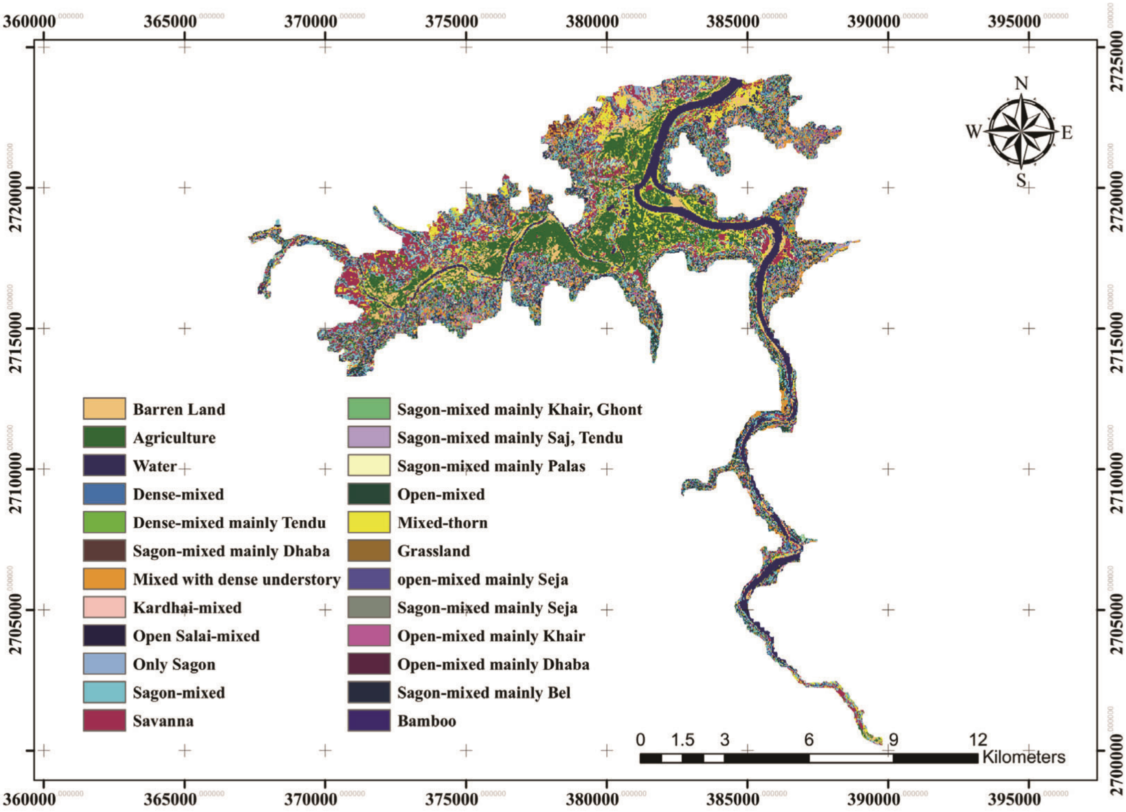

Figure 2. Land use land cover (LULC) map of submerged area in PTR.

Methodology

Data collection

Vegetation and Animal sampling: To assess the biodiversity loss likely to occur due to the KBRIL Project, two areas were selected within PTR. The first was the area within the proposed submerged area, which is also a part of the core zone. The other was from the non-submerged area for vegetation as well as ungulate population sampling. Comparative areas were selected to determine the density and diversity of plants and animals in the submerged and non-submerged areas. In order to estimate how much biodiversity we will be losing in PTR due to the river interlinking project, line transects of different lengths were laid and vegetation data were collected on the transects. Data were collected from 97 plots on 10 line transects within the submerged area and 241 plots on 25 transects from the non-submerged area. For vegetation data collection, number of tree species was recorded in a 10 m radius circular plot for density, diversity and species richness estimation. All shrubs, tree species seedlings and saplings were recorded within a radius of 5 m. For herbs and grasses, 0.5×0.5 m quadrates were used within a 10 m radius circular plot. Canopy cover and shrub cover were measured using ocular estimation in different percentage classes: 0–20%, 20–40%, 40–60%, 60–80%, 80–100%. Ground cover was recorded by point intercept method. Along with vegetation, data were also collected for the indirect evidences of ungulates (pellet groups) in each 10 m radius plot. Disturbance data were also collected for tree-cutting, tree-lopping, and grazing and cattle dung within the same 10 m radius circular plot. The LANDSAT 8 data were used to prepare the LULC map of PTR as well as the area which will be submerged due to the KBRIL Project.

Data analysis

Pellet group density = No. of pellet groups/area. Mean pellet group density was calculated for the submerged and non-submerged areas using the following formula

$$\text{Mean pellet group density} = \frac{\text{No of pellet groups} \times 10{,}000}{\text{Area}}.$$

The density of trees, shrubs, herbs and grasses was also enumerated in each plot using the above formula. Following this, mean densities were taken for both areas.

Shannon–Wiener's and Simpson's indices were calculated[7]. Margalef's species richness was also calculated. The independent samples *t*-test was used for comparing the mean vegetation density, diversity and richness between

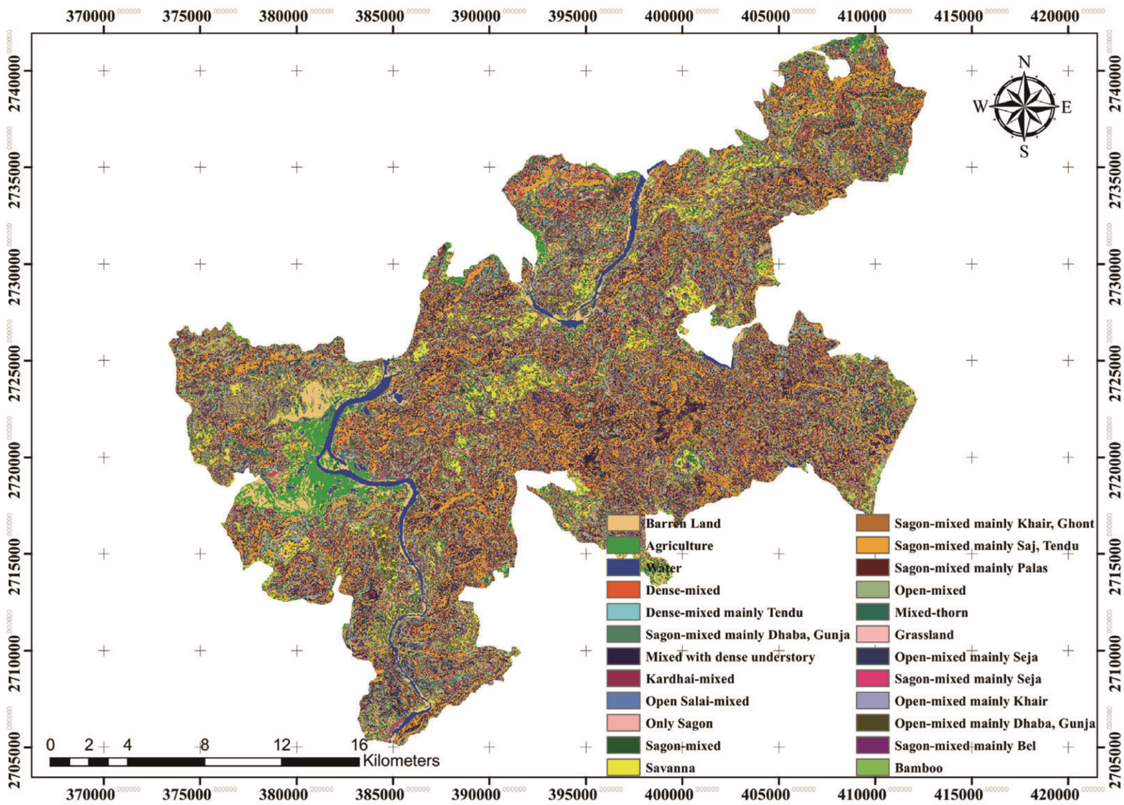

Figure 3. LULC map of PTR.

two habitats. Non-parametric Man–Whitney *U* test was used for comparing interval data of tree cover and shrub cover.

The important value index (IVI) for each tree species was calculated from relative density, relative frequency and relative dominance. The data were grouped into ten different girth classes. Stand density and basal area for each species and each diameter class were estimated.

Results

The LULC (Land Use/Land Cover) map was prepared for both the submerged and non-submerged area. LANDSAT 8 data were used for the classification of land use patterns within the study area and were classified into 24 categories (Table 1, Figure 2). The total area of submerged is 86.50 sq. km. Out of the total submerged area, 57.21 sq. km (65.50% of total submergence) lies within Panna Tiger Reserve (Table 1, Figure 3).

Vegetation structure of PTR

The habitat parameters for trees, regenerating trees species, shrubs species and ground cover vegetation were collected for both submerged and non-submerged areas and the data were compared.

Trees and regenerating tree species: Tree density, diversity and richness were found to be maximum in the submerged area (16.30 ± 0.729, 1.18 ± 0.027 and 1.24 ± 0.032 respectively) and minimum in the non-submerged area (14.10 ± 0.404, 0.99 ± 0.018 and 1.05 ± 0.022 respectively). However the results were also found to be highly significant for tree density, diversity and richness ($t_{158} = -2.64$, $P < 0.01$; $t_{195} = -5.461$, $P < 0.001$ and $t_{195} = -4.98$, $P < 0.001$ respectively; Table 2).

Data were also collected for regenerating tree species. The tree species seedling density was found to be maximum in the non-submerged area (10.96 ± 0.839), whereas it was minimum in the submerged area (0.859 ± 0.022). The results were also found to be highly significant ($t_{240} = 12.018$, $P < 0.001$). However, the tree species seedling diversity and richness were found to be significantly maximum in submerged area (0.859 ± 0.022 and 0.893 ± 0.028 respectively) and minimum in non-submerged area (0.787 ± 0.011 and 0.802 ± 0.014 respectively). Results for Mann–Whitney *U* test were found to be highly significant ($t_{148} = -2.868$, $P < 0.01$ and $t_{147} = -2.881$, $P < 0.01$ respectively; Table 2).

Tree species sapling density, diversity and richness were found to be significantly maximum in submerged area (16.08 ± 1.59, 0.842 ± 0.022 and 0.856 ± 0.025 respectively) whereas minimum in non-submerged area (11.67 ± 0.833, 0.824 ± 0.013 and 0.836 ± 0.015 respectively) and

Table 2. Mean density, diversity and richness of vegetation parameters in submerged and non-submerged areas

Habitat parameters	Submerged area	Non-submerged area
Tree density (individual ha^{-1})	16.30 ± 0.729	14.10 ± 0.404
Tree diversity (individual ha^{-1})	1.18 ± 0.027	0.99 ± 0.018
Tree richness (individual ha^{-1})	1.05 ± 0.022	1.24 ± 0.032
Seedling density (individual ha^{-1})	0.859 ± 0.022	10.96 ± 0.839
Seedling diversity (individual ha^{-1})	0.859 ± 0.022	0.787 ± 0.011
Seedling richness (individual ha^{-1})	0.893 ± 0.028	0.802 ± 0.014
Sapling density (individual ha^{-1})	16.08 ± 1.59	11.67 ± 0.833
Sapling diversity (individual ha^{-1})	0.842 ± 0.022	0.824 ± 0.013
Sapling richness (individual ha^{-1})	0.856 ± 0.025	0.836 ± 0.015
Shrub density (individual ha^{-1})	25.02 ± 2.027	15.56 ± 0.986
Shrub diversity (individual ha^{-1})	0.889 ± 0.022	0.800 ± 0.011
Shrub richness (individual ha^{-1})	0.899 ± 0.024	0.817 ± 0.014
Herb density (m^2)	2.24 ± 0.111	15.89 ± 3.50
Herb diversity (m^2)	1.03 ± 0.024	0.839 ± 0.012
Herb richness (m^2)	1.04 ± 0.024	0.825 ± 0.012
Grass density (m^2)	2.56 ± 0.114	29.26 ± 4.75
Grass diversity (m^2)	0.966 ± 0.023	0.918 ± 0.016
Grass richness (m^2)	0.917 ± 0.018	0.867 ± 0.012
Herb cover (%)	16.28 ± 0.869	16.19 ± 0.884
Grass cover (%)	35.36 ± 1.63	23.12 ± 1.05
Tree cover (mean rank)	190.53	161.04
Shrub cover (mean rank)	184.48	163.47
Basal area (m^2 ha^{-1})	9.91 ± 0.459	7.69 ± 0.292

results were found to be significant for tree sapling density ($t_{151} = -2.47$, $P < 0.05$; Table 2).

Shrub species density, diversity and richness: The shrub density, diversity and richness were found to be maximum in submerged area (25.02 ± 2.027, 0.889 ± 0.022 and 0.899 ± 0.024 respectively), and minimum in non-submerged area (15.56 ± 0.986, 0.800 ± 0.011 and 0.817 ± 0.014 respectively). However, the results were found to be highly significant ($t_{143} = -4.196$, $P < 0.001$, $t_{148} = -3.613$, $P < 0.001$ and $t_{162} = -3.011$, $P < 0.01$ respectively; Table 2).

Herbs and grass species density, diversity and richness: Herbs and grasses were assessed in 0.5 × 0.5 m quadrate within a 10 m radius circular plot. The herb species density was found to be maximum in non-submerged area (15.89 ± 3.50), and minimum in the submerged area (2.24 ± 0.111). Results were found to be highly significant ($t_{240} = 4.010$, $P < 0.001$). Herb species diversity and richness were found to be maximum in the submerged area (1.03 ± 0.024 and 1.04 ± 0.024 respectively), and minimum in the non-submerged area (0.839 ± 0.012 and 0.825 ± 0.012 respectively). The results were also found to be highly significant for diversity and richness ($t_{151} = -6.966$, $P < 0.001$ and $t_{139} = -8.051$, $P < 0.001$; Table 2). Overall the herb species density, diversity and richness were significantly higher in the area which will be submerged due to the river interlinking project.

Among grasses, grass density was found to be maximum in the non-submerged area (29.26 ± 4.751) and minimum in the submerged area (2.56 ± 0.114). The result was found to be highly significant ($t_{240} = 5.629$, $P < 0.001$). However, grass species diversity and richness were found to be maximum in submerged area (0.966 ± 0.023 and 0.917 ± 0.018 respectively). The results were also found to be significant ($t_{190} = -1.778$, $P > 0.05$ and $t_{336} = -2.237$, $P < 0.05$ respectively). Table 2 also shows that per cent herb cover and grass cover are maximum in the submerged area (16.28 ± 0.869 and 35.36 ± 1.63 respectively). The result was also found to be significant for both ($t_{278} = -0.068$, $P > 0.05$ and $t_{336} = -6.281$, $P < 0.001$ respectively). Hence grass diversity, richness and herb and grass cover were significantly higher in the submerged area.

The mean rank of tree cover as well as shrub cover was found to be maximum in submerged area (190.53 and 184.48 respectively). The result was found to be highly significant for tree cover ($U = 9648.5$, $P < 0.01$). However it was not found to be significant for shrub cover ($U = 10{,}235$, $P > 0.05$). The mean basal area of all trees was found to be maximum in the submerged area (9.91 ± 0.459 m^2 ha^{-1}), and minimum in the non-submerged area (7.69 ± 0.292). The results were found to be significant ($t_{336} = 4.089$, $P < 0.001$; Table 2). Overall plant density, diversity, richness as well as regenerating tree species diversity and richness were significantly higher in the area which will be submerged due to the KBRIL Project.

Ungulates density in submerged and non-submerged areas

Along with the vegetation parameters on transects, data were also collected on ungulate abundance through indirect

Table 3. Mean pellet group density of different ungulates in submerged and non-submerged areas

Species	Scientific name	Submerged area	Non-submerged area
Sambar	*Rusa unicolor*	5.16 ± 0.424	3.39 ± 0.196
Chital	*Axis axis*	5.93 ± 0.519	2.75 ± 0.190
Blue bull	*Boselaphus tragocamelus*	3.56 ± 0.375	2.36 ± 0.159
Chinkara	*Gazella bennettii*	0.834 ± 0.090	1.92 ± 0.150
Chausingha	*Tetracerus quadricornis*	0.70 ± 0.00	1.25 ± 0.099
Wild boar	*Sus scrofa*	1.38 ± 0.225	0.862 ± 0.059

evidences, i.e. pellet group. Pellet group density was enumerated in both submerged and non-submerged areas in PTR. The mean pellet group density of *R. unicolor*, *A. axis*, *B. tragocamelus* and *S. scrofa* was found to be maximum in submerged area (5.16 ± 0.424, 5.93 ± 0.519, 2.36 ± 0.159 and 1.38 ± 0.225 respectively). The results were also found to be highly significant for all the four species ($t_{138} = –3.802$, $P < 0.001$; $t_{122} = –5.759$, $P < 0.00$; $t_{131} = –2.956$, $P < 0.01$ and $t_{109} = –2.24$, $P < 0.05$ respectively).

While mean pellet group densities of *G. bennettii* and *T. quadricornis* were found to be maximum in the non-submerged area (1.92 ± 0.150 and 1.25 ± 0.099 respectively) and results were also found to be highly significant ($t_{335} = 6.134$, $P < 0.001$ and $t_{240} = 5.387$, $P < 0.001$ respectively) (Table 3). Overall the ungulates density was recorded high in the submerged area except *T. quadricornis* and *G. bennettii.*

Important values index and regeneration pattern of tree species in submerged and non-submerged areas

A total of 36 tree species and 974 individuals were recorded from the submerged area and 38 tree species and 1417 individuals from the non-submerged area (Table 4). Table 4 shows the IVI of different tree species in both the submerged and non-submerged areas. The overall density of trees was 319.785 ha^{-1} and 187.250 individuals ha^{-1} in the submerged and non-submerged areas respectively. In the present study, IVI of species varied from 0.202 to 58.618 in the non-submerged area and from 0.401 to 60.987 in the submerged area. *T. grandis* was the dominant species (IVI = 60.987) and *Aegle marmelos* was the co-dominant species (IVI = 27.793) in the submerged area.

In the non-submerged area, *T. grandis* and *A. catechu* were the dominant species with 47.309 and 22.200 individuals ha^{-1} respectively. These two species contributed to 37.122% of the total vegetation density. However, in the submerged area *T. grandis* and *A. marmelos* were the dominant species (79.454 and 43.339 individuals ha^{-1} respectively). Both species contributed to 38.399% of the total vegetation density (Table 4). The total basal area of the trees was 118.887 and 78.398 $m^2\ ha^{-1}$ in the submerged and non-submerged areas respectively. In the non-submerged area, the three dominant species were *T. grandis*, *B. monosperma* and *E. jambolana* (26.179, 9.576 and 7.995 $m^2\ ha^{-1}$ respectively). Whereas in the submerged area the three dominant species were *T. grandis*, *A. catechu* and *Abrus precatorius* (15.26, 8.95 and 5.07 $m^2\ ha^{-1}$ respectively). The overall IVI, dominance as well density were recorded much higher in the area that would be submerged due to river interlinking project.

Tree species regeneration status: The total density of seedlings and saplings in all the 97 sample plots of the submerged area was 63.7 and 124.1 individuals ha^{-1} respectively (Table 4). For instance, in the non-submerged area density of seedlings and saplings in all 241 sample plots was 72.945 and 74.795 individuals ha^{-1} respectively. This indicates higher tree species regeneration in the submerged area and its productivity.

In the submerged area *A. marmelos* and *D. melanoxylon* were the denser seedling species with 17.402 and 8.209 seedling ha^{-1} respectively. Whereas, *A. marmelos* and *W. tintoria* were the denser sapling species with 41.697 and 15.432 sapling ha^{-1} respectively. While in non-submerged area, *D. melanoxylon* and *Z. xylopyra* were the denser seedling species with 19.426 and 12.158 seedling ha^{-1} respectivley. Whereas, *T. grandis*, *Z. xylopyra* and *D. melanoxylon* were the denser sapling species with 18.500, 11.100, and 11.100 sapling ha^{-1} respectively (Table 4). Overall the seedling as well as sampling density of most of the tree species was higher in the submerged areas compared to non-submerged areas.

Tree density and dominance in different girth classes: Girth at breast height (GBH) of tree species varied from 10 to 386.02 cm in the submerged area and from 10 to 466 cm in the non-submerged area. In the deciduous forest of the region, tree density decreased with increasing girth. Maximum density of trees per unit area (58.769 individuals ha^{-1}) in the girth class of 20–30 cm contributed 18.303% of the tree population in the submerged area. However, the maximum density of tree species was found in the girth class of 40–50 cm (44.4 individuals ha^{-1}) which contributed 18.698% of the tree population in the non-submerged area (Table 5). In the submerged area maximum basal area (63.477 $m^2\ ha^{-1}$) was recorded from

Table 4. Density (individuals ha^{-1}) of tree species and its regeneration, and tree species (IVI) in the submerged and non-submerged areas

		Submerged area				Non-submerged area			
Species	Family	Seedling density	Sapling density	Tree density	Tree species (IVI)	Seedling density	Sapling density	Tree density	Tree species (IVI)
Aegle marmelos	Rutaceae	17.40	41.7	43.34	27.64	3.31	2.38	2.51	4.76
Abrus precatorius	Fabaceae	0	0	13.13	15.34	–	–	–	27.79
Adina cordifolia	Rubiacea	0	0	0.99	3.98	0	0	0.13	0.28
Anogeissus latifolia	Combretaceae	1.31	0	27.25	26.99	0.39	0	10.84	19.20
Anogeissus pendula	Comretaceae	1.64	0.33	25.61	14.52	5.95	4.89	5.55	9.93
Acacia catechu	Leguminosae	1.31	0.66	24.95	21.63	1.59	1.453	22.20	27.29
Albizzia procera	Leguminosae	0.33	0	1.97	4.99	1.06	0.27	0	0
Acacia ferruginea	Leguminosae	0.33	0.33	1.97	2.99	0.13	0.13	0.79	1.45
Buchanania latifolia	Anacardiaceae	0.66	0	0		0	0	1.19	3.24
Bauhinia racemosa	Leguminosae	0.33	1.64	3.94	4.98	0.93	0.53	1.72	3.27
Bassia latifolia	Sapotaceae	0	0	1.31	5.167	0.26	0	2.12	8.43
Butea monosperma	Leguminosae	0.33	1.97	8.21	15.81	0.13	0.39	3.97	7.62
Bombax ceiba	Malvaceae	0.33	0	0.66	1.40	0	0	0.53	1.20
Boswellia serrata	Burseraceae	0	0	1.97	2.51	0	0	1.72	6.00
Careya arborea	Myrtaceae	0	0	0.33	0.42				
Cassia fistula	Leguminosae	1.31	2.95	1.97	1.28	0.39	1.45	2.25	3.31
Ceriscoides turgida	Rubiaceae	4.27	0.66	0.33	0.40	1.06	0.53	0.39	0.62
Diospyros melanoxylon	Ebenaceae	8.21	9.52	7.88	10.33	19.43	11.1	16.39	22.95
Euginea jambolana	Myrtaceae	0.66	4.93	2.63	8.7	4.1	1.98	0.27	0.68
Feronia elephantum	Rutaceae	0	3.28	0.99	1.80	0	0	0.13	0.61
Ficus infectoria	Moraceae	0	0	1.64	3.71				
Ficus benghalensis	Moraceae	0	0	0	0	0	0	0.13	1.88
Ficus religiosa	Moraceae	0	0	0	0	0	0	0.27	1.15
Gardenia latifolia	Rubiaceae	0.99	1.31	1.969	2.39	2.34	1.45	5.29	6.48
Gmelina arborea	Verbenaceae	0.33	0.33	0.985	0.63	0	0	0	0
Holarrhena pubescens	Apocynaceae	0	0	0.657	0.53	0	0	0	0
Holoptelea integrifolia	Ulmaceae	0	0	0	0	0	0.13	0.13	0.80
Lagerstroemia parviflora	Lythraceae	1.97	6.89	20.028	16.76	2.78	5.82	18.10	25.36
Limonia acidissima	Rutaceae	6.57	6.57	3.939	3.35	1.59	2.642	0.53	0.82
Mangifera indica	Anacardiaceae	0	0	0	0	0	0	0.27	3.86
Pterocarpus marsupium	Leguminoseae	0	0	0.329	0.41	0	0	0	0
Stephegyne parvifolia	Rubiacea	0	0.98	6.239	14.41	0	0.265	0.53	5.23
Schrebera swietenioides	Oleaceae	0	0	0	0	0	0	0.13	0.20
Saccopetalum tomentosum	Anonaceae	0	0	0.329	0.41	0	0	1.85	2.34
Sterculia urens	Sterculiaceae	0	0	1.642	1.78	0	0	0	0
Soymida febrifuga	Meliaceae	0	0	0	0	0	0	0.53	1.55
Tectona grandis	Verbenaceae	3.61	20.36	79.454	60.99	5.95	18.500	47.31	58.62
Terminalia tomentosa	Combretaceae	0	0	1.642	1.76	.850	0	1.72	3.32
Terminalia arjuna	Combretaceae	0.33	0.66	1.642	1.85	0	0	0.66	4.99
Tamarindus indica	Leguminosae	0	0	0.329	1.012	0	0	0	0
Terminalia belerica	Combretaceae	0	0	0	0	0	0	0.79	4.78
Wrightia tintoria	Apocynaceae	5.91	15.43	2.299	2.27	7.12	9.382	1.19	1.98
Zizyphus xylopyra	Rhamnaceae	4.93	3.61	25.938	18.5	12.16	11.100	17.18	25.2
Total		63.7	124.11	319.79	300	72.95	74.8	187.25	300

trees of >100 cm girth class, whereas in the non-submerged area maximum basal area was 8.389 m^2 ha^{-1} from trees of >100 cm girth class (Table 5).

Discussion

PTR was constituted principally considering the unique geomorphological features of the location. The riverine vegetation in the area expected to be submerged provides a good cover for the animals residing inside, including tigers in the shaded spaces of trees. PTR has been recently declared as a Biosphere Reserve under Man and the Biosphere Programme of UNESCO. It represents one of the successful examples of reintroduction and establishment of the tiger population after local extinction. The tiger population increased to 54 in 2019 from nil in 2009. This was because of the favourable habitat with available preybase, such as chital, sambar, nilgai, chausingh, chinkara, wild boar, etc. However, with the growing needs of the rising population, we are sacrificing many natural resources. Bundelkhand is an area that suffers from severe crisis of water for drinking as well as for irrigation[8]. The KBRIL Project will fulfil the needs of Bundelkhand, by

Table 5. Tree species density (ha^{-1}) in different girth classes in the submerged and non-submerged areas

Girth class	Submerged area: No. of individuals	Density	Percentage contribution to density	Basal area (m^2 ha^{-1})	Percentage contribution to basal area	Non-submerged area: No. of individual	Density (individual ha^{-1})	Percentage contribution to density	Basal area (m^2 ha^{-1})	Percentage to basal area
10–20	65	21.34	6.65	0.57	0.48	110	14.54	6.12	0.08	0.48
20–30	179	58.77	18.30	3.2	2.69	290	38.32	16.14	0.42	2.69
30–40	174	57.13	17.79	5.78	4.86	290	38.32	16.14	0.76	4.86
40–50	169	55.49	17.28	9.24	7.78	336	44.40	18.69	1.22	7.77
50–60	113	37.10	11.55	9.09	7.67	272	35.94	15.14	1.20	7.64
60–70	67	21.99	6.85	7.46	6.28	156	20.61	8.68	0.99	6.28
70–80	56	18.39	5.73	8.21	6.90	93	12.29	5.18	1.08	6.90
80–90	32	10.51	3.27	6.22	5.23	69	9.12	3.84	0.82	5.23
90–100	24	7.88	2.45	5.69	4.79	53	7.01	2.95	0.75	4.78
>100	99	32.50	10.12	63.48	53.37	128	16.91	7.12	8.39	53.37

sacrificing around 58.03 sq. km (10.07%) of CTH of PTR owing to submergence, and an indirect loss of 105.23 sq. km of CTH due to fragmentation and loss of connectivity. The KBRIL Project envisages the diversion of water from the Ken basin to Betwa basin affecting biodiversity, migration paths and land loss of a national reserve. The present study was conducted to understand the intensity of loss in terms of animal habitat as well as vegetation.

Direct as well as indirect evidences were used to assess the mammal population along with vegetation data, including regenerating tree species. There have been rapid advancements in the field of population estimation using direct as well as indirect methods such as line transects or more appropriately distance sampling[9,10]. Line transects have been widely used to estimate populations of ungulates[11–15]. Data on pellet groups as well as vegetation data were collected on the line transects. The most common indirect method of assessing the ungulate population is through faecal matter count. Pellet group or faecal matter is the best sign for the presence of species[15,16]. This method has been extensively used for assessing pellet group density[17–24].

The LULC map was finalized using geospatial technique and the submerged area was marked on a separate map. It has been observed that a large chunk of the core forest will be submerged due to the KBRIL Project. Based on recommendations of the Forest Advisory Committee, the Centre has approved Stage-I Forest Clearance for KBLP Phase-I vide MoEF and CC, GoI letter dated 25 May 2017. About 9000 ha would be submerged (out of which 4141 ha is forest land in PTR); in return about 6 lakh ha would be irrigated. The project would displace 7000 households, but 70 lakh people would benefit. According to Water Resources Minister, GoI, 7000 households are happy to leave their homes, for larger benefits[25].

The LULC and vegetation data show that tree density and diversity are comparatively higher in the submerged area. The regeneration pattern also shows that the seedling diversity and richness and sapling density, diversity and richness are high in the submerged area. Though from seedling to sapling stage the mortality is very high, the submerged area has a greater sapling density compared to the non-submerged area. The density and IVI were calculated for each sampled tree species. These were higher in the submerged area for most of the dominating trees. However, the total tree density was higher in the submerged area. Overall in the case of vegetation, the area that will be submerged due to the KBRIL Project has a rich floral density and diversity.

Ungulates are the best indicators of good health of a habitat. With higher density of plants, ungulates like sambar, chital, bluebull and wild boar were found higher in submerged areas as these species prefer moist areas with high vegetation cover[26–28]. The density of four-horned antelope and chinkara was higher in non-submerged area, as they are grassland species that prefer comparatively open habitat, which is available in non-submerged area[27,29–31].

The density, abundance and distribution of individual species are measurable indicators of plant diversity[32]. Species richness was recorded low in submerged area, i.e. 36 species over 3.046 ha, while it was high in non-submerged area, i.e. 38 species over 7.568 ha. Overall, PTR is rich in vegetation.

The tree density and basal area data collected in different girth classes show that the stem density decreases with increase in girth class, as found in other studies[33–36]. The maximum density contribution was recorded in the girth class of 20–50 in submerged and non-submerged areas. This shows that the whole area of PTR is rich in terms of the availability of plants and animals.

The present quantitative inventory of tree species diversity revealed considerable variation in the composition of dominant species in both submerged and non-submerged areas. IVI shows the relative ecological importance, conspicuousness or dominance of each species in a stand[37]. It is therefore a good index for summarizing vegetation characteristics, ranking species for management and conservation practices. This study suggests that tree diversity in tropical forests of PTR varied greatly due to variation in slope, aspect, elevation and watershed system, etc.

PTR is rich in overall biodiversity. The overall tree density was found to be higher in submerged area (319.785 ha^{-1}) compared to non-submerged area (187.250 ha^{-1}). IVI was also higher for tree species present in the area which will be submerged. The species regeneration (sapling) was also higher in submerged area (124.1). The ungulate species density was maximum in the submerged area. Hence, it may not be justified to sacrifice the area for the KBRIL Project, simply because the proposed submerged area is much more diverse and rich in floral as well as faunal diversity.

PTR is a success story for the reintroduction of tigers. GoI has recommended to integrate three wildlife sanctuaries, i.e. Nauradehi, Rani Durgawati and Ranipur with PTR. The proposed connectivity of PTR to these three sanctuaries mostly passes through densely populated and cultivated areas, and no such biodiversity assessment has been done in them. Nonetheless, we can still argue that for the larger conservation issue, integration of smaller areas need not be justified. A study by the Centre for Inland Waters in South Asia revealed that the Bundelkhand sub-region is no longer a rain-starved area[38]. Rather, it receives more rainfall than the national average. Unfortunately, the rain runs-off too quickly. The study stresses that Bundelkhand's drought stress has been as much man-made as weather-induced. Thus, rainwater management is the key in the long term[38]. Possibilities can be explored for holding rainwater through small dams. However, it cannot ignore the increasing demand for water by the people of Bundelkhand. Also, the important area of PTR cannot be left to submerge. The Reserve is not only a success story of tiger translocation, but it is also an ecologically important area. The submerged area is the most suitable habitat for tigers[39].

As already discussed based on vegetation and ungulate density, PTR is one of the best areas for conservation. Not only the tree species regeneration pattern is high, but also PTR is the most suitable habitat for tiger which is an endangered species. If the potential areas of PTR are diverted for the KBRIL Project, no amount of mitigating measures can create a unique ecosystem for the Reserve again. PTR has evolved over millions of years to reach the present level of biodiversity. The CEC report indicates that it is ecologically disastrous as it will destroy 104 sq. km of Panna National Park (including habitat for ungulates and high tree density, diversity, richness and IVI). Such an activity is not permissible under the provisions of the Wildlife (Protection) Act, 1972. The project was approved by the National Board for Wildlife, although India is a signatory of CBD-1992. The damage will be irreversible. The very purpose of the Wildlife (Protection) Act, 1972 to declare any area ecological and evolutionary significance as a National Park will be defeated. There are certain examples in Bundelkhand for water management. According to a 2019 report by NITI Aayog, five years ago, Jakhni village of Banda district in Bundelkhand, was one of the most water-scarce regions of India. The area was witnessing heavy out-migration in search of water and better livelihood opportunities. For the last five years (since 2014), through rigorous water conservation efforts, such as the construction of farm ponds, restoration/rejuvenation/restoration of water bodies, collection and utilization of grey water, raising of farm bunds and intensive plantation of trees, the water situation has considerably improved. The farmers of Jakhni undertook the entire work, without any external funding, machinery or resources. Now, Jakhni village has become a water self-sufficient village. It is reaping the benefits of improved agricultural production. Once a drought-prone village, it now produces nearly 23,000 quintals of basmati rice. Production of other crops has also increased manyfold. Jakhani village, therefore, serves as an excellent example for village water-budgeting, modelled around the collection and storage of rainwater within the village boundaries, and utilizing it for life protection and economic development[40].

The cost-benefit analysis of KBRIL Project is yet to be confirmed, and we are also concerned about the construction of the Daudhan dam[3]. This will result in the submergence of 10% of CTH in PTR, and adversely affect the tiger conservation efforts. Along with the tiger, its prey base will be critically affected due to submergence. The area which has good teak species density and high tree species regeneration compared to non-submerged area will be critically affected. The submerged area which has higher ungulate and tree density will completely lose its diversity due to submergence. There will be a negative impact due to habitat fragmentation on the non-submerged area of PTR. The height of the proposed dam (77 m) will affect the nesting sites of vultures. Construction of a barrage inside the Ken Gharial Sanctuary will adversely affect the sustainability of the Sanctuary. Submergence by Daudhan and Makodia reservoirs will result in the displacement of 20,000 people from the Bundelkhand region. This will inevitably give rise to rehabilitation issues. Since we have a success story of water harvesting from the Bundelkhand region itself, we should therefore consider the Jakhni village as a successful model and implement the same in other water-scarce areas of Bundelkhand to avoid mass destruction.

Conclusion

The proposed work highlights issues related to interlinking of two rivers (KBRIL) to provide water to the drought prone areas of Bundelkhand region. This will sacrifice around 58.03 sq. km (10.07%) of the Critical Tiger Habitat of Panna Tiger Reserve, adding to submergence, indirect loss of 105.23 sq. km of CTH due to fragmentation and loss connectivity. PTR has a success story of zero tiger in 2009 to 54 tiger in 2019 due to favourable habitat and our study also shows the continuing and good growth of forest. The unique ecosystem of PTR containing wildlife and rich biodiversity will vanish after the inception of the river interlinking project. No amount of mitigation measures can create this kind of unique ecosystem which has evolved over million of years to reach the present level of biodiversity. The height of the dam (77 m) will affect the nesting sites of vultures. Construction of one of the barrages inside the Ken Gharial Sanctuary will adversely affect the sustainability of the sanctuary. The NITI Ayog report of 2019 provided a major example of the Jakhni village in the Bundelkhand area of Banda district of Uttar Pradesh. The villagers have managed the severe water crisis, which stopped mass out-migration of locals due to drought. Though the construction of dam in Bundelkhand region is a settled fact now, keeping in the view the sensitivity of the Tiger reserve, we should implement the Jakhni village model in the other water-scarce areas of Bundelkhand to avoid mass destruction.

1. Ramesh, K., Samuel, A. C., Mriganka, S. S., Manjari, M., Moorthy Jeyaraj, A. J. and Subharanjan, S., Multi-scale prediction of landscape resistance for tiger dispersal in central India. *Lands. Ecol.*, 2016, **31**, 1355–1368; doi:10.1007/s10980-016-0363-0.
2. Bhardwaj, T., Panna National Park: a gem among Madhya Pradesh's Tiger Reserves. *Financial Express*, 8 March 2021; https://www.financialexpress.com/lifestyle/travel-tourism/panna-national-park-a-gem-among-madhya-pradeshs-tiger-reserves/2208426/
3. Anon., Comprehensive environmental impact assessment of Ken–Betwa link project, phase-I, National Water Development Agency (a Government of India Society under the Ministry of Water Resources), 2012, **XXII**, 2012.
4. Anon., Ken–Betwa river linking project: recalling an old idea whose time may have come. *The Indian Express*, 16 May 2016; https://indianexpress.com/article/explained/ken-betwa-river-linking-project-wildlife-clearance-panna-tiger-reserve-forest-land-2797614/
5. Mayank, A., Ken–Betwa river linking project may be economically unviable, says Supreme Court's committee. Environment and Election Mongabay, News and inspiration from nature's frontline in India, Mongabay, 2019.
6. Nandi, J., Ken–Betwa project could hit wildlife. *Hindustan Times*, 8 September 2019; https://www.hindustantimes.com/bhopal/wildlife-activist-to-challenge-ken-betwa-river-project-in-ngt/story-bV-PRidu8xqv1z0aXMO0mgI.html
7. Magurran, A. E., *Ecological Diversity and its Measurement*, Princeton University Press, Princeton, NJ, USA, 1998, p. 192.
8. Saxena, D., River linking project a conspiracy to deny Bundelkhand of Ken river water. *The Times of India*, 29 March 2019; https://timesofindia.indiatimes.com/city/bhopal/river-linking-project-a-conspiracy-to-deny-bundelkhand-of-ken-river-water/articleshow/68629990.cms
9. Burnham, K. P., Anderson, D. R. and Laake, J. L., Estimation of density from line transect sampling of biological population. *Wildl. Monogr.*, 1980, **72**, 1–202.
10. Buckland, S. T., Aanderson, D. R., Burnham, K. P. and Laake, J. L., *Distance Sampling: Estimating Abundance of Biological Population*, Chapman and Hall, New York, USA, 1993.
11. Biswas, S. and Sankar, K., Prey abundance and food habit of tigers (*Panthera tigris tigris*) in Pench National Park, Madhya Pradesh, India. *J. Zool.*, 2002, **256**, 411–420.
12. Bagchi, S., Goyal, S. P. and Sankar, K., Prey abundance and prey selection by tigers (*Panthera tigris*) in a semi-arid, dry-deciduous forest in western India. *J. Zool.*, 2003, **260**, 285–290.
13. Harihar A., Population, food habits and prey densities of tiger in Chilla Range, Rajaji National Park, Uttaranchal, India. Masters' dissertation, Saurashtra University, Rajkot, 2005.
14. Ramesh, T., Prey selection and food habits of large carnivores (tiger, leopard and dhole) in Mudumalai Tiger Reserve, Western Ghat, India. Ph D thesis, Saurashtra University, 2010, p. 178.
15. Ilyas, O., Status and conservation of ungulates in the Kumaon Himalaya with Special Reference to barking deer (*Muntiacus muntjac*) and goral (*Nemorhaedus goral*). Ph D thesis, Aligarh Muslim University, Aligarh, 2001.
16. Ilyas, O., Khan, J. A. and Khan, A., Status, distribution and conservation of deer populations of oak forests in Kumaon Himalayas, India. In *Advances in Deer Biology* (ed. Zobborszky, Z.), Tipo-Express Ltd, Kaposvar, Hungary, 1998, pp. 18–24.
17. Cairns, A. L. and Telfer, E., Habitat use by 4 four sympatric ungulates in boreal mixed-wood forest. *J. Wildl. Manage.*, 1980, **44**, 849–857.
18. Forbes, G. J. and Theberge, J. B., Multiple landscape scales and winter distribution of moose, *Alces alces*, in a forest ecotone. *Can. Field-Nat.*, 1993, **107**, 201–207.
19. Mitchell, B., Rowe, J. J., Ratcliffe, P. R. and Hinage, M., Defecation frequency in roe deer (*Capreolus capreolus*) in relation to the accumulation rates of fecal deposits. *J. Zool.*, 1985, **207**, 1–7.
20. Rowland, M. M., White, G. C. and Karlen, E. M., Use of pellet-groups plots to measure trends in deer and elk populations. *Wildl. Soc. Bull.*, 1984, **12**, 147–155.
21. Neff, D. J., The pellet group count technique for big game trend, census and distribution: a review. *J. Wildl. Manage.*, 1068, **32**, 597–561.
22. Stormer, F. A., Hoekstra, T. W., White, C. IVI and Kirkpatrick, C. M., Frequency distribution of deer pellet groups in southern Indian. *J. Wildl. Manage.*, 1977, **41**, 779–782.
23. Putman, R. J., *Competition and Resource Partitioning in Temperate Ungulate Assemblies*, Chapman and Hall, London, UK, 1996, p. 131.
24. Dinerstein, E. and Dublin, H. T., Daily defecation rate of captive axis deer. *J. Wildl. Manage.*, 1982, **46**, 833–835.
25. Anon., Phase 1 of Ken-Betwa river link project gets all clearances. *The Hindu*, 2 July 2017; https://www.thehindubusinessline.com/news/national/phase-1-of-kenbetwa-river-link-project-gets-all-clearances/article9781741.ece (updated 11 January 2018).
26. Karanth, K. U. and Sunquist, M. E., Population structure, density and biomass of large herbivores in the tropical forests of Nagarahole, India. *J. Trop. Ecol.*, 1992, **8**, 21–35.
27. Rahmani, A. R., India. In *Antelopes. Part 4: North Africa, the Middle East, and Asia* (eds Mallon, D. P. and Kingswood, S. C.), Global Survey and Regional Action Plans, IUCN, Gland, Switzerland, 2001, pp. 178–187.
28. Fuchs, E. R., Behaviour. In *The Axis Deer in Texas* (ed. Ables, E. B.), Ceasar Kleberg, Texas, USA, 1977, pp. 24–52.
29. Sharma, K., Distribution, status, ecology and behaviour of the four-horned antelope *Tetracerus quadricornis*, Ph D thesis, University of Mumbai, Mumbai, 2006.
30. Sharma, K., Chundawat, R. S. and Rahmani, A. R., Resource selection by four-horned antelope *Tetracerus quadricornis* in a tropical dry deciduous forest. *Hystrix Ital. J. Mammal.*, 2007, p. 568.
31. Leslie, D. M. and Sharma, K., *Tetracerus quadricornis* (Artiodactyla: Bovidae). *Mammal. Species*, 2009, **843**, 1–11.
32. Wattenberg, I. and Breckle, S., Tree species diversity of a premontane rain forest sin the Cordillera de Tilaren, Costa Rica. *Biotropica*, 1995, **1**, 21–30.
33. Lieberman, D. and Lieberman, M., Forest tree growth and dynamics at La Selva, Costa Rica (1969–1982). *J. Trop. Ecol.*, 1987, **3**, 347–358.

34. Swine, M. D., Lieberman, D. and Putz, F. E., The dynamics of tree populations in a tropical forest: a review. *J. Trop. Ecol.*, 1987, **3**, 359.
35. Campbell, D. G., Daly, D. C., Prance, G. T. and Maciel, U. N., Quantitative ecological inventory of Terra Firme and Várzea Tropical Forest on the Rio Xingu, Brazilian Amazon. *Brittonia*, 1986, **38**, 369–393.
36. Chandrashekara, U. M. and Ramakrishnan, P. S., Vegetation and gap dynamics of a tropical wet evergreen forest in the Western Ghats of Kerala, India. *J. Trop. Ecol*., 1994, **10**, 337–354.
37. Brown, R. J. and Curtis, J. J., The upland conifer–hardwood communities of southern Wisconsin. *Ecol. Monogr*., 1952, **22**, 217–234.
38. Colopy, C., Ken to Betwa, the link that destroys. 15 October 2018; https://indiaclimatedialogue.net/2018/10/15/ken-to-betwa-the-link-that-destroys
39. Singh, R., Kumar, A. and Singh, P. S., Spatial analysis of tiger habitat suitability in Panna Tiger Reserve of Madhya Pradesh, India. *Life Sci. Bull*., 2013, **10**, 95–98.
40. Anon., Composite water management index. NITI Aayog Report No. 218, 2019; https://niti.gov.in/sites/default/files/2019-08/CWMI-2.0-latest.pdf

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