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Article

Impact of Dams on Riparian Frog Communities in the Southern Western Ghats, India

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Abstract: The Western Ghats is a global biodiversity hotspot and home to diverse and unique assemblages of amphibians. Several rivers originate from these mountains and hydropower is being tapped from them. The impacts of hydrological regulation of riparian ecosystems to wildlife and its habitat are poorly documented, and in particular the fate of frog populations is unknown. We examined the effects of dams on riparian frog communities in the Thamirabarani catchment in southern Western Ghats. We used nocturnal visual encounter surveys constrained for time, to document the species richness of frogs below and above the dam, and also at control sites in the same catchment. While we did not find differences in species richness below and above the dams, the frog community composition was significantly altered as a likely consequence of altered flow regime. The frog species compositions in control sites were similar to above-dam sites. Below-dam sites had a distinctly different species composition. Select endemic frog species appeared to be adversely impacted due to the dams. Below-dam sites had a greater proportion of generalist and widely distributed species. Dams in the Western Ghats appeared to adversely impact population of endemic species, particularly those belonging to the genus *Nyctibatrachus* that shows specialization for intact streams.

Keywords: stream frogs; indicators; *Nyctibatrachus*; endemic species; rivers; species turnover

1. Introduction

Western Ghats runs north to south along the west coast of India. It receives rainfall from both the southwest (May to September) and the northeast monsoon (October to January). These natural hydrological systems are a rich source of perennial fresh water, and serve as important habitats for diverse lotic flora and fauna. In particular, the Western Ghats is home to a distinctive assemblage of amphibians (see [1,2]). It is also known for high generic and species level endemism in frogs [2,3]. The perennial montane streams are important for frogs, where their diversity is the highest in the Western Ghats [4–6].

The water of this region has a huge bearing for irrigation. Approximately 245 million people live in the peninsular India, and meet their freshwater requirement from rivers originating in the Western Ghats. When compared with other hotspots, the soil and water of this region has a huge bearing on the livelihood of a large human population. The rivers originating from these hills are targeted for generating hydropower and channelized for irrigation.

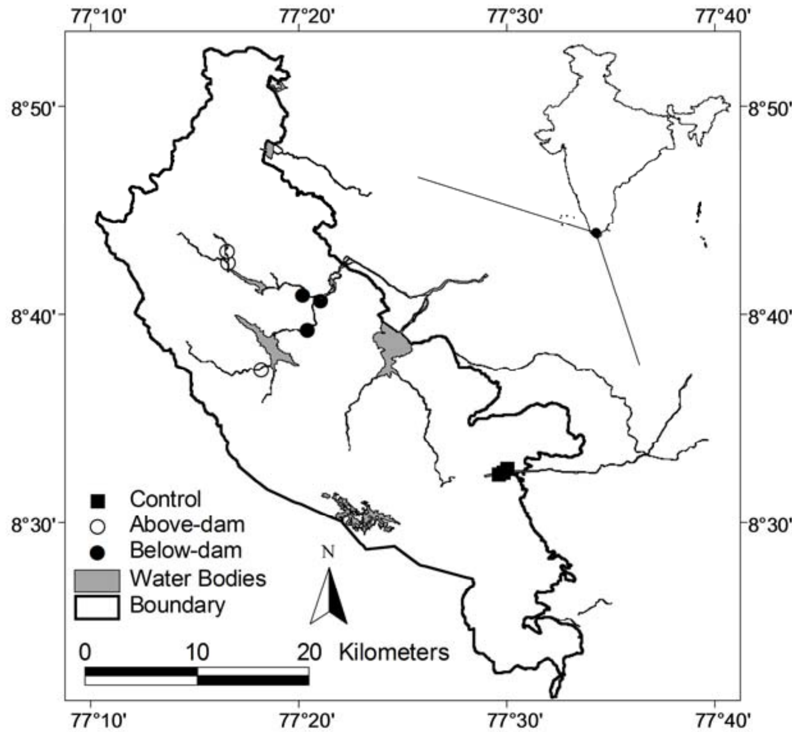
Dams foster economic growth by generating hydropower and protecting agricultural land from flood damages, but they are also known to impact aquatic species adversely [7,8]. Worldwide, human regulation of approximately 60% of stream flow has led to irreversible loss to species and ecosystems [9]. Dams profoundly influence river hydrology, primarily through changes in timing, magnitude, and frequency of high and low flows, ultimately resulting in a hydrologic regime differing significantly from the pre-impoundment natural flow regime [7,10]. Changes in the hydrologic regime can result in the disruption of aquatic life cycles [11] and change in the riparian community structure. This could also promote invasive exotics [12]. Sudden water level changes downstream of dams contribute to riparian habitat loss [13,14], and disrupt migration and habitat connectivity for aquatic animals [15–18]. Negative impacts of dams on populations of fishes (e.g., [19,20], turtles [21], large mammals [22], and frogs [23] have been documented. The Western Ghats has many endemic and globally threatened amphibians, and their habitats face a potentially severe threat because more than twenty dam projects are currently being constructed, or are planned. Herein, we conduct one of the first empirical studies that documents likely impacts of hydropower dams on riparian frog communities.

We conducted a retrospective examination of the effects of two hydropower dams installed two decades ago on the riparian frog communities created in the southern Western Ghats. We examined, if there were differences in above-dam and below-dam (1) abundance of specific species of frogs, (2) frog species richness, and (3) frog species composition above and below the dams. Through these investigations, we identified species of frogs, which would act as indicators of unaltered and altered flow regimes in the landscape.

2. Methods

The study was carried out in Kalakad-Mundanthurai Tiger Reserve (KMTR, 8°25′–8°53′N and 77°10′–77°35′E) in the Ashambhu hills of Tamil Nadu. The altitude ranges from 50 m to 1800 m above sea level, with rainforests occurring mainly above 600 m. The mean annual temperature ranges between 24 °C and 30 °C. The annual rainfall ranges from 750 mm in the rain shadow region in the eastern slopes, to over 3000 mm in the western slopes. KMTR contains a significant part of one of the largest remaining contiguous tracts of tropical rainforests in the Western Ghats, spreading over 400 km^2 [24,25]. The study focused on two dams that were built in the early 1980s, on two major rivers, the Banathirtam and the Valayar, at an elevation of 250 m above sea level. After the construction of the dam, the entire landscape was declared as a wildlife reserve and protected.

Figure 1. Map indicating the location of Kalakad-Mundanthurai Tiger Reserve in India (top right corner) with the sampling sites indicated.



Sampling for frog diversity was carried out between December 2004 and April 2005, upstream and downstream of two major dams in the area, namely Karayar and Servalar (Figure 1). Karayar and Servalar dams are at similar elevations (250 m above sea level), thereby providing comparable sites for studies. The other dams in the landscape are either much higher in elevation (~1000 m above sea level) or too low (~100 m above sea level) thereby restricting our sampling to just two comparable sites. The below-dam sites were located <4 km downstream of the dam. The elevation of the below-dam sites ranged from 40–200 m above sea level. The vegetation of the below-dam sites was characterized by dry-deciduous forests dominated by *Tectona grandis*, *Erythroxylum monogynum*, *Zizyphus xylopyrus*, and *Atalantia monophylla*. Above-dam sites were located at the mouth of the rivulet <1 km above the high water mark on the reservoir. The elevation of the above-dam sites was characterized by semi-evergreen forests dominated by *Aglaia elaegnoidea*, *Suregada angustifolia*, *Mallotus philippensis*, and *Mitrephora heyneana* amongst others. In addition to this, sampling was also carried out in three different segments separated by 50 m distance in the Pachayar drainage at Thalayanai (190–220 m above sea level) where there was no dam, this served as the control site. The control site in Thalayanai was the site in the landscape that had similar vegetation type to the below-dam sites dominated by *Tectona grandis*, *Erythroxylum monogynum*, *Zizyphus xylopyrus*, *Anogeissus latifolia*, and

Atalantia monophylla amongst others. The east-facing low elevation slopes have dry deciduous vegetation in general and have riparian forests along the streams. The control site also enabled us to control for the possible bias caused by the termination of elevational ranges of endemic stream dwelling frog species from *ca.* 1200 m to 250 m (see [5]), where the dams were located (see Table 1) and for possible biases caused by changes in vegetation types above and below the dams. Unfortunately, this was the only site in the landscape that was similar in elevation to the below-dam sites but without a dam. All the streams sampled during the study were uniformly 10–15 m wide and had similar tree cover, and other physical features. They were characterized by presence of bedrock and boulders jutting out of the streams except in Karayar and Kodamadi where there were stretches of sand along the stream banks.

Table 1. Details of the sampling sites (first six are the test sites and the last one is the control site) along with details of the observed and estimated (Jackknife 1) species richness for the three categories.

Site Name	Sampling Time	Drainage	Location w.r.t. Dam	Elevation (m)	Observed Frog Species Richness	Estimated Frog Species Richness (±SE)
Agastiyar Falls	December-04	Thamirabarani	Below	40		
Karayar	March-05	Banathirtam	Below	180	10	10.69 ± 0.53
Mundanthurai	December-04	Valayar	Below	180		
Banathirtam	January-05	Banathirtam	Above	350		
Kodamadi	December-04	Valayar	Above	240	10	10.67 ± 0.37
Madangal	December-04 and January-05	Valayar	Above	390		
Thalayanai 1	April-05	Pachayar	No Dam	190		
Thalayanai 2	April-05	Pachayar	No Dam	200	9	9.67 ± 0.39
Thalayanai 3	April-05	Pachayar	No Dam	210		

Sampling involved three, one-hour Visual Encounter Surveys (VES) [26], at each of the sites. Previous studies in KMTR have shown that frogs aggregate along watercourses [5,25] and hence, all the sampling effort was concentrated along the river course. This involved two people walking abreast with torches, along the river course looking for frogs on the banks or on the rocks inside the streams. The VES were carried out between 6:30–9:00 pm. The method did not involve active searching, and only those frogs that were spotted by the torchlight were recorded. The details of the sampling sites are given in Table 1. We used this information to estimate encounter rates (per hour) of endemic frogs in each of the three categories.

EstimateS software [27] was used to obtain a Jackknife 1 estimate of species richness for each of the two treatments and the control. Jackknife 1 is a nonparametric estimator of species richness and the estimate approximates to the asymptotic estimate calculated based on the mark–recapture method. It uses species represented by one (singletons) or two (doubletons) individuals in the samples to estimate species richness.

Species presence/absence in each of the samples was used to calculate species turnover between sites that were sampled. It was estimated as (1-*X*), where *X* is the Sorensen's index [28]. Sorenson index was calculated using EstimateS software [27]. Mean species turnover and the 95% confidence limits were calculated using pair-wise differences between one hour visual encounter survey samples for the following categories: (1) above dam; (2) below dam; (3) above dam and control; (4) below dam and control; and (5) below dam and above dam. The mean turnovers of frog species within above and below dam signify the turnover of frog species caused by factors that operate within the site level, such as microhabitat differences. In order to test the hypothesis, that the mean turnovers of species in control and below- dam, and above and below-dam sites were significantly greater than the other categories, *z* tests were used. We performed a cluster analysis using the Average-Linkage method and the Bray-Curtis measure to depict the similarity between sites in composition of frog species. Statistical analyses described were carried out using SPSS 8.0 (SPSS Inc., Chicago IL, USA). Indicator values for each species in each of the two groups (control and below dams) were calculated [29]. Indicator species are defined as the most characteristic species of each group, found mostly in a single group, and also present in the majority of the sites belonging to that group [29]. The objective of this analysis was to identify species which are potentially affected (positively/negatively) by dams, and to identify frog species which could be used as indicators of manipulated or natural hydrological systems. Indicator species analysis was done using the software PC-ORD [30] with 10,000 iterations.

3. Results

Fifteen species were detected during the sampling period: 10 species, each, were found in the above dam and below dam sites, and nine species were found in the control sites (see Table 2). There was no significant difference between the treatments and the control in their estimated species richness (see Table 1). Five species that were detected above-dam, were not found below-dam, and among them four species are endemic to the Western Ghats. Five species were detected below the dam, but they were not detected above the dam; one of these five species is endemic to the Western Ghats (*C. curtipes*). There were differences in the mean encounter rates of some species in the above and below-dam sites (Figure 2). Species, such as *Nyctibatrachus vasanthi*, *N. aliceae* and *Hylarana temporalis*, are specialized hill stream dwelling frogs in the Western Ghats. They were conspicuously missing below the dams. The encounter rate of *Indirana brachytarsus*, an endemic species that inhabits streams with large rocky substrates, was lower below than above-dam and the control sites (Figure 2). *Clinotarsus curtipes* an explosive breeder, which survives in seasonal habitats, was abundant below the dams (Figure 2). The turnover of species within above dam, below dam, and between above dam and control sites were similar (Figure 3). The mean turnovers of species in control and below-dam, and above and below-dam sites were significantly greater than in the other categories (control and below-dam: $z = -8.38$, $p < 0.05$; above and below-dam: $z = -8.38$, $p < 0.05$, Figure 3). Hierarchical cluster analysis revealed that the above-dam and the control sites together formed a distinct cluster, while the below dam sites formed distinct cluster with the exception of one above dam site (Figure 4). Indicator value analysis revealed that *Fejervarya keralensis*, *I. brachytarsus*, *N. vasanthi*, *N. aliciae*, and *H. temporalis*, most endemic species (except *C. curtipes*) were indicators of rivers without dams (Table 2). All the above-mentioned species (except *I. brachytarsus* detected only once in a below dam site) were missing in the below-dam sites, but were abundant in the control sites, thus, suggesting their preference for unaltered flow regime.

Table 2. Number of individuals of the fifteen species of frogs seen in each of the two treatments and control along with information on distribution of each of the species. The last three columns summarize the information of the Indicator Value analysis for each species. Indicator Value % is the maximum indicator value observed for the species in the two groups (below- and above-dam) and 'p' is the proportion of randomized trials with indicator value equal to or exceeding the observed indicator value.

Species	**Below-Dam**	**Above-Dam**	**Control**	**Distribution**	**Indicator Value %**	**Group**	***P***
Clinotarsus curtipes	94	0	0	Endemic	56	Below-dam	0.806
Indirana brachytarsus	1	109	16	Endemic	98	Above-dam	**0.004**
Micrixalus fuscus	0	55	0	Endemic			
Nyctibatrachus aliciae	0	11	3	Endemic	67	Above-dam	**0.046**
Nyctibatrachus vasanthi	0	50	18	Endemic	67	Above-dam	**0.046**
Philautus sp.*	0	1	0	Endemic			
Hylarana aurantiaca	1	4	3	Endemic	60	Above-dam	0.089
Duttaphrynus melanostictus	6	3	0	Non-endemic	22	Below-dam	0.806
Euphlyctis cyanophlyctis	86	4	97	Non-endemic	77	Above-dam	0.114
Fejervarya cf. *limnocharis*	138	0	29	Non-endemic	48	Below-dam	0.779
Hoplobatrachus crassus	7	0	0	Non-endemic	44	Below-dam	0.446
Microhyla rubra	5	0	0	Non-endemic	22	Below-dam	1.000
Polypedates maculatus	2	0	3	Non-endemic	27	Above-dam	0.683
Hylarana temporalis	0	48	7	Non-endemic	67	Above-dam	**0.046**
Fejervarya keralensis	2	15	22	Non-endemic	97	Above-dam	**0.009**
Total	**342**	**300**	**198**				

* All *Philautus* were identified only up to the genus level due to ambiguity in taxonomy of the group.

Figure 2. Mean number of individuals of the six species seen (with the standard errors) in below-dam, above-dam and in control sites.

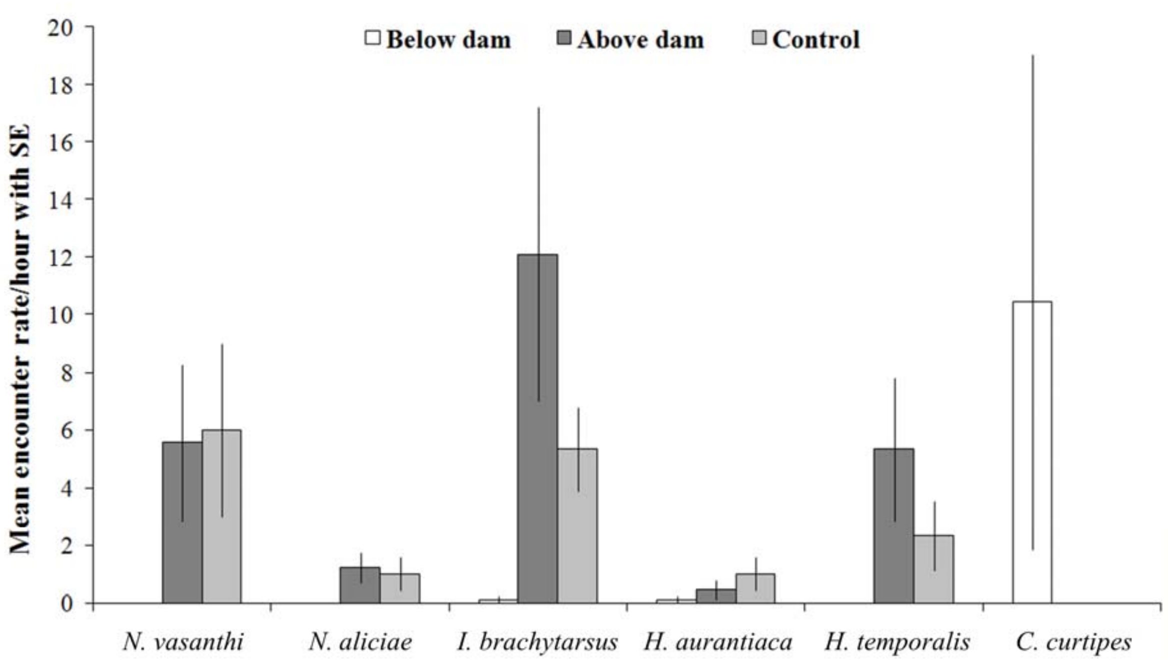


Figure 3. Mean turnover (with CI) for above dam, below dam, above and control, below and control and above and below sites.

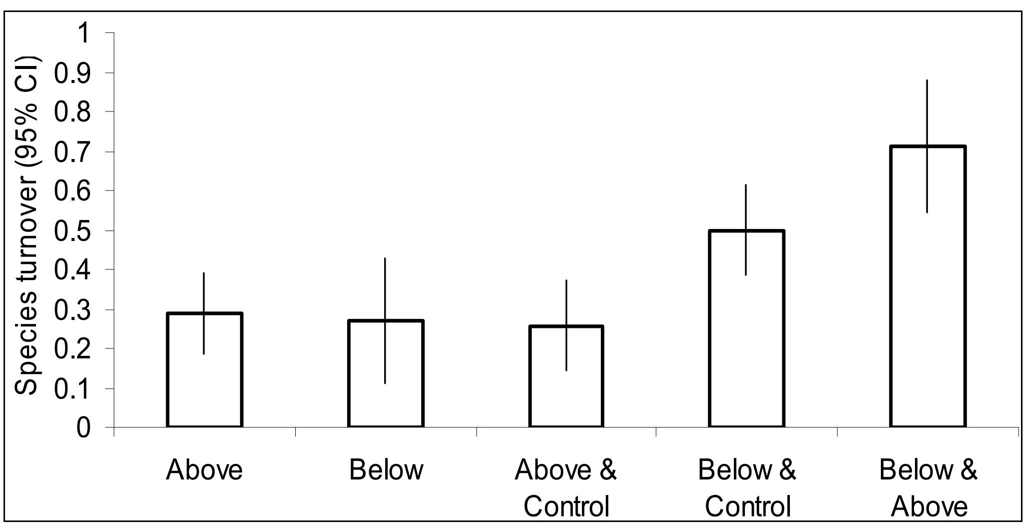
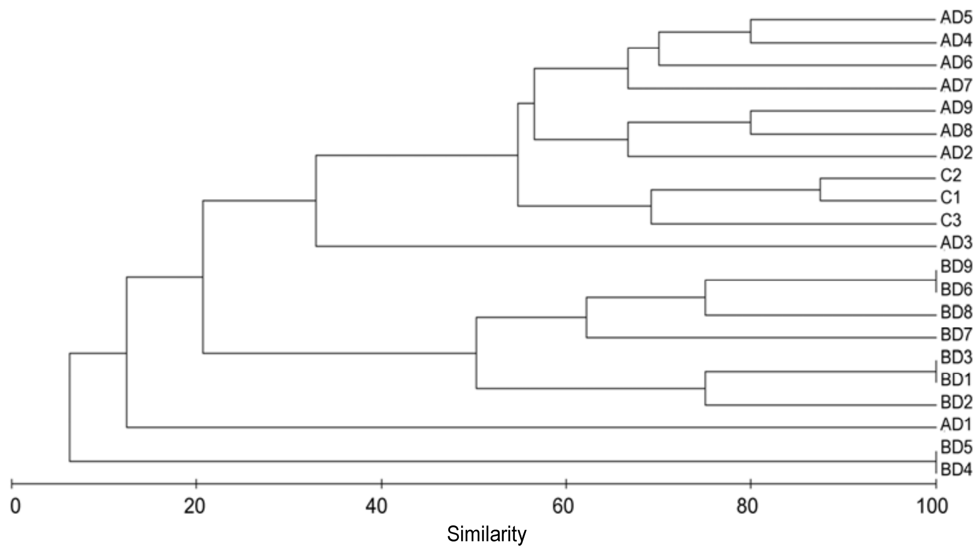


Figure 4. Dendrogram showing clustering of sites: above-dam (AD), below-dam (BD), and control (C).



4. Discussion

In this study, we found that dams can potentially alter amphibian communities as the mean abundance of several endemic species was higher in the above dam and control sites as compared to below dam sites, with the amphibian community composition with below dam sites having more generalist and widespread species as compared to control and above-dam sites. This study also highlights the need to focus on community composition metrics because species richness, which was similar in above-dam, below-dam and control sites, by itself is a poor indicator of effects of dams. In context of the Western Ghats, which is a biodiversity hotspot, and India, this is one of the first studies to document the likely impacts of dams on amphibian communities. Unfortunately, since the dams were constructed 20 years prior to this study, we could not document dam impacts by collecting data on amphibian communities before and after the dam construction. However, presence of two dams at similar elevations and with similar construction histories allowed us to conduct a space for time study with above dam sites and a control site acting as our undisturbed sites and the below-dam sites as the disturbed sites. Given this, there are ~~a~~ certain limitations in the inferences we can draw from the study. However, the differences in amphibian community composition below dams and in above dam and control sites point towards the negative effects of dams on stream dwelling amphibians some of which were endemic species.

In our study, after accounting for the undetected species during sampling, frog species richness was similar in above and below dam sites. However, there was a difference in the frog species composition. Five species that were observed in above-dam sites were not found in the below-dam sites. Similarly, four species found in the below-dams sites were not found in the above-dams sites. Three of the five frog species (*N. vasanthi*, *N. aliciae*, and *Micrixalus fuscus*) were found only in the above-dam and not in the below-dam sites. These species were also endemics to the Western Ghats. Although we did not examine proximate causes of the differences in frog communities above and below dams, these findings are consistent with the hypothesis that endemic frogs in our sample which are specialists to fast-flowing stream habitats face problems with the likely altered flows downstream of dams. Only one endemic frog species (*C. curtipes*) was recorded below the dam. This species was also detected above the dams, in deep and calm portions of streams. This species was patchily distributed in natural flowing streams, but with the alteration in flow regime due to dam installation, favorable conditions were probably created for the species in the below-dam sites. It dwells in the forest floor adjacent to stagnant pools and breeds in reservoirs. The other three species recorded below the dams were widely distributed, occur in disturbed and man-made habitats [3], and breed in lentic habitats. The alteration of the riparian habitat for frogs below dams might have created favorable conditions for widespread generalist frog species, and unfavourable conditions for the endemic frog species that breed in fast flowing streams in the Western Ghats.

Regulation of flow in the river due to dams likely causes fluctuation in the downstream water level. This in turn, causes loss of crucial microhabitats for the adult and larval stages of endemic frogs of the genera, *Nyctibatrachus*, *Indirana*, and *Hylarana* in rivers flowing through KMTR. Generalist and stagnant pool breeding species, such as, *C. curtipes*, *H. crassus*, and *Fejervarya* cf. *limnocharis*. *Euphlyctis cyanophlyctis*, appeared to be unaffected by the fluctuation in the downstream water level. Altered flow regimes in rivers are known to impact the life history processes, causing declines in frog populations [31,32,33]. Frogs belonging to the endemic genus *Nyctibatrachus* are probably adversely impacted due to dams in the Western Ghats. These frogs lay their eggs outside water—on ground, rocks in streams or vegetation with the protection of foam [34]. During the dry season in KMTR, eggs of *N. vasanthi* were observed on rock surfaces near small water torrents. The water from the torrents splash over the eggs and keep them moist. The altered flow regime downstream of dams due fluctuations of water levels would expose the eggs leading to desiccation, when the water level is low; or drown them when the water level is high. We suggest this to be one of the main reasons for their low numbers or complete absence downstream of dams. Dams also disrupt lateral habitat connectivity for riparian fauna causing fragmentation of their population [35,36]. *Nyctibatrachus* frogs, unlike *Indirana* and *Hylarana*, are exclusively stream dwelling frogs. We suspect that the populations of *Nyctibatrachus* frogs in two major rivulets have probably permanently lost connectivity downstream due to dams in KMTR.

Density of riparian habitats is an important determinant of anuran density on the tropical forest floor [6]. Dams alter the landscape by submerging and fragmenting riparian habitats, thereby likely impacting species occurring in those zones such as populations of endemic frogs in the Western Ghats. Through our observations, we highlight concerns on the persistent influences of dams on frog communities, in the Western Ghats, a change that continues to persist even 20 years after the dams have been constructed. This indicates towards permanent alterations caused by dams to amphibian communities particularly influencing endemic frog species. Elevations from 900–1300 m above sea level in the Western Ghats Mountains have most frog species and endemic ones [5]. We speculate that large dams built in this elevational range in the Western Ghats might have the greatest adverse impact on endemic frog fauna in the mountain range. We emphasize that before dam projects are formulated in biodiversity rich mountains such as the Western Ghats, due considerations need to be given to ensure appropriate areas of riparian forests are left unaltered so as to prevent complete loss of habitat of typical stream dwelling frog species many of which are also endemic to the region.

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Author Contributions

R.N. and K.V. conceived the study; K.V. obtained funding and permissions for the work; R.N. did the fieldwork for the study; R.N. and K.V. analyzed the data; R.N. and K.V. wrote the paper.

Conflicts of Interest

The authors declare no conflict of interest.

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