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Deaths of overwintering *Nanorana* spp. tadpoles due to desiccation during check dam maintenance in a western Himalayan stream, India

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All amphibian life stages may be directly or indirectly affected by drought, although many amphibians exhibit plasticity in the duration of tadpole development, in response to drought conditions, with trade-offs such as reduced body condition, survival etc. (Cayuela et al., 2016; Yeung, 2021). Droughts may be induced by human activity such as when check dams are drained for maintenance purposes. Check dams are important civil engineering structures built for soil conservation, groundwater recharging and water extraction, and are very common in Indian streams (Agoramoorthy et al., 2008). Here, we report the first observations of the deaths of overwintering tadpoles of two species of *Nanorana* during check dam maintenance. It is known that check dams have negative impacts on stream channel morphology (Fortugno et al., 2017), water quality, velocity, and substrate fineness (Kang & Kazama, 2012), cause loss of larval microhabitat (Thomas et al., 2019), and influence the breeding ecology of frogs (Lind et al., 1996). However the influence of check dam maintenance has been little documented.

Our observations concern two dicroglossid frog species. The small paa frog *Nanorana minica* (Dubois, 1975) that is associated with montane subtropical forests and streams distributed in Nepal, Uttarakhand and Himachal Pradesh at 1000–2400 m a.s.l. (Ohler et al., 2004; Bhattarai et al., 2020; Frost, 2021). It is listed as Vulnerable on the IUCN Red List and major conservation threats are waterway management and loss of habitat through forest clearance (Ohler et al., 2004). The other species is the Himalaya paa frog *Nanorana vicina* (Dubois, 1976) that is distributed in the Himalayan front of India, north-central Pakistan from Kashmir, Himachal Pradesh to Punjab, and Uttarakhand ranging from 2000–3000 m a.s.l. and is associated with montane streams, springs, fountains and other running water within open forest and grassland habitats (Ohler & Dutta, 2004; Frost 2021). Apart from morphological descriptions and other natural history records, little is known of the larval ecology of either species (Das & Dutta, 2007; Sircar, 2010; Banerjee et al., 2020; Gill et al., 2020; Jithin, 2021). Jithin (2021) reported overwintering tadpoles of *N. minica* and *N. vicina* from the western Himalaya, India. The overwintering tadpoles feed on periphyton growing on check dam walls, bedrocks, boulders, cobbles, leaf litter surface, submerged logs in the pool; humus and animal carcasses; the check dam pools also offer a temperature gradient (Boix-Fayos et al., 2007: Banerjee et al., 2020; Jithin, 2021).

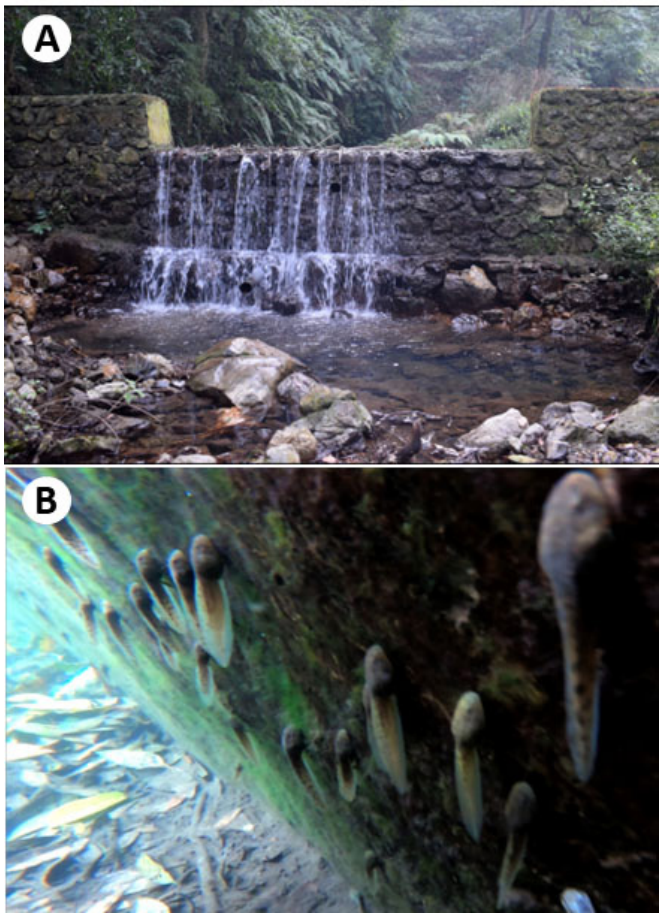

Figure 1. **A.** Example of a check dam pool with wider broad-crested weir, and **B.** Overwintering tadpoles feeding on the periphytons growing on the check dam walls in the Mussoorie Wildlife Sanctuary, Uttarakhand, India

We recorded tadpole mortality at two check dam maintenance events along the Dhobhighat (Ringali Gad) stream, flowing through the Mussoorie Wildlife Sanctuary. This second-order stream flows through private resorts,

agricultural fields, and human habitations and is dammed in several places creating large check dam pool habitats. These check dams were built during the 1960s and are presently used for torrent control, water recharge and extracting drinking water for Mussoorie town. The check dams are managed by the Uttarakhand Jal Sansthan and a pump house is situated in the sanctuary (Management Plan, 2010). Concrete or stone-mortar walls are present with wider broad-crested weirs in the check dam pools. Filtered water goes directly to a pump house via long underground pipes from the check dams. The dams are used by overwintering tadpoles, fish: snow trout (*Schizothorax richardsonii*; Cyprinidae), stone loach (*Schistura rupecula*; Nemacheilidae) and other aquatic organisms (Management Plan 2010; Jithin, 2021).

Annual maintenance of check dams is essential. Water is usually diverted from the original channel making the area dry apart from a few shallow pools that act as refugia for aquatic organisms. Then broken walls are renovated, pipes repaired and silt removed, after which the bottom is cleaned and pebbles and small boulders from other natural pools are deposited in the dam pool bed to facilitate water filtration. These maintenance activities usually take 2–3 days to finish and by this time, tadpoles, fish and crabs are either dead or are predated by birds. During one such maintenance event on 16 March 2021 at 12:32 h in a check dam pool (30° 28' 2.06" N, 78° 01'45.19" E, 1645 m a.s.l.) we quantified the death of overwintering tadpoles. There were a total of ~150 tadpoles in an area of 2.5 m^2 (Fig. 2 and Fig. 3D) of which 32 were found dead (21.3 %) and 61 alive, but stuck in the silt (40.7 %).

We collected a representative sample of the dead tadpoles and deposited it at the Wildlife Institute of India Herpetofauna Collection (N=14, WIIAD T-175-188). The size of these tadpoles ranged from 25.32 to 63.4 mm (total length) and stages from 26 to 36 (Gosner, 1960). We could not quantify the deaths of two species separately as field identification is difficult (Jithin, 2021). Apart from the mortality of tadpoles, newly laid egg strings of Himalayan toad *Duttaphrynus himalayanus* were also found in the dried stream bed.

On 20 March 2021 at 17:00 h, we recorded another maintenance event in another stream portion (30° 27'57.90" N; 78° 01'46.40" E; 1751 m a.s.l.) where the death of tadpoles resulted from deposition of silt, which was dug out while cleaning a cement-lined tank built near the stream for water filtration (Fig. 3A-C, BHS video, 2022). The silt flow made the water downstream turbid; we measured pH and Total Dissolved Solids (TDS) using a portable pH meter (Aquasole Digital Pen Type Meter, AM-P-PH) and a portable EC/TDS meter (Aquasole Digital Pen Type Meter, AM-P-EC) and Dissolved Oxygen (DO) levels using the modified iodometric (Winkler) method (Jithin, 2021). These values were compared with a dataset we generated from other check dams and natural pools in the same stream (Jithin, 2021). All parameters were above mean [± 95 % CI] values for the month of March (pH: 8.7 [8.356±0.063], DO: 10.145 [7.736±0.471] mg/L), but TDS showed a very high value (275 ppm), beyond the measurement range recorded (205–228 ppm) in the whole month from similar check dam pools.

Figure 2. Tadpole mortality during check dam maintenance and renovation - **A.** The pool before maintenance when the water flow had been stopped and diverted, circles showing close-up images of dead overwintering tadpoles, **B.** The check dam after maintenance

Figure 3. Tadpole mortalities in a stream clogged with silt from the maintenance of a check dam - **A.** Portion of stream clogged with silt deposition, **B.** The cement-lined tank from where the silt was removed, **C.** White circles showing dead overwintering tadpoles of *Nanorana* spp. embedded in silt, **D.** Image showing the size range among dead overwintering tadpoles of *Nanorana* spp. and a dead stone loach *Schistura rupecula* fish at bottom centre of the photograph

Considering the large-scale killing of overwintering tadpoles in check dam pools during maintenance, we discourage complete draining of pools as this could lead to the loss of refuge areas for the tadpoles. A reasonable water volume should be left in the pools in such cases. When complete draining operations are required during maintenance, aquatic organisms (including tadpoles, fish, crabs etc.) must be carefully transferred to nearby pools to avoid large-scale deaths due to desiccation. A standard protocol for this procedure should be developed in collaboration with the Forest Department and Water Supply Department.

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