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Conservation of *Cremnoconchus* Blanford 1869, an iconic freshwater gastropod genus from the Western Ghats, India

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Freshwater ecosystems in the Western Ghats are fragile and highly susceptible to environmental disturbances. The freshwater biota is particularly vulnerable because even the slightest change in habitat can lead to extinction. Freshwater gastropods are an important and diverse group in the freshwater ecosystem, accounting for about 20% of all metazoan animal recorded extinctions. The Western Ghats in India harbours an endemic genus of freshwater mollusc, *Cremnoconchus*. To date, 12 species of *Cremnoconchus* are known, and they are recorded only from the spray zones of waterfalls in the Western Ghats biodiversity hotspot. They are point endemic and confined to the western escarpments of the Ghats between 300 m to

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1400 m asl. Only three species have been assessed for the IUCN Red List of Threatened Species. Given the limited distribution and vulnerability to environmental changes of all known *Cremnoconchus* species, we assess their conservation status using standard ‘Red List’ criteria and recommend conservation measures.

Keywords: Critically endangered, endemic radiation, mollusc, Red List, waterfalls.

FRESHWATER ecosystems are highly vulnerable to environmental perturbations making the biodiversity they harbour more prone to extinction than terrestrial or marine species^{1,2}. Freshwater biota account for nearly 10% of total biodiversity described so far^{3–5}. Thus, there is an urgent need to develop conservation measures for freshwater ecosystems⁶. Endemic freshwater molluscs, in general, are sensitive to habitat degradation because of their low dispersal ability, habitat specialization, and relatively small ranges which make them more vulnerable to extinction. Of these, freshwater gastropods are an important and diverse component of freshwater ecosystems worldwide⁷ and are also among the most vulnerable groups, making their conservation a matter of concern⁸. So far, the status of only 1500 out of 5000 freshwater gastropods has been assessed⁹. They comprise only 5% of the world’s snail fauna but account for 20% of recorded extinctions⁷. The status of a majority of them is unknown, due to lack of experts and baseline data relating to their distribution, population, threats, basic life history, physiology, morphology and diet⁹. Thus, the already considerable magnitude of extinction and levels of threat indicated by the IUCN Red List is likely to be an underestimate¹⁰.

The Western Ghats in India is not only a biodiversity hotspot¹¹ for terrestrial biological diversity, but also for freshwater taxa such as fishes, crabs and molluscs^{7,12}. A recent assessment of freshwater biodiversity of the Western Ghats shows that it is a ‘globally significant centre of diversity and endemism for freshwater species’¹³. Until recently, except for the recent Red List assessment of freshwater biodiversity, there are no comprehensive studies¹³. Molur *et al.*¹³ showed that nearly 16% of the 1,146 freshwater species assessed are threatened with extinction¹³. Much of these threatened species are narrow-range endemics which are under severe threat¹³. Among them is the species that belongs to freshwater gastropod genus *Cremnoconchus*. This genus is one of the unique components of freshwater ecosystems of the Western Ghats with a high endemic radiation¹⁴.

Cremnoconchus is the only freshwater genus from Littorinidae, and the rest are exclusively marine. This family is one of the five gastropod families of marine origin that have radiated into freshwater habitats in tropical regions of Asia. The family consists of about 205 species in 17 genera^{15,16}. Of this, genus *Cremnoconchus* is known only from the Western Ghats of India, where it is mostly confined to the western escarpment (except for two records)

between altitudes of 300 m and 1400 m asl (refs 14, 17). It is restricted to spray zones of waterfalls in the central and northern Western Ghats (between 13.90°N and 20.77°N). The species confined to the central Western Ghats are point-endemic and in a highly specialized habitat, which makes this group highly vulnerable to even subtle changes in the environment. Three species were described by British malacologists between 1863 and 1870 from the northern Western Ghats, and recently six more have been described from the central Western Ghats¹⁴, while three more new species are under description (Aravind and Roshmi, under preparation). Of all the freshwater gastropods reported from this region, only three species of *Cremnoconchus* have been listed in the IUCN Red List (*C. syhadrensis* and *C. carinatus* as ‘Endangered’ and *C. conicus* as ‘Vulnerable’¹⁷).

Despite being a biogeographically interesting taxon, there has been no study on the ecology and conservation of *Cremnoconchus*. A literature survey shows that only 18 papers have been published on *Cremnoconchus*, of which only 2 dealt with conservation while others were on taxonomy and distribution. In this paper, we assess the conservation status of all known *Cremnoconchus* species using standard Red List criteria (version 3.1) and draw a conservation plan.

The distribution data of *Cremnoconchus* was compiled from extensive field surveys undertaken in the past 15

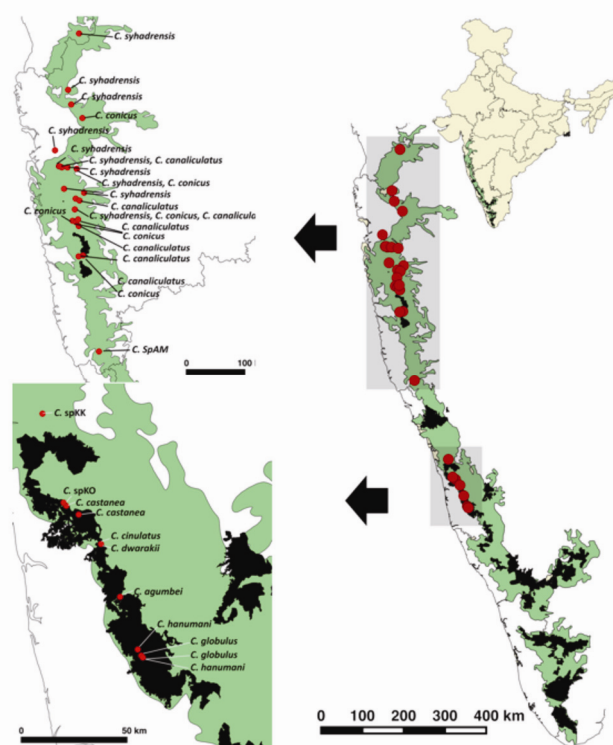


Figure 1. Distribution of *Cremnoconchus* in the Western Ghats, India.

Table 1. Distribution of different species of *Cremnoconchus* in the Western Ghats

Species	Location	Coordinates	Altitude (m asl)	River basin
<i>Cremnoconchus syhadrensis</i>	Ahwa, Gujarat	20.77°N; 73.68°E	404	NWG west flowing river basin
<i>Cremnoconchus syhadrensis</i>	Harishchandraghad, Maharashtra	19.50°N; 73.72°E	773	Krishna
<i>Cremnoconchus syhadrensis</i>	Anjani, Nashik district, Maharashtra	19.92°N; 73.50°E	1219	NWG west flowing river basin
<i>Cremnoconchus syhadrensis</i>	Igatpuri, Nashik district, Maharashtra	19.70°N; 73.55°E	600	NWG west flowing river basin
<i>Cremnoconchus syhadrensis</i>	Matheran, Raigad district, Maharashtra	19.01°N; 73.29°E	416–569	NWG west flowing river basin
<i>Cremnoconchus syhadrensis</i>	Khandala, Pune district, Maharashtra	18.77°N; 73.35°E	297	NWG west flowing river basin
<i>Cremnoconchus syhadrensis</i>	Lonavala, Pune district, Maharashtra	18.75°N; 73.40°E	610	NWG west flowing river basin
<i>Cremnoconchus syhadrensis</i>	Bhor Ghat, Pune district, Maharashtra	18.77°N; 73.37°E	599	NWG west flowing river basin
<i>Cremnoconchus syhadrensis</i>	Vadgaon, Pune district, Maharashtra	18.73°N; 73.64°E	729	Krishna
<i>Cremnoconchus syhadrensis</i>	Khandala, Pune district, Maharashtra	18.75°N; 73.49°E	610	Krishna
<i>Cremnoconchus syhadrensis</i>	Sinhgargh Fort, Pune district, Maharashtra	18.37°N; 73.76°E	1000	NWG west flowing river basin
<i>Cremnoconchus syhadrensis</i>	Torna Fort, Pune district, Maharashtra	18.28°N; 73.62°E	1400	Krishna
<i>Cremnoconchus syhadrensis</i>	Rajgarh Fort, Pune district, Maharashtra	18.25°N; 73.68°E	1300	Krishna
<i>Cremnoconchus canaliculatus</i>	Bhor Ghat, Pune district, Maharashtra	18.77°N; 73.37°E	599	NWG west flowing river basin
<i>Cremnoconchus canaliculatus</i>	Tamhini, Pune district, Maharashtra	18.43°N; 73.44°E	650	NWG west flowing river basin
<i>Cremnoconchus canaliculatus</i>	Mahabaleshwar, Raigad district, Maharashtra	17.94°N; 73.57°E	692	NWG west flowing river basin
<i>Cremnoconchus canaliculatus</i>	Torna Fort, Pune district, Maharashtra	18.28°N; 73.62°E	1400	Krishna
<i>Cremnoconchus canaliculatus</i>	Mahabaleshwar, Satara district, Maharashtra	17.92°N; 73.63°E	1092	NWG west flowing river basin
<i>Cremnoconchus canaliculatus</i>	Mahabaleshwar, Satara district, Maharashtra	17.86°N; 73.67°E	1125	NWG west flowing river basin
<i>Cremnoconchus canaliculatus</i>	Mahabaleshwar, Satara district, Maharashtra	17.96°N; 73.66°E	1200	NWG west flowing river basin
<i>Cremnoconchus conicus</i>	Harishchandraghad, Maharashtra	19.50°N; 73.72°E	773	NWG west flowing river basin
<i>Cremnoconchus conicus</i>	Khandala, Pune district, Maharashtra	18.75°N; 73.49°E	610	Krishna
<i>Cremnoconchus conicus</i>	Torna Fort, Pune district, Maharashtra	18.28°N; 73.62°E	1400	Krishna
<i>Cremnoconchus conicus</i>	Bhor Ghat, Pune district, Maharashtra	18.11°N; 73.61°E	645	NWG west flowing river basin
<i>Cremnoconchus conicus</i>	Mahabaleshwar, Satara district, Maharashtra	17.96°N; 73.66°E	1200	NWG west flowing river basin
<i>Cremnoconchus conicus</i>	Mahabaleshwar, Satara district, Maharashtra	17.92°N; 73.63°E	1103	NWG west flowing river basin
<i>Cremnoconchus spAM</i>	Amboli, Sawantwadi district, Maharashtra	15.95°N; 73.99°E	720	NWG west flowing river basin
<i>Cremnoconchus castanea</i>	Belkal Thirtha, Udupi district, Karnataka	13.84°N; 74.90°E	373	Suparnika
<i>Cremnoconchus castanea</i>	Arasinagundi, Udupi district, Karnataka	13.88°N; 74.84°E	384	Suparnika
<i>Cremnoconchus cingulatus</i>	Hulikal, Udupi district, Karnataka	13.72°N; 74.99°E	475	Haladi
<i>Cremnoconchus dwarakii</i>	Hulikal, Udupi district, Karnataka	13.72°N; 74.99°E	475	Haladi
<i>Cremnoconchus agumbensis</i>	Someshwara, Udupi district, Karnataka	13.49°N; 75.08°E	379	Swarna
<i>Cremnoconchus hanumani</i>	Hanuman Gundi, Chikmagalur district, Karnataka	13.27°N; 75.16°E	830	Swarna
<i>Cremnoconchus hanumani</i>	Kadambi 1, Chikmagalur district, Karnataka	13.24°N; 75.18°E	941	Swarna
<i>Cremnoconchus globulus</i>	Kadambi 2, Chikmagalur district, Karnataka	13.24°N; 75.17°E	967	Swarna
<i>Cremnoconchus globulus</i>	Kadambi 1, Chikmagalur district, Karnataka	13.24°N; 75.18°E	941	Swarna
<i>Cremnoconchus spKK</i>	Kathlekan, Uttara Kannada district, Karnataka	14.27°N; 74.74°E	436	Sharavathy
<i>Cremnoconchus spKO</i>	Kollur Ghat, Udupi district, Karnataka	13.90°N; 74.82°E	250	Suparnika

years throughout the Western Ghats from Kanyakumari (8°N) in south till Tapti in North (21°N), and complemented from published literature, collections in the Zoological Survey of India, Pune and the Natural History Museum, London. All data are georeferenced using Google Earth. Garmin eTrex GPS was used to record coordinates for the primary data collection, and QGIS Software was used to map the distributions (Figure 1 and Table 1).

The geographic range of *Cremnoconchus* was calculated using the extent of occurrence (EOO) and area of occupancy (AOO) methods¹⁸. These two measures were used to assess restricted-range species under criterion B of IUCN's Red List procedure¹⁹. The extent of occurrence was calculated by constructing the minimum convex polygon around known occurrence points of *Cremnoconchus* in GEOCAT^{19,20} and AOO was calcu-

lated as the number of grids occupied by points multiplied by 4 km². We used a grid size of 2 km × 2 km as recommended by IUCN for conservation assessment¹⁸.

For each site where *Cremnoconchus* was seen, several disturbance parameters were recorded (Table 2). The ranking is purely based on presence or absence of a particular type of disturbance.

All known *Cremnoconchus* species are endemic to the Western Ghats between latitudes 13.90°N and 20.77°N; four are endemic to the northern Western Ghats (15.95°N and 20.77°N) and eight are endemic to the central Western Ghats (between 13.90°N and 15.75°N) (Table 1). All central Western Ghats species are point endemics known only from either one or two localities. *Cremnoconchus syhadrensis* and *C. canaliculatus* are the only two species that are widely distributed in the northern Western Ghats. All northern Western Ghats species, except *Cremnoconchus*

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Table 2. Different types of disturbances recorded in waterfalls where different species of *Cremanoconchus* were recorded

Species	LULCC*	Recreational [#]	Tourism**	Washing/cleaning ¹	Garbage/sewage ²	Others ³	Disturbance score
<i>Cremanoconchus syhadrensis</i>	+	+	+	+	+	+	6
<i>Cremanoconchus conicus</i>	+	+	+	+	+		5
<i>Cremanoconchus canaliculatus</i>	+	+	+	+	+		5
<i>Cremanoconchus</i> spAM	+	+	+	+	+	+	6
<i>Cremanoconchus castanea</i>		+	+				2
<i>Cremanoconchus cingulatus</i>	+	+		+	+	+	5
<i>Cremanoconchus dwarakii</i>	+	+		+	+	+	5
<i>Cremanoconchus agumbensis</i>		+				+	2
<i>Cremanoconchus hanumani</i>		+	+				2
<i>Cremanoconchus globulus</i>		+	+				2
<i>Cremanoconchus</i> spKK	+	+					2
<i>Cremanoconchus</i> spKO		+				+	2

*Land-use and land-cover change around waterfalls; **Large-scale tourism with more than 25 people; [#]Small scale recreational activities with less than 15 persons; ¹Washing and cleaning includes bathing, washing clothes and cleaning vehicles; ²Dumping of garbage and sewage influx; ³This includes road-widening activities, vehicular disturbance, etc.

Table 3. Number of sites, altitudinal range and region in the Western Ghats where *Cremanoconchus* was reported

Species	No. of sites	Altitude (m asl)	Distribution**	Size of the waterfalls
<i>Cremanoconchus syhadrensis</i>	10	404–1400	NWG	Small, medium and large
<i>Cremanoconchus conicus</i>	3	610–1400	NWG	Small, medium and large
<i>Cremanoconchus canaliculatus</i>	7	599–1400	NWG	Small, medium and large
<i>Cremanoconchus</i> spAM*	1	720	NWG	Large and medium
<i>Cremanoconchus castanea</i>	2	373–384	CWG	Large
<i>Cremanoconchus cingulatus</i>	1	475	CWG	Medium
<i>Cremanoconchus dwarakii</i>	1	475	CWG	Medium
<i>Cremanoconchus agumbensis</i>	1	379	CWG	Small
<i>Cremanoconchus hanumani</i>	1	830–941	CWG	Large
<i>Cremanoconchus globulus</i>	2	941–967	CWG	Large
<i>Cremanoconchus</i> spKK*	1	436	CWG	Small
<i>Cremanoconchus</i> spKO*	1	250	CWG	Small

*Species yet to be described formally; **NWG, Northern Western Ghats; CWG, Central Western Ghats.

spAM from Amboli have wide altitudinal (400 m–1400 m asl) (Table 3) and latitudinal range. Six out of eight species in the central Western Ghats species are found at lower altitudes (<800 m asl) (Table 1).

Of the 12 currently recognized *Cremanoconchus* species, only 3 have been assessed for IUCN Red List status, they are: *C. syhadrensis* (Blanford 1863) and *C. canaliculatus* Blanford 1870 were categorized as endangered and *C. conicus* Blanford 1870 as vulnerable¹⁶ (*C. carinatus* is synonym of *C. conicus* according to Reid *et al.*¹⁴). The GeoCAT analyses for all species show that 9 out of 12 species should be treated as critically endangered (CR) and the remaining 3 as endangered (EN) purely based on AOO and EOO. Nine species have AOO less than 8 km² and zero EOO. For three species, EOO cannot be calculated because a minimum of three points is required for plotting a convex hull, and these species are found in one or two locations only (Table 4). Among three remaining species, *C. syhadrensis* has maximum EOO and AOO (EOO = 4405.25 km², AOO = 44 km²), followed by *C. canaliculatus* (EOO = 952.13 km², AOO = 28 km²) and

C. conicus (EOO = 323.26, AOO = 20 km²) (Table 4). Six of the 12 species are found within protected areas in the Western Ghats, and all these species are found in central Western Ghats (Table 4).

Most waterfalls surveyed are experiencing threats in some form or the other (Table 2). Species of northern Western Ghats with wide distribution have a higher disturbance score of six compared to eight central Western Ghats species with low disturbance score except for *C. cingulatus* and *C. dwarakii* which get disturbance scores of five.

Based on EOO, AOO, protection status and threats, *Cremanoconchus* spAm from Amboli, *C. cingulatus* and *C. dwarakii* should be treated as CR and the rest as EN under B1ab(iii)(iii)(iv), B2(iii)(iii)(iv). We also suggest elevating to a higher conservation status, *C. conicus*, which is currently assessed as vulnerable (VU) because of low EOO, AOO, high threats and as this species is not known to occur within any protected area. This species should be treated as EN under B1ab(iii)(iii)(iv), B2ab(iii)(iii)(iv).

Table 4. Extent of occurrence (EOO) and area of occupancy (AOO) and suggested status for different species of *Cremnoconchus*

Species	No. of sites	EOO (km ²)	AOO (km ²)	Current status*	Status (GeoCAT)	Protected area**	Disturbance score	Suggested status*
<i>Cremnoconchus syhadrensis</i>	8	4,405.24	44	EN	EN	No	6	EN
<i>Cremnoconchus conicus</i>	3	323.26	20	VU	EN	No	5	EN
<i>Cremnoconchus canaliculatus</i>	7	952.13	28	EN	EN	No	5	EN
<i>Cremnoconchus</i> spAM [#]	1	0	4	NA	CR	No	6	CR
<i>Cremnoconchus castanea</i>	2	0	8	NA	CR	Mookambika WLS	2	EN
<i>Cremnoconchus cingulatus</i>	1	0	4	NA	CR	No	5	CR
<i>Cremnoconchus dwarakii</i>	1	0	4	NA	CR	No	5	CR
<i>Cremnoconchus agumbensis</i>	1	0	4	NA	CR	Someshwara WLS	2	EN
<i>Cremnoconchus hanumani</i>	1	0	4	NA	CR	Kudremukh NP	2	EN
<i>Cremnoconchus globulus</i>	2	0	8	NA	CR	Kudremukh NP	2	EN
<i>Cremnoconchus</i> spKK [#]	1	0	4	NA	CR	Sharavthi-Aganashini CR	2	EN
<i>Cremnoconchus</i> spKO [#]	1	0	4	NA	CR	Mookambika WLS	2	EN

*CR, Critically endangered; EN, Endangered; VU, Vulnerable; NA, Not assessed; **WLS, Wildlife Sanctuary; NP, National Park; CR, Conservation reserve; [#]These species yet to described formally.

The recent taxonomic review and subsequent field surveys have shown that the genus *Cremnoconchus* has high diversification, especially in the central Western Ghats with several cryptic species¹⁴ (Figure 1). All the species found in the northern Western Ghats are sympatric with each other. There were only two incidences of sympatry in the central Western Ghats (*C. globulus* and *C. hanumani* in Kadambi and *C. dwarakii* and *C. cingulatus* in Hulikal). In the northern Western Ghats, the habitats of *Cremnoconchus* are damp cliffs, streams, and waterfalls at an altitude between 400 m and 1400 m asl (ref. 14) (Aravind, unpublished data). In the Central Western Ghats, all the species are restricted to spray zones of perennial waterfalls between 370 m and 970 m asl. The species found in the northern Western Ghats undergoes aestivation during post-monsoon season once the streams dry up²¹.

The current distributional range of *Cremnoconchus* varies from less than 100 m² for point endemic species that are restricted to the central Western Ghats, to 4,400 km² for the most widespread species *C. syhadrensis*. However, both AOO and EOO overestimate the area. In reality, the AOO for most of the point endemics will be as small as 50 m² as they are confined to small to medium waterfalls. For the widespread species *C. syhadrensis*, AOO will be less than 1500 m². EOO and AOO analyses have limited application for species such as *Cremnoconchus*, which are highly restricted to specialized habitats such as waterfalls. Hence, one has to be careful when using these measures for highly habitat specialist taxa such as *Cremnoconchus*.

Hora²² indicated the uniqueness of waterfalls as a specialized habitat. Since then, a few studies have been carried out to assess the biodiversity of this unique habitat. The Western Ghats waterfalls harbour some of the interesting flora and fauna which are restricted to spray zones such as endemic grass *Hubbardia heptaneuron*²³, variety of liverworts²⁴ and a Gesneriaceae member *Henckelia pradeepiana*²⁵, to name few. The grass *Hub-*

bardia heptaneuron has possibly gone extinct in Jog Falls, the type locality, due to the construction of dam upstream²³. Many waterfalls where *Cremnoconchus* is found are under severe pressure from anthropogenic activities such as recreation even inside protected areas. For example, Hanuman Gundi Falls in Kudremukh National Park in central Western Ghats, where *C. hanumani* (type locality) is found, is a famous tourist spot. The Hulikal waterfalls which has two sympatric species *C. dwarakii* and *C. cingulatus* is experiencing threat from the dumping of waste, recreation, clearing of riparian habitat and pollution from the temple situated upstream of the falls (Figure 2). In an extreme case, the stream flowing through Mahabaleshwar, a hill station in the northern Western Ghats and a probable type locality for *C. conicus*, is filled with sewage water, and efforts to locate from neighbouring town *C. conicus* was not successful¹⁷. The conservation of waterfalls along with the riparian habitat that maintains water flow during drier months is critical for the survival of *Cremnoconchus*.

Narrow endemic²⁶ as well as ecologically specialized species^{27,28} are highly vulnerable to habitat changes due to anthropogenic activities. *Cremnoconchus* has all the features that make it highly vulnerable to habitat modification. Nine out of 12 species are narrow endemics and occupy specialized habitats. The *Cremnoconchus* population is threatened by land-use changes taking place upstream of the falls, disturbance in the form of recreation, dumping, development and riparian forest loss which are common features in these habitats¹⁸. All four northern Western Ghats species have high population density with more than 20 individuals per m². These species are also experiencing high threats as most of the suitable habitats are in highly human-dominated landscape. Six out of 12 species are found within the protected area (PA), and the rest are seen outside. PA sites in India are well-managed and protected; however, some of the famous waterfalls experience anthropogenic pressure from tourists, and others are relatively safe.



Figure 2. *a*, Waterfalls in Mahabaleshwar, the type locality of *C. cingulatus*; *b*, Medium size waterfalls in Hulikal, Karnataka; *c*, Small roadside waterfalls in Mahabaleshwar. *d*, *C. syhadrensis*; *e*, *C. canaliculatus*; *f*, *C. dwarakii*. *g*, Aestivating population of *C. syhadrensis*; *h*, Dumping of garbage upstream of waterfalls in Mahabaleshwar.

The study presented here is an attempt of a comprehensive Red List assessment for any freshwater mollusc of India based on extensive field data unlike previous assessment. All three *Cremanoconchus* described from the northern Western Ghats have been assessed as threatened mostly based on secondary data. Given the low AOO and EOO, severe threats and occurrence in few localities for *C. cingulatus*, *C. dwarakii* and *Cremanoconchus* spAM from Amboli, we assess these three species as critically endangered. Even though *C. agumbensis*, *C. hanumani*, *C. globulus*, *C. castanea*, *Cremanoconchus* spKK from Kathlekan and *Cremanoconchus* spKO from Kollur have low EOO and AOO and are found in only one locality, these species should be treated as endangered because they are found in PAs that are not greatly affected by direct human activities. However, land-use change in the upper catchment area might influence populations downstream, and this needs further investigation.

Predominantly restricted to western slopes of the central and northern Western Ghats¹⁴, *Cremanoconchus* is an iconic component of the Indian freshwater biota. It is of global significance being the only freshwater genus of the near cosmopolitan otherwise exclusively marine, largely intertidal Littorinidae¹⁴. The waterfalls in the Western Ghats with highly specialist taxa such as *Cremanoconchus* face considerable conservation challenges. These unique

habitats are under tremendous pressure from human-mediated activities. A systematic conservation action plan needs to be developed which include restoration of riparian habitats surrounding the falls and restriction of anthropogenic activities not only in and around the waterfalls but also upstream. Habitat and catchment-based conservation approaches should be employed rather than a species-based approach. Long-term monitoring of the population trends and threats also needs to be studied.

Thus based on information available on the distribution, population status, specific habitat preference, threats and unique evolutionary history, there is strong reason to prioritize conservation efforts for these narrow range species and the habitat in which they occur.

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