International Journal of Ecology and Environmental Sciences
www.ecologyjournal.in
Online ISSN: 2664-7133
Received: 07-08-2026, Accepted: 06-09-2026, Published: 21-09-2026
Volume 8, Issue 3, 2026, Page No. 72-81

Spatio-temporal thermal patterns of western Himalayan River corridors and temperature-based habitat suitability for freshwater fishes

Ankit Singh[1], Suneet Naithani[1], Deepika Bhandari[1], Vibhuti[1], Yash Kumar Shah[2], Harshit Agarwal[2]
[1] School of Environment and Natural Resources, Doon University, Uttarakhand, India
[2] Urban Development Management Global South Center for Studies, Uttarakhand, India
DOI: https://doi.org/10.66856/ijees.2026.8.3.8073

Abstract
Mountain rivers of the Western Himalaya support freshwater biodiversity that is sensitive to thermal change, but spatially continuous observations are difficult to obtain across remote terrain. We used Landsat 8 thermal observations to characterize seasonal thermal conditions within selected river corridors in Uttarakhand, Himachal Pradesh, Jammu & Kashmir, and Ladakh during 2014-2024. Four perennial, glacier-fed rivers-Alaknanda, Beas, Chenab, and Indus-were delineated from SRTM-derived drainage networks, and a 50-m corridor was used as a consistent spatial unit for extracting satellite-derived land surface temperature (LST). We quantified seasonal and interannual thermal patterns and screened temperature-based habitat suitability for 10 freshwater fish species using published thermal ranges. Summer thermal conditions increased across the study regions, with the largest reported increases of approximately 2°C over the study period in Jammu & Kashmir, Himachal Pradesh, and Uttarakhand; Ladakh remained the coldest region. Temperature-based suitability declined for several cold-water species, including Schizothorax richardsonii, Salmo trutta, and Oncorhynchus mykiss, whereas some warm-water species showed stable or slightly increasing suitable area. Pixel-level linear trends were extrapolated to 2044 as a scenario representing continuation of the observed 2014-2024 trend. The results demonstrate the value of satellite thermal observations for screening spatial and temporal changes in river-corridor thermal conditions and identifying areas where freshwater fishes may experience increasing thermal pressure. Because the analysis uses LST within a river corridor rather than direct in-water temperature measurements, the results represent the thermal component of habitat suitability and should not be interpreted as a complete assessment of fish habitat.

Keywords: Landsat 8, thermal remote sensing, river corridors, land surface temperature, freshwater fish, thermal habitat

Introduction
Rivers of the Western Himalaya form important ecological connections between high-elevation headwaters and downstream valleys and support freshwater communities adapted to strong thermal gradients. Glacier- and snow-fed rivers provide cold environments for species such as Schizothorax richardsonii and other Himalayan fishes whose distributions are influenced by thermal conditions. River temperature affects oxygen availability, metabolic processes, nutrient cycling, and biological activity [1, 2]. Consequently, warming of river environments can alter the spatial availability of conditions suitable for cold-water fishes and may contribute to shifts in their distributions [4, 19].

Cold-water fishes can have relatively narrow thermal tolerance ranges, and temperatures outside suitable ranges can affect metabolism, growth, reproduction, and survival. Water temperature also influences oxygen solubility, nutrient cycling, and biological activity in streams [2]. These relationships are particularly important in Mountain Rivers where thermal conditions vary strongly with elevation and season. Elevation-dependent warming has been documented across mountain regions, including the Himalaya [5].

Long-term observations of river thermal conditions are difficult to obtain in remote mountain regions because monitoring infrastructure is spatially sparse. Thermal remote sensing provides a means of examining spatial patterns over large areas and through time. Landsat observations have been used to characterize riverine thermal environments, while previous studies have highlighted both the potential and the limitations of remotely sensed river temperature, particularly where river channels are narrower than the thermal pixel size or where adjacent land surfaces contribute to the measured signal [7, 8, 24]. In the present study, Landsat-derived LST extracted from standardized river corridors is used to characterize satellite-observed thermal conditions rather than as a direct measurement of in-water temperature.

The objectives of this study were to: (i) characterize seasonal and interannual patterns in Landsat-derived thermal conditions within selected Western Himalayan river corridors during 2014-2024; (ii) quantify spatial and temporal changes in these thermal conditions; (iii) assess temperature-based habitat suitability for selected freshwater fish species using published thermal tolerance ranges; and (iv) explore a trend-based 2044 scenario representing continuation of the recent thermal trend.

Materials and Methods
Study area: The study was conducted in four regions in the Western Himalayan Mountains: Uttarakhand, Himachal Pradesh, Jammu & Kashmir, and Ladakh. These regions are renowned worldwide for the diversity of river system and vulnerable glacial-fed hydrology. The chosen rivers represent the variation in the altitudinal belt (1,000 m to >3,500 m a.s.l.), climatic zone (temperate to sub-arctic), and topographic gradient, which makes them optimal for comparative thermal studies. Uttarakhand features the range of altitude from about 300 m to more than 7,000 m above the sea level and includes the sources of the Ganga and Yamuna rivers. According to the 2023 India State of Forest

Report (ISFR), the total area of forest cover in Uttarakhand is estimated at about 38,000 km² (71.05% of the total area). The total area of forest cover in Himachal Pradesh equals 37,948 km² (68.16% of the total area), while it is characterized by the major river systems: Satluj, Beas, Ravi, and Chenab. The forest cover in Jammu & Kashmir equals approximately 20,230 km² (19.95% of the total area); there are major river systems in Jammu & Kashmir: Jhelum, Chenab, Tawi, Lidder, and Sindh.

River selection: Through hydrological extraction techniques based on high-resolution DEM, rivers in the 3rd- and 4th-order were identified, representing mid to large streams essential for sustaining aquatic ecosystems. Four rivers have been chosen: Indus (Ladakh, 34.15°N, 77.58°E, 4th order), Beas (Himachal Pradesh, 31.81°N, 76.98°E, 3rd order), Alaknanda (Uttarakhand, 30.03°N, 78.28°E, 4th order), and Chenab (Jammu & Kashmir, 32.98°N, 75.53°E, 3rd order). All these selected rivers are fed by glaciers and are perennial. Therefore, they form the perfect candidates for conducting a thermal regime study of rivers under the impact of climate change.

River extraction and corridor delineation: River networks were delineated from SRTM-derived elevation data using sink filling, D8 flow direction, flow accumulation, stream thresholding, and Strahler stream ordering. Third- and fourth-order segments corresponding to the selected rivers were retained. A 50-m buffer on either side of each selected river segment was then generated as a consistent spatial unit for extracting the thermal observations through time. The buffer size was selected in relation to the spatial-resolution limitations of Landsat thermal observations and the river-temperature literature [9]. The resulting polygon represents a river corridor rather than the wetted channel itself; consequently, pixels may include water, exposed sediment, riparian vegetation, or adjacent land, particularly in narrow channels.

Satellite data and pre-processing: Landsat 8 Thermal Infrared Sensor (TIRS) Band 10 observations were used for 2014-2024. Cloud-free seasonal composites were generated for summer (May-June) and winter (December-January). Band 10 has an original spatial resolution of 100 m and was resampled to 30 m for spatial alignment with the analysis layers; resampling does not add spatial information beyond the original thermal measurement. Level-1 terrain-corrected data were obtained from USGS Earth Explorer. Cloud masking was performed in Google Earth Engine using the quality-assurance bands with a cloud threshold of less than 20%. Thermal rasters were reprojected to the appropriate UTM zone and clipped to the 50-m river-corridor polygons. Temperatures were converted from Kelvin to degrees Celsius.

Methods: Landsat-derived thermal condition estimation: A surface-temperature estimate was derived from TIRS Band 10 using the radiance, brightness-temperature, and emissivity-correction procedure described by Avdan and Jovanovska [10]. Digital numbers were converted to spectral radiance using the sensor scaling factors, and brightness temperature was calculated using the Landsat calibration constants

$K1 = 774.89\ W\ m^{-2}\ sr^{-1}\ \mu m^{-1}$ and $K2 = 1321.08\ K$.
An emissivity of 0.98 was used for water pixels,
While the NDVI-based expression $\varepsilon = 0.004 \times NDVI + 0.986$

Was applied to riparian or mixed pixels. The corrected surface temperature was calculated using the radiative-transfer formulation and converted to degrees Celsius. Because the analysis is based on a 50-m river corridor and the Landsat thermal measurement can integrate adjacent surfaces, the resulting variable is referred to as Landsat-derived thermal conditions or LST within the river corridor, rather than direct thermal conditions.

Fish species selection and temperature-based suitability: Ten freshwater fish species representing cold-, cool-, and warm-water thermal guilds were analysed using the species-specific temperature ranges listed in Table 1. Each analysis pixel was classified as thermally suitable (1) when the Landsat-derived temperature fell within the species-specific Tmin-Tmax interval and as thermally unsuitable (0) otherwise. Suitable area was calculated from the number of suitable 30-m pixels. This is a temperature-based screening of potential habitat conditions; it does not represent complete habitat suitability because flow, depth, substrate, oxygen, connectivity, biotic interactions, and other ecological factors were not modelled.

Table 1: Species-specific temperature ranges used for thermal-suitability classification

Scientific Name	Common Name	Temperature Range (°C)	Thermal Guild
Tor putitora	Golden Mahseer	5-25	Cool-water
Schizothorax richardsonii	Snow Trout	10-15	Cold-water
Schizothorax plagiostomus	Punjab Snow Trout	15-22	Cool-water
Neolissochilus hexagonolepis	Copper Mahseer	18-22	Cool-water
Salmo trutta	Brown Trout	12.77-18.33	Cold-water
Oncorhynchus mykiss	Rainbow Trout	14-18	Cold-water
Bagarius yarrelli	Goonch Catfish	16-23	Cool-water
Notopterus notopterus	Featherback	20-28	Warm-water
Clarias batrachus	Catfish	20-26	Warm-water
Amblypharyngodon mola	Mola Carplet	22.2-25.6	Warm-water

Trend analysis and 2044 scenario: Interannual trends were examined using linear regression of seasonal mean LST against year for 2014-2024. Pixel-level linear regression was also used to characterize the spatial pattern of recent thermal change. For the 2044 scenario, the 2024 LST was extrapolated using the fitted 2014-2024 slope: LST2044 =

LST2024 + (slope × 20). The 2044 results therefore represent a scenario in which the recent linear trend continues at the same rate; they are not climate-model projections and should not be interpreted as predictions under specified greenhouse-gas scenarios. Raster processing and spatial analyses were performed using the R packages terra, dplyr, sf, and ggplot2, with QGIS used for spatial visualization.

Occurrence-based evaluation: The 2024 temperature-based suitability maps were compared with independent species-occurrence information obtained from field survey efforts and the Global Biodiversity Information Facility (GBIF). Occurrence points were overlaid on the 2024 binary thermal-suitability layers, and the proportion of occurrence points falling within thermally suitable pixels was calculated. This provides an occurrence-based assessment of ecological consistency rather than a full validation of habitat suitability, because species occurrence is influenced by environmental and biological factors beyond temperature.

Results and Discussion

Seasonal and spatial thermal patterns: Landsat-derived thermal conditions within the river corridors showed warming tendencies across the four Western Himalayan regions during 2014-2024. Summer values were generally higher than winter values, and the magnitude of change varied geographically. Jammu & Kashmir summer LST increased from approximately 22°C in 2014 to 24°C in 2024, with a reported slope of about 0.2°C yr^{-1} ($p < 0.05$); winter values increased from approximately 4°C to 6°C. In Ladakh, summer LST increased from about 15°C to 17°C and winter LST from about −5°C to −3°C, although winter variability reduced the strength of the fitted trend. Himachal Pradesh summer LST increased from approximately 20°C to 22°C (slope about 0.2°C yr^{-1}; $p < 0.05$). Uttarakhand had the highest summer values among the four regions, increasing from approximately 24°C to 26°C ($p < 0.05$). These results describe changes in satellite-observed thermal conditions within the river corridors and should not be interpreted as direct measurements of in-water temperature.

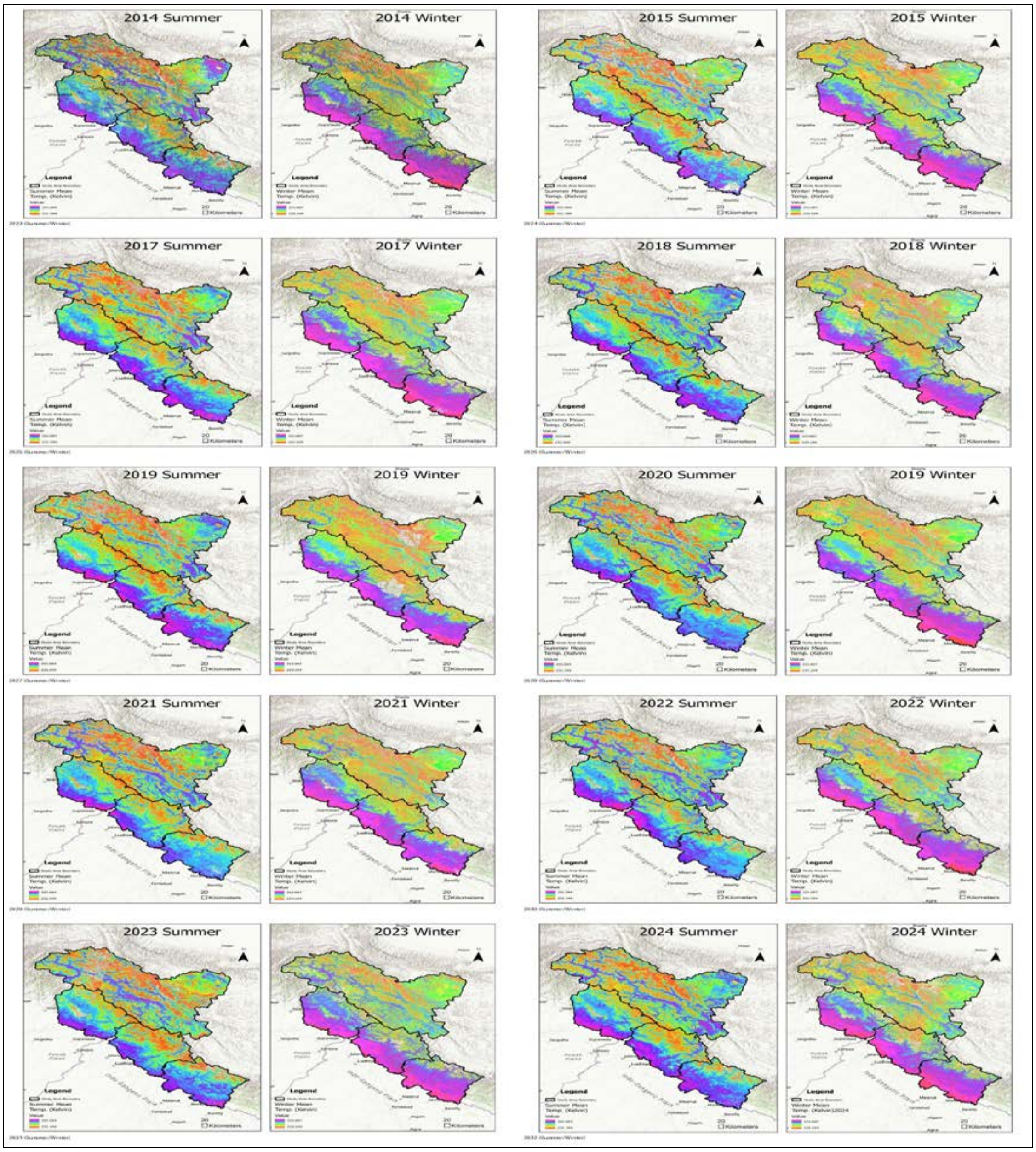

Fig 1: Landsat-derived land surface temperature (LST) for river buffer zones across all four Himalayan states from 2014 to 2024 (summer and winter seasonal maps).

Changes in temperature-based habitat suitability: The seasonally available LST dataset was used to quantify areas meeting the temperature ranges assigned to the 10 fish species from 2014 through 2024. The temporal patterns varied among species. Several cold-water species showed declines in temperature-based suitable area, whereas some warm-water species showed stable or slightly increasing suitable area. For example, Schizothorax richardsonii summer suitable area decreased from 84.05 km² in 2014 to 52.74 km² in 2024, with a low of 27.04 km² in 2022. Salmo trutta declined from 135.57 to 76.20 km², while Oncorhynchus mykiss declined from 101.90 to 56.55 km². Tor putitora and Neolissochilus hexagonolepis showed smaller and statistically weaker declines, whereas Amblypharyngodon mola and Notopterus notopterus showed slight positive tendencies that were not statistically significant ($p > 0.1$). These results indicate changes in temperature-based suitability rather than confirmed changes in species abundance or distribution.

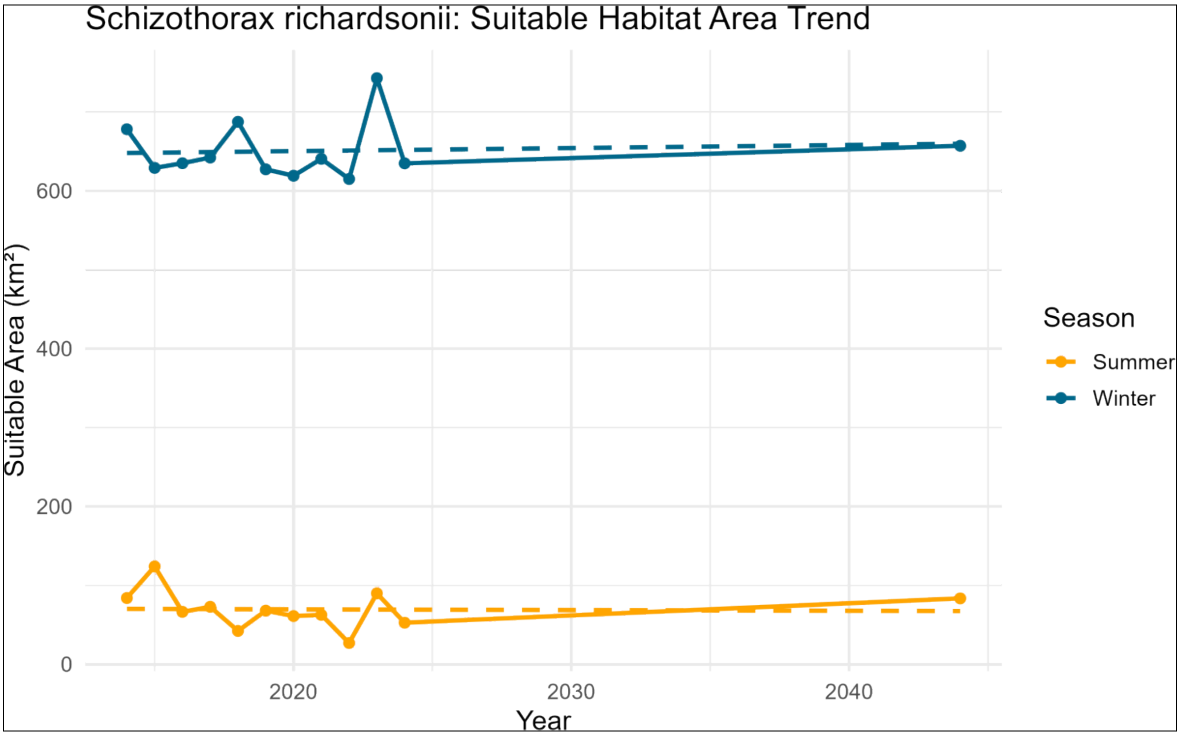

Fig 2: Suitable habitat area trend of Schizothorax richardsonii.

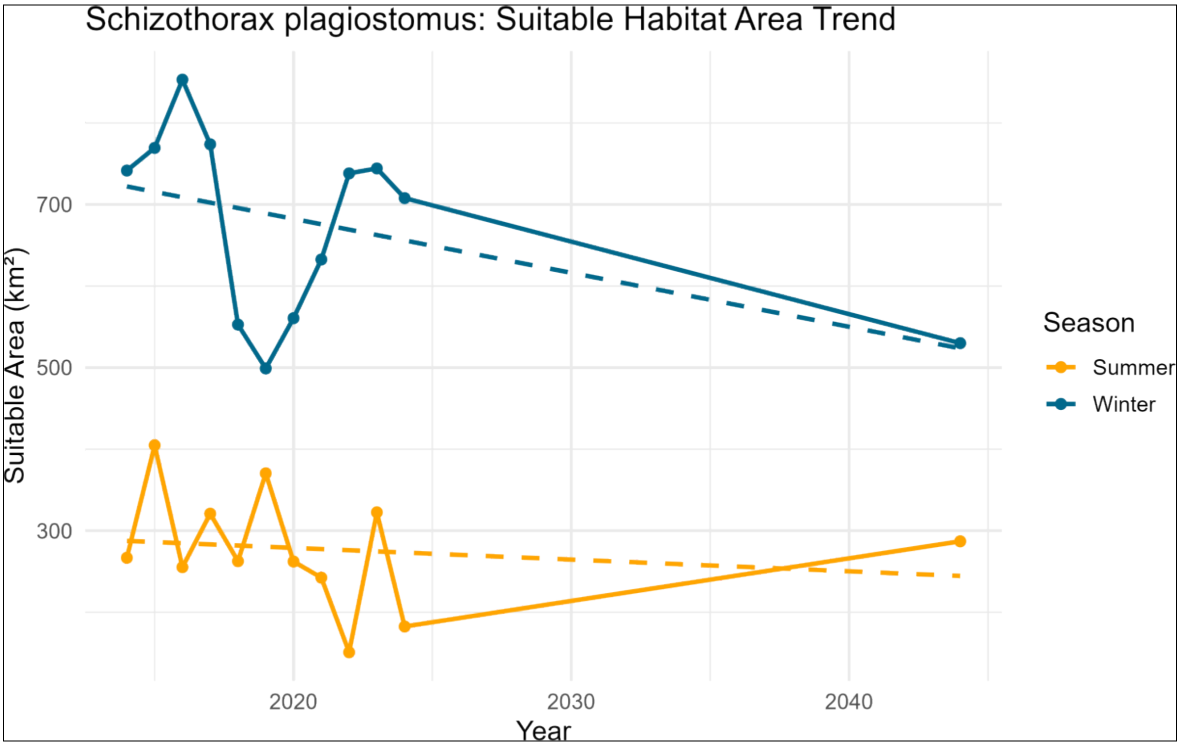

Fig 3: Suitable habitat area trend of Schizothorax plagiostomus

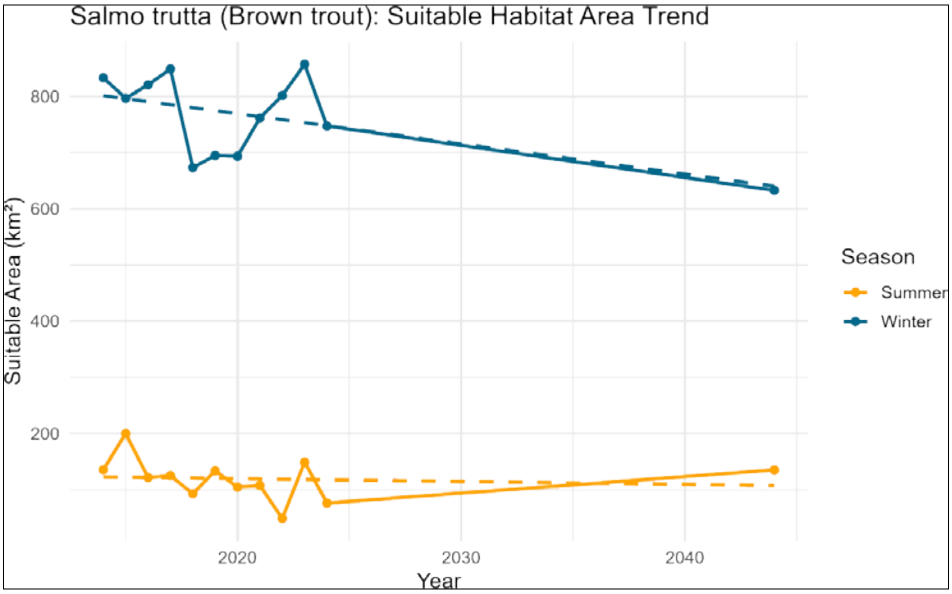

Fig 4: Suitable habitat area trend of Salmo trutta (Brown Trout).

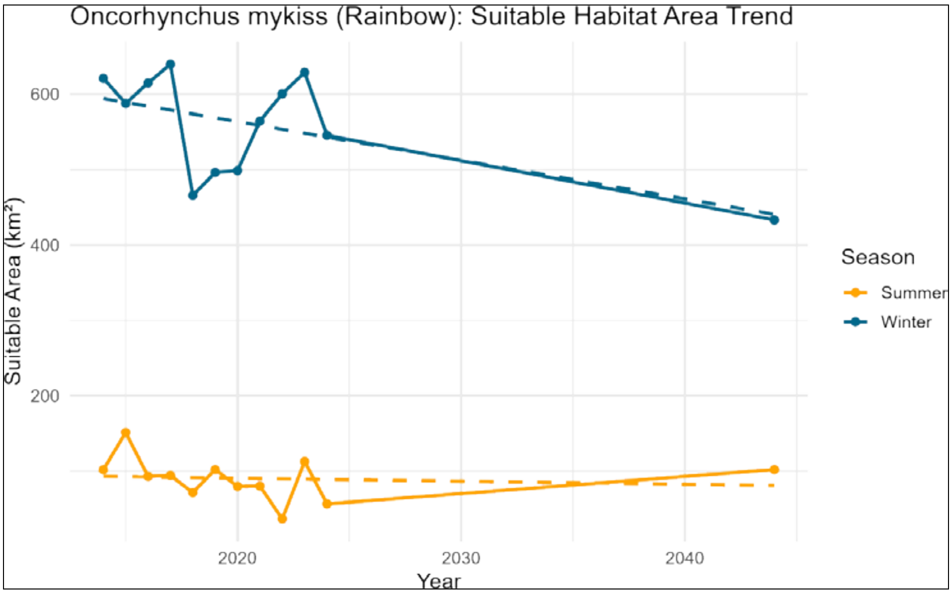

Fig 5: Suitable habitat area trend of Oncorhynchus mykiss (Rainbow Trout).

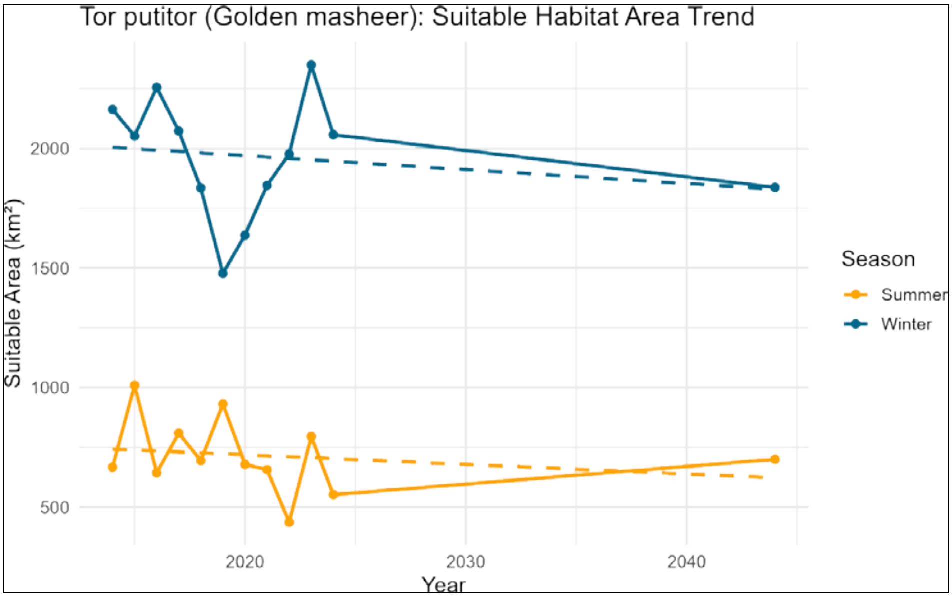

Fig 6: Suitable habitat area trend of Tor putitora (Golden Mahseer).

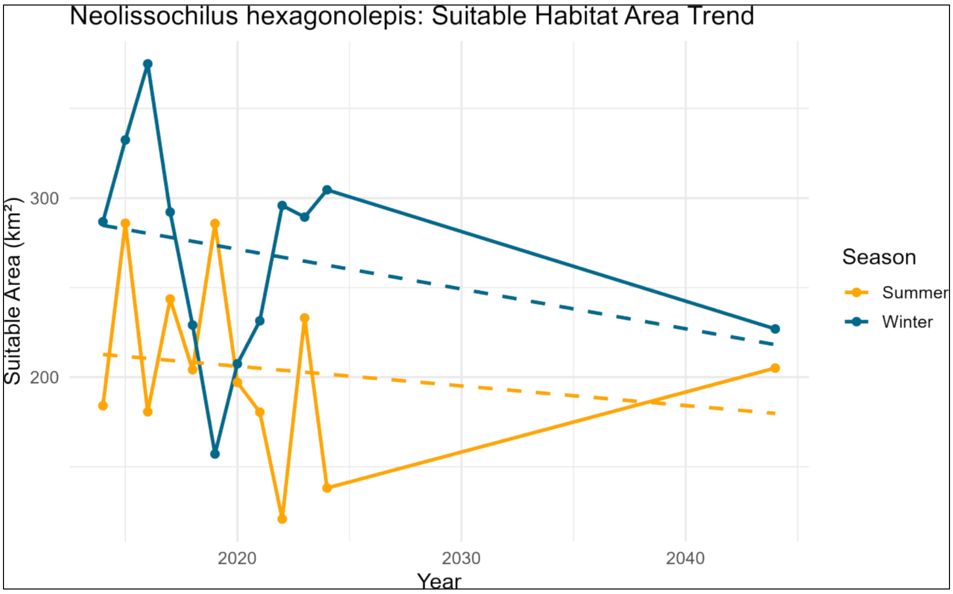

Fig 7: Suitable habitat area trend of Neolissochilus hexagonolepis.

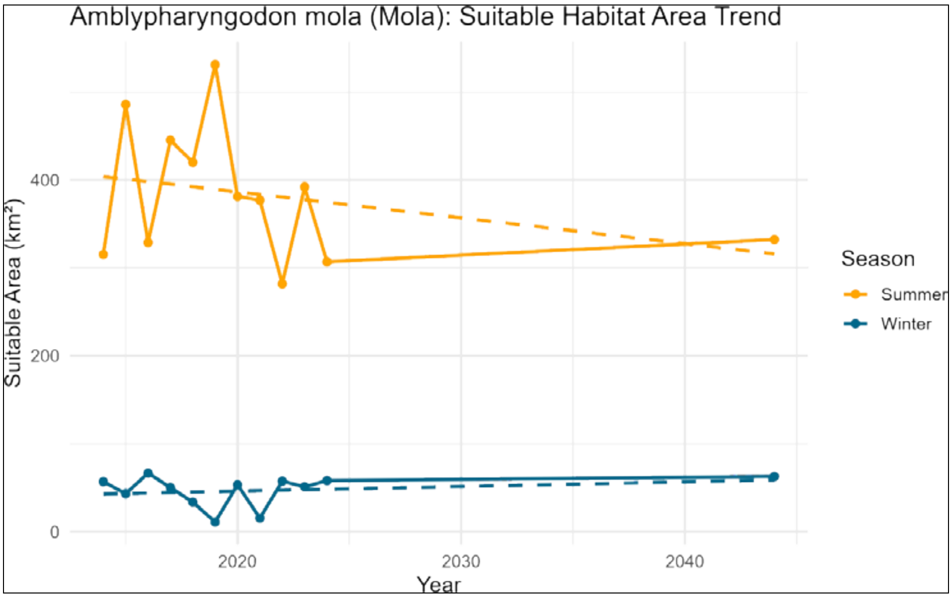

Fig 8: Suitable habitat area trend of Amblypharyngodon mola (Mola).

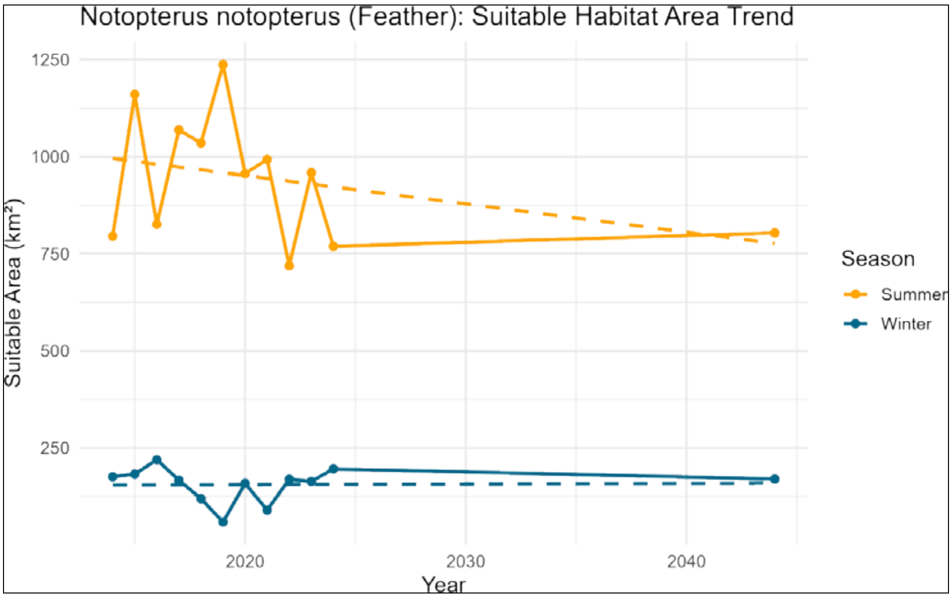

Fig 9: Suitable habitat area trend of Notopterus notopterus (Featherback).

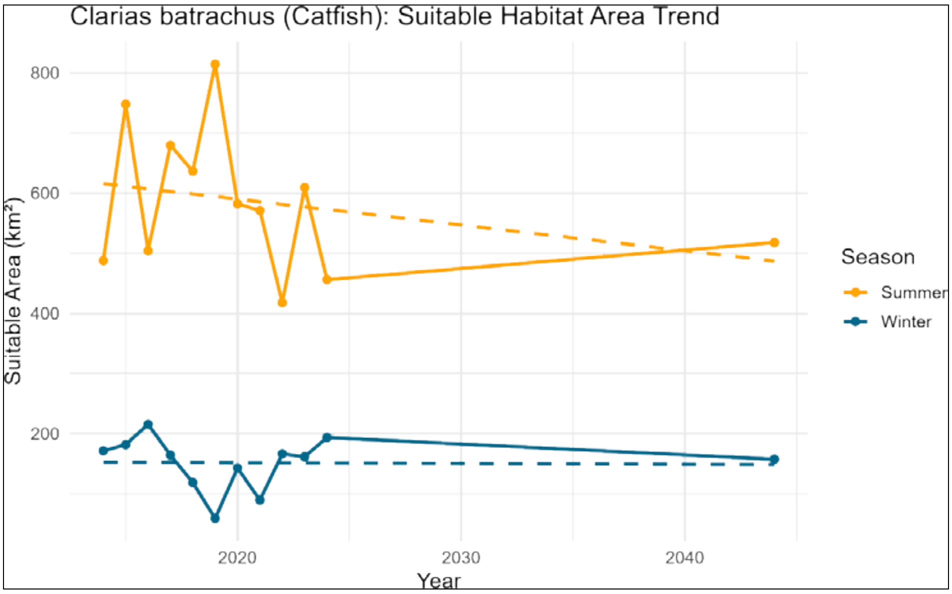

Fig 10: Suitable habitat area trend of Clarias batrachus (Catfish).

Table 2: Seasonal suitable habitat area (km²) for selected species, 2014-2044 (2044 = trend-based projection)

Year	*S. richardsonii Summer*	*S. richardsonii Winter*	*Tor putitora Summer*	*Tor putitora Winter*	*Amblypharyngodon mola Summer*	*Notopterus notopterus Summer*
2014	84.05	678.06	667.16	2163.79	315.29	795.26
2015	124.06	629.06	1009.62	2052.27	485.90	1160.65
2016	66.48	634.98	643.57	2255.84	328.87	825.77
2017	72.90	642.15	809.83	2073.11	445.34	1069.01
2018	42.37	687.43	694.58	1834.93	420.13	1035.36
2019	68.01	627.27	931.75	1477.61	531.24	1237.11
2020	61.17	619.07	679.01	1637.65	381.21	956.30
2021	62.67	640.53	656.60	1845.98	377.03	992.88
2022	27.04	614.99	436.58	1977.26	281.92	718.76
2023	89.94	742.78	795.65	2349.82	392.12	958.84
2024	52.74	634.83	552.21	2057.85	306.95	769.13
2044 (proj.)	83.59	657.07	700.01	1837.27	332.23	803.67

Seasonal contrasts: Summer showed a stronger and more spatially consistent warming tendency than winter. In lower-elevation Uttarakhand reaches, the reported summer increase over the decade was approximately 2°C compared with about 1°C in winter. The seasonal contrast is relevant because cold-water fishes are most likely to encounter temperatures near or above their upper tolerance during warmer months. Conversely, some warm-water fishes may retain or gain temperature-based suitability under warmer conditions. These patterns provide a remote-sensing indicator of thermal pressure rather than a complete ecological response.

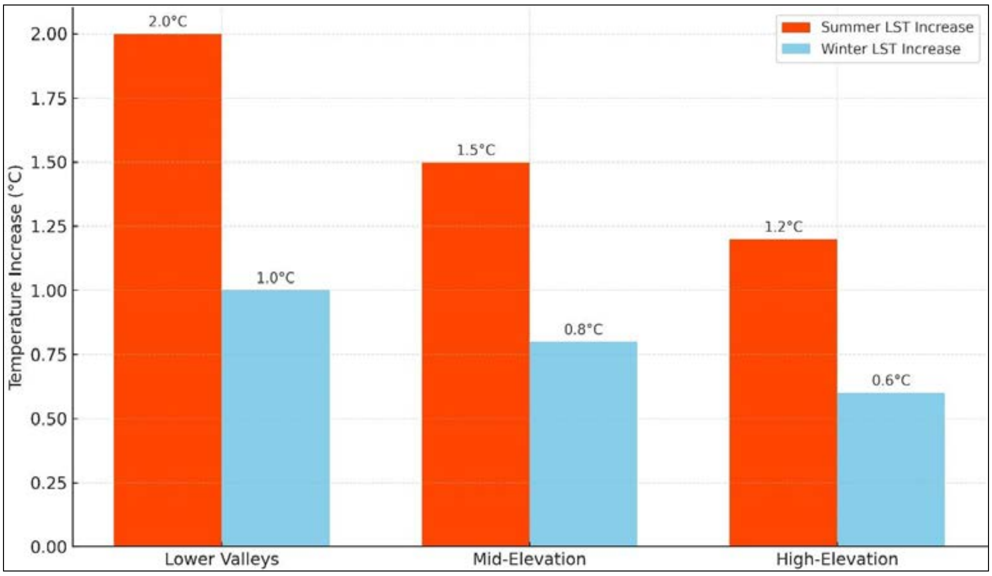

Fig 11: Comparison of summer and winter LST changes by elevation.

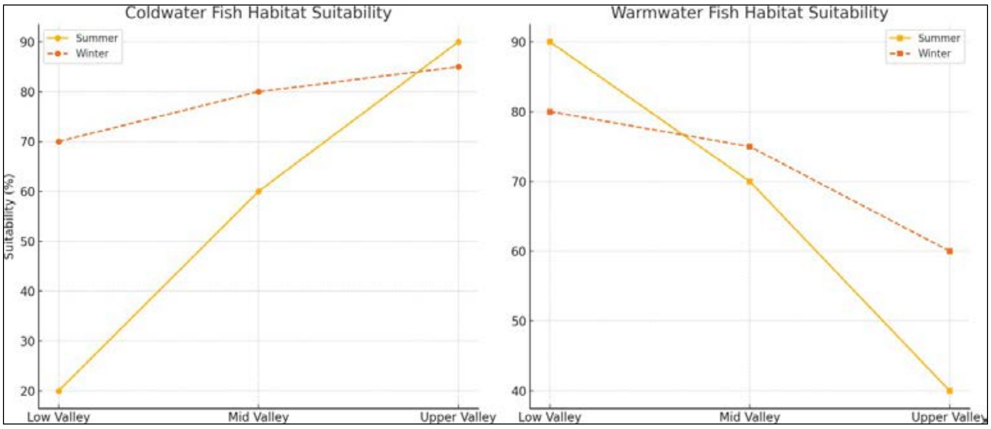

Fig 12: Comparison of cold-water and warm-water fish thermal suitability.

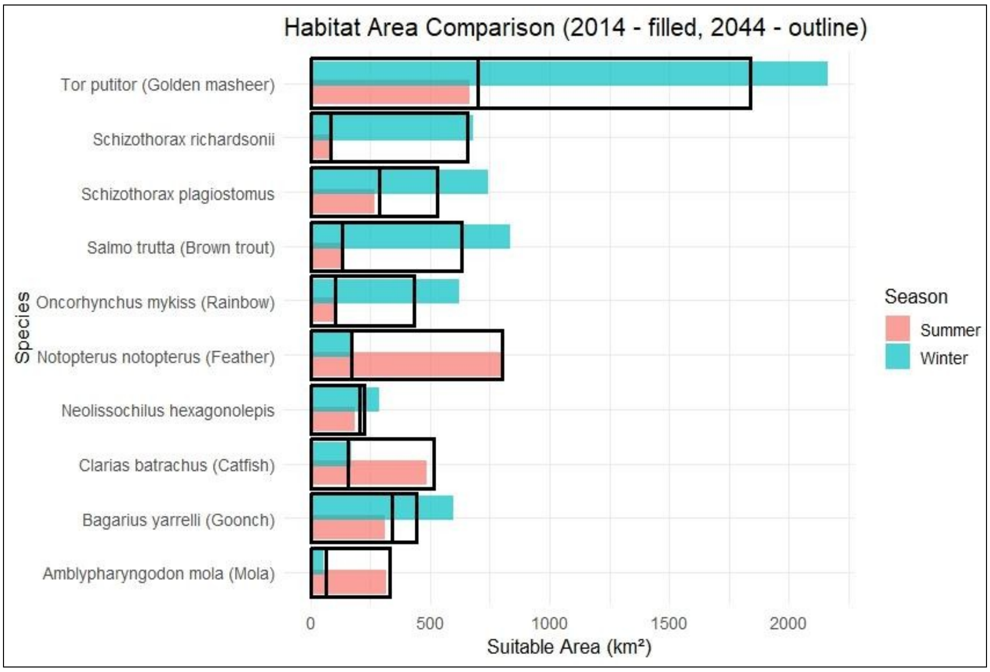

Fig 13: Habitat area comparison across selected fish species for 2014-2044.

Linear trend analysis: Linear regression was used to characterize the direction and magnitude of change in the 2014-2024 time series. Positive slopes were reported across the study regions, with summer slopes generally stronger than winter slopes. Pixel-level results showed a predominantly positive spatial pattern of thermal change. Because the observation period is limited to 11 years and seasonal variability is substantial, the fitted slopes should be interpreted as recent trends rather than long-term climate trajectories.

Trend-based 2044 scenario: The pixel-level 2014-2024 trends were extrapolated to 2044 using the linear relationship described in the Methods. The resulting scenario indicates warmer thermal conditions and associated changes in temperature-based suitability for the selected fish species. The scenario is conditional on continuation of the recent linear trend and is therefore not equivalent to a climate-model projection. It should be used to identify potential thermal-pressure hotspots for monitoring rather than as a prediction of future species distributions.

Ecological and conservation implications: The results illustrate how remotely sensed thermal conditions can provide a broad screening layer for freshwater conservation in data-sparse mountain environments. The decline in temperature-based suitability for several cold-water fishes is consistent with their sensitivity to thermal conditions [13, 14, 16, 19]. However, the maps should not be interpreted as evidence of population decline, extinction risk, or complete habitat loss. Their principal conservation value is to identify river reaches and species groups where targeted field monitoring and more detailed ecological assessment may be warranted.

Limitations and uncertainty: Four limitations are important when interpreting the results. First, Landsat-derived LST from a 50-m river corridor is not equivalent to direct in-water temperature; surface energy conditions, riparian vegetation, exposed sediment, channel width, shading, and groundwater inputs can cause differences between satellite-observed surface temperature and water temperature. Second, the 50-m corridor and 30-m resampled grid can contain mixed pixels, particularly along narrow channels. Third, the fish analysis represents only the thermal component of habitat suitability and does not include flow, depth, substrate, dissolved oxygen, food availability, connectivity, or biotic interactions. Fourth, the observation period is limited to 2014-2024; consequently, the 2044 results are trend-based scenarios rather than robust long-term forecasts.

Conclusion

The analysis demonstrates that Landsat-derived thermal observations can characterize seasonal and interannual thermal patterns within Western Himalayan river corridors and provide a spatial screening layer for freshwater ecological assessment. Across the selected regions, the analysis identified warming tendencies from 2014 to 2024, with stronger increases generally occurring during summer. Applying published species-specific temperature ranges indicated potential contraction of thermally suitable conditions for several cold-water fishes and relative persistence or expansion for some warm-water species. A linear 2044 scenario further illustrated how continuation of the recent trend could alter the spatial distribution of thermal conditions. The outputs should be interpreted as satellite-derived thermal conditions and temperature-based habitat indicators rather than direct water-temperature measurements or complete habitat-suitability models. Their principal application is to identify river reaches and species groups where increasing thermal pressure warrants targeted field monitoring and more detailed ecological assessment.

References

1. Allan JD, Castillo MM. Stream Ecology: Structure and Function of Running Waters. Springer, 2007.
2. Caissie D. The thermal regime of rivers: A review. Freshwater Biology,2006:51(8):1389-1406. https://doi.org/10.1111/j.1365-2427.2006.01597.x
3. Mohseni O, Stefan HG. Stream temperature/air temperature relationship: A physical interpretation. Journal of Hydrology,1999:218(3-4):128-141. https://doi.org/10.1016/S0022-1694(99)00034-7
4. Ruesch AS, *et al*. Projected climate-induced habitat loss for salmonids in the U.S. West. Ecological Applications,2012:22(4):1111-1131. https://doi.org/10.1890/11-0389.1
5. Pepin N, *et al*. Elevation-dependent warming in mountain regions of the world. Nature Climate Change. 2015:5:424-430.
6. Fenocchi A, *et al*. Applicability of a one-dimensional coupled ecological-hydrodynamic numerical model to future projections in a very deep large lake. Ecological Modelling, 2017.
7. Handcock RN, *et al*. Thermal infrared remote sensing of water temperature in riverine landscapes. Remote Sensing of Environment,2012:118:375-384. https://doi.org/10.1016/j.rse.2011.11.012
8. Dugdale SJ, *et al*. Remote sensing of riverine thermal environments: Current challenges and future prospects. Remote Sensing of Environment,2017:202:226-245. https://doi.org/10.1016/j.rse.2017.02.005
9. Liu X, *et al*. Buffer zone selection for riverine thermal conditions analysis. Hydrological Sciences Journal,2023:68(3):312-325.
10. Avdan U, Jovanovska G. Algorithm for Automated Mapping of Land Surface Temperature Using LANDSAT 8 Satellite Data. Journal of Sensors,2016:2016:1480307.
11. Jarahizadeh S, *et al*. Water surface temperature retrieval from Landsat data in mountainous regions. Environmental Monitoring and Assessment,2024:196:211.
12. Mehra R, *et al*. Modeling cold-water habitat loss in Himalayan headwaters under climate change. Ecological Indicators,2022:137:108707.
13. Ficke AD, Myrick CA, Hansen LJ. Potential impacts of global climate change on freshwater fisheries. Reviews in Fish Biology and Fisheries,2007:17:581-613.
14. Sharma A, *et al*. Himalaya in a Rapidly Changing World: Climate Change Impacts on Montane Freshwater Fauna. CRC Press, 2021. https://doi.org/10.1201/9781003220824-24
15. Sinha S, *et al*. Thermal variability in Himalayan rivers using MODIS data. Remote Sensing Letters,2020:11(6):520-529.
16. Gillette DP, *et al*. Thirty years of environmental change reduces local, but not regional, fish diversity in a Himalayan biodiversity hotspot. Biological Conservation,2022:266:109434. https://doi.org/10.1016/j.biocon.2021.109434
17. Webb BW, Hannah DM, Moore RD. Recent advances in stream and river temperature research. Hydrological Processes,2008:22(7):902-918. https://doi.org/10.1002/hyp.6994
18. Bhatt JP, Manish K, Pandit MK. Elevational gradients in fish diversity in the Himalaya: water discharge is the key driver. PLOS ONE,2012:7(9):46237.
19. Jackson ST, *et al*. Shifting cold-water fish habitats in the face of climate change. Ecological Applications,2018:28(6):1353-1368. https://doi.org/10.1002/eap.1755
20. Van Vliet MTH, *et al*. Global river discharge and water temperature under climate change. Global Environmental Change,2013:23(2):450-464. https://doi.org/10.1016/j.gloenvcha.2012.11.002
21. Gu RR, Stefan HG, Chen YD. Air-water temperature relations and impact of climate warming on stream temperature. Journal of Environmental Hydrology,1998:6(1):1-13.
22. Herb WR, Stefan HG. Heat transfer and equilibrium temperature in streams. Water Resources Research,2011:47(12). https://doi.org/10.1029/2010WR009678
23. Luo B, *et al*. Performance assessment of Sentinel-3 SLSTR SST retrievals using shipboard radiometry. Remote Sensing of Environment,2020:244:111826.
24. Ling F, *et al*. Mapping spatiotemporal variability of river temperature using Landsat and ground observations. Hydrology and Earth System Sciences,2017:21:2799-2815.
25. Toffolon M, Piccolroaz S. A hybrid model for river temperature forecasting under climate change scenarios. Water Resources Research,2015:51(4):2816-2830.
26. Mohanty B, *et al*. Modeling water temperature in snow-fed rivers under climate change: A case study from

Uttarakhand, India. Environmental Modelling & Software,2020:127:104683.
27. Mukherji A, *et al*. Sustaining Himalayan Water Resources in a Changing Climate. Environmental Science & Policy,2015:50:28-39.
28. Akhtar MS, Singh AK. Coldwater fish diversity of India and its sustainable development. Uttar Pradesh State Biodiversity Board, 2015.
29. Jamwal A, Phulia V, Mushtaq ST. Predictable Threats to Coldwater Fisheries. Taylor & Francis Group, 2023.
30. Pande A, Posti R. Impact of climate change in temperate fisheries of the Himalayas. Springer Nature, 2023.