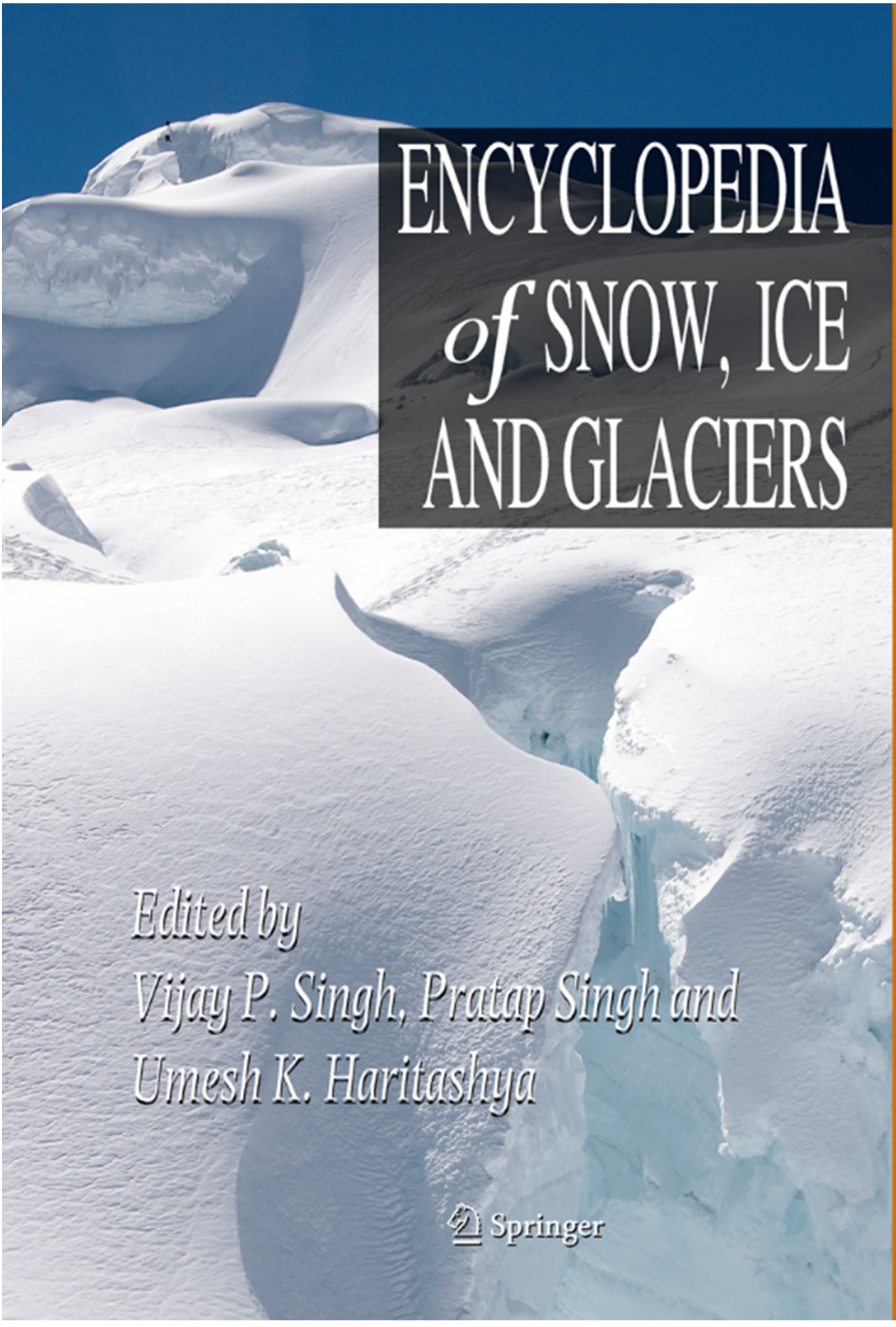

ENCYCLOPEDIA of EARTH SCIENCES SERIES

Encyclopedia of Earth Sciences Series

ENCYCLOPEDIA OF SNOW, ICE AND GLACIERS

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Professor Charles W. Finkl has edited and/or contributed to more than eight volumes in the Encyclopedia of Earth Sciences Series. For the past 25 years he has been the Executive Director of the Coastal Education & Research Foundation and Editor-in-Chief of the international *Journal of Coastal Research*. In addition to these duties, he is Research Professor at Florida Atlantic University in Boca Raton, Florida, USA. He is a graduate of the University of Western Australia (Perth) and previously worked for a wholly owned Australian subsidiary of the International Nickel Company of Canada (INCO). During his career, he acquired field experience in Australia; the Caribbean; South America; SW Pacific islands; southern Africa; Western Europe; and the Pacific Northwest, Midwest, and Southeast USA.

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Accumulation Zone: The part of a glacier that is perennially covered with snow, extending between equilibrium line/firn line and brugschund called accumulation zone of the glacier. This occurs through a variety of processes including precipitation, firnification, and wind transportation of snow into a glacier basin from an adjacent area.

Ablation zone: The area extended between the snout and equilibrium line altitudes or firn line is defined as glacier ablation zone. This is the area where ice and snow are lost through a variety of processes including melting and runoff, sublimation, evaporation, calving, and wind transportation of snow out of a glacier basin.

Terminus (snout) zone: The end edge beyond which there is no glacier and from where a stream emerges is called snout/terminus of a glacier. Snout of the glaciers exhibit varying shapes and characters, depending upon the size of glacier, nature of valley, bed rock slope, and of course, mass balance of the glacier.

GLACIER BIRD OF THE ANDES

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Definition

White-winged Diuca Finch (*Diuca speculifera*) is a bird species that uses glaciers in the High Andes for both roosting and nesting.

Many birds are well adapted to environments seasonally dominated by snow or sea ice, but excepting penguins, birds are not generally associated with glaciers. Even flying over mountain glaciers and ice caps can be hazardous to birds, subjecting them to low oxygen pressure, low temperatures, and harsh environmental conditions such as snowstorms; mortality has been documented from glaciers in Alaska, USA and Yukon Territory, Canada (Krajick, 2002), Greenland (Pfeffer W. T., 2009, personal communication), the Himalaya (Thompson L. G., 2007, personal communication), and on Kilimanjaro (Hardy D. R., 2008, unpublished data).

Conditions on glaciers are usually not well suited for nesting in particular, being cold, actively changing through accumulation and ablation, and at times wet. Until recently the ornithological literature contained only one detailed account of nesting on a glacier, the unusual circumstance where glaciers advancing into Alaska's Prince William Sound overran a Black-legged Kittiwake (*Rissa tridactyla*) colony (Irons, 1988). Previously used nest sites became unavailable and 77 kittiwake nests were constructed on the glacier face; all failed.

One bird species is exceptional, roosting at night within glaciers and perennially nesting on glaciers. This is the White-winged Diuca Finch (*Diuca speculifera* hereafter WWDF), found above 4,500 m elevation in the High Andes of Perú, western Bolivia, and northern Chile (Fjeldså and Krabbe, 1990). Their association with glaciers was first noted at Chacaltaya (5,200 m) near La Paz Bolivia, gathering for the night inside a crevasse (Niethammer, 1953), and Johnson (1967) provides a second-hand report – also from Chacaltaya – of the species nesting in a generalized "ice cave" at 5,300 m. Hardy and Hardy (2008) documented roosting and numerous glacier nests of WWDF in the Cordillera Vilcanota of southern Perú. Nests were found primarily on the near-vertical, retreating glacier margin of the Quelccaya Ice Cap, at elevations up to 5,300 m, over several consecutive years. Observed nests were both in situ on the ice and recently fallen. Supporting evidence, including WWDF eggs and feathers within glacier nests, remains on the ice of WWDF victimized by predation, as well as active WWDF in the area. Glacier nesting by WWDF occurs at Quelccaya Ice Cap despite subfreezing air temperature throughout the year, with extreme night-time radiational cooling whenever cloud cover is low. Furthermore, WWDF is among the highest-elevation nesting bird species of the Western Hemisphere.

Bibliography

Fjeldså, J., and Krabbe, N., 1990. *Birds of the High Andes*. Svendborg: Zoological Museum, University of Copenhagen, and Apollo Books.

Hardy, D. R., and Hardy, S. P., 2008. White-winged Diuca Finch (Diuca speculifera) Nesting on Quelccaya Ice Cap, Perú. *Wilson Journal of Ornithology*, **120**, 613–617, doi:10.1676/06-165.1.

Irons, D. B., 1988. Black-legged Kittiwakes nest on advancing glacier. *Wilson Bulletin*, **100**, 324–325.

Johnson, A. W., 1967. *The birds of Chile and adjacent regions of Argentina, Bolivia and Perú*. Buenos Aires: Platt Establecimientos Gráficos, Vol. 2.

Krajick, K., 2002. Melting glaciers release ancient relics. *Science*, **296**, 454–456.

Niethammer, G., 1953. Zur Vogelwelt Boliviens. *Bonner Zoologische Beiträge*, **4**, 195–303.

GLACIER CAVE

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Caves formed completely in ice are termed as glacier caves and are also very often called ice caves. Glacier caves almost always form from flowing water entering the glacier through cracks or crevasses, which are then enlarged over time, both by erosion and melting. Glacier caves serve as conduits for water through glaciers. Glacier caves are rarely extensive, and may come and go as glaciers recede. Glacier caves are very dynamic and change from year to year. Large glacier cave systems have disappeared as glaciers melt and retreat. The Paradise Glacier Cave system on Mt. Rainier was at one time several