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José M. García-Ruiz · José Arnáez ·
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Mountain Environments: Changes and Impacts

Natural Landscapes and Human
Adaptations to Diversity

 Springer

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Foreword

Complex, diverse and beautiful, mountain regions are among the most fascinating landscapes on Earth. Who hasn't felt awe-struck gazing from the bottom of a deep valley or overlooking a divide? Precipices, steep slopes, sharp inclines, canyon rivers, landslide flows, alluvial fans, avalanche channels, snow patches, glaciers, large rocky accumulations, delicate plants hidden away in sunny places sheltered from the worst frosts, immense forests, subalpine pastures generated by human deforestation and wild herbivores, animals seeking their last refuge at the head of narrow valleys, fields on unlikely slopes that were transformed by cultures leaving indelible traces behind, terraces of exceptional workmanship displaying the capacity of human societies to transform the slopes, meadows and orchards, all these can be found in mountains, a place where interactions between culture, nature and the need for survival meet.

Every good book can be defined as an open door to the imagination and as the resulting emotions conveyed by the authors. Each page contains years of experience and knowledge, also sensitivity and a desire to share what the author has learned. We are the embodiment of a succession of gained knowledge and emotions handed down from generation to generation, from Herodotus (and more especially from the first mountain dwellers, the hunters and gatherers) to the present day, including the great scholars of the mountains (Alexander von Humboldt, Louis Agassiz, Louis Ramond de Charbonnières, Jean Tricart, Jack D. Ives, Bruno Messerli, Hans Hurni, Martin J. Price, Eduardo Martínez de Pisón and so many others) from whom every one of us can learn something. They opened up almost impossible paths for us, asked questions that no one had asked until then and embarked on a journey of no return toward understanding mountain landscapes. Thanks to them we can now enjoy the book presented in this foreword: *Mountain environments: Changes and impacts*, by José M. García-Ruiz, José Arnáez, Teodoro Lasanta, Estela Nadal-Romero and Juan Ignacio López-Moreno. This book is the direct legacy of a long tradition of scientific books on mountains, a monumental compilation of accumulated knowledge as a gift for university professors, scientists, technicians, territorial planning managers, students and anyone interested in understanding how mountains function at different spatial and temporal scales. It is a necessary book, given the urgency of the answers

that today's society must give to the great social and environmental challenges posed by the changes affecting the world's mountains.

In this book, the reader will find a great deal of information on, and respect for, the mountains. Anyone might think that explaining what a mountain is in a few words is a simple matter, but this is not the case. The extreme variety of the Earth's landscapes and geological formations causes endless confusion. What are mountains? Sometimes they are defined by what they are not: platforms raised above the plain, deep canyons with steep drops and vertical escarpments, a succession of small isolated elevations. None of these are mountains. Something more is needed: high altitude, accompanied by steep slopes and widely contrasting topography, a variety of geomorphological processes and vegetation varying at different levels. The book shows us how the mountains became populated, how the first hunters entered unexplored landscapes that posed a danger at every step, how the first permanent settlers established themselves and began to transform the vegetation to their own advantage, leading to the first scientific approaches culminating in Alexander von Humboldt. From there, the reader will find exhaustive information on the characteristics of mountains, in particular on six aspects that are, in my opinion, key to interpreting why mountains are of planetary importance and affect not only ecosystems but also human populations:

- (i) The peculiar climate of mountains, including wind circulation, cooling with altitude, irregular increase in precipitation the higher up the slope, and topoclimates, which explain so many endemisms.
- (ii) Snow is transcendental in the phenology of plants and animals, in runoff generation, in the irregular way in which snow accumulates in the rugged topography of the mountains, and in its capacity to erode and transport sediment by means of avalanches. Glaciers also receive special attention for their influence on mountain and lowland ecosystems, emphasizing the evolution of ice masses from the beginning of the Holocene and especially during the Little Ice Age. It should not be forgotten that in the last two million years there have been 40 cold cycles alternating with warm periods, which have left numerous traces in the relief, especially during the Last Glacial Cycle.
- (iii) The altitudinal organization of vegetation belts, resulting from the climate changing in the ascent from the base to the summits. This organization is particularly evident in the transition between the subalpine and alpine belts, which is the critical frontier established in the great mountain ranges between the forest and the world of high mountain pastures, so transcendental from many points of view. The authors also present the characteristics that best define mountain vegetation, highlighting the ecophysiological adaptations, and the functioning of many mountains as biogeographic islands.
- (iv) Mountain hydrology involves the development of highly seasonal fluvial regimes and conditions the management of reservoirs, sediment transfer and fluvial morphology, as a synthesis of the geomorphological processes found in mountains and the relationships between erosion and connectivity among slopes and channels.

- (v) The spatial organization of landforms and, especially, of geomorphological processes. This chapter is of great interest because it analyzes mountain geomorphology as a set of cascading processes interrelating various morphoclimatic levels.
- (vi) The ways of life in the mountains are studied as the result of a long history of human occupation, different cultures leaving traces in the shape of cultivated fields which partly condition current human activities. The types of fields, variety of crops, the tendency to abandon agriculture and the importance of transterminant and transhumant movements are examined. The authors are aware that from a human point of view, the mountains form a global entity in which nothing is independent of the rest: The mountains are thus perceived by their inhabitants as a territory offering a great variety of opportunities throughout the year, with certain places coming into productivity before others. In addition, transhumant movements have made it possible to draw energy from the lowlands surrounding the mountains and reinforced the strong social organization that characterizes mountain villages.

Two final chapters underline the scientific and emotional value of this book: on the one hand, Global Change, linked not only to the warming trend but also, and perhaps more important, to the changes introduced by human societies in land use. Global Change shows us changing mountains, with shifting vegetation, reduction in runoff generation and sediment yield, alterations in river dynamics, and a dramatic retreat of most glaciers, general abandonment of farmland in the mountains of developed countries, changing at a slower pace in the mountains of developing countries. Everything is changing in the mountains, and this change, perfectly explained in this book, affects not only the mountains themselves, but also the planet as a whole: There are alterations in river regimes and in the availability of water resources; and there is also a loss of biodiversity which can be tackled through land management systems that take into account the global functioning of mountains.

The book culminates with a chapter that should be a future reference for mountain development: an integrative look at mountain landscapes and societies, an approach that shows the authors' admiration for mountains and their belief that they hold many of the solutions that will need to be applied to the Earth as a whole in the future. We scientists who love and admire mountains needed a chapter that explains why mountains are so important for the good ecological health of the Earth, why they are so special. And we are comforted by the knowledge that the authors' proposal is to maintain a living mountain, a mountain in which human beings live fully adapted to the huge diversity of mountain regions and their many limitations; mountain landscapes, those that are the heritage of many generations following the Neolithic, need the presence of humans capable of maintaining landscapes that are a lesson in work and balance for all of us, and that the relationship between livestock, agriculture and other activities respectful of diversity is essential for the conservation of the territory.

These final chapters are the culmination of a book in which all the information provided is closely related: The study of snow cannot be separated from that of vegetation, rivers or geomorphological processes, just as human activities are

linked to topographic diversity and the altitudinal organization of temperatures and precipitation. We can only learn from the mountains if we are able to integrate very different, extremely varied information and to achieve an essential global vision that promotes respect for fauna and flora, the generation of runoff, and the conservation of singular landscapes, which have become monuments to the history of mankind. A gigantic task for geographers and ecologists, with the collaboration of other specialists (foresters, paleoenvironmentalists, geologists, historians). It is not by chance that the authors of this book are geographers, with long experience in the scientific research of mountains from very different points of view. They are a team of recognized international prestige that has worked on snow, glaciers, soil erosion, sediment transport, fluvial dynamics, land-use changes and land management. In addition, they have a dynamic approach to changes in mountain regions seeing them as a set of intertwined processes.

Special reference must be made to the scientific literature and photographs. The large number of bibliographical references explains the high informative load of the book. There is a respect for ancient authors, who are especially referred to in the study of mountains, and there is admiration for more recent works, which are an example of the current level of sophistication in the research. There has been, therefore, an effort to consider classic ideas that are still essential while keeping up to date with the most recent scientific advances. Regarding the photographs, it is sufficient to point out that rarely does a scientific book bring together the quantity and quality of images on relief, vegetation and land use in mountain areas, with representation from a large part of the world's mountains. The photos are also accompanied by detailed comments to help the reader interpret not only the image but also the content of the book. A hospitable book that opens its doors to everyone interested in finding out and understanding what mountains are and why we need them so much.

December 2023

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Preface

I have asked the people with whom I have the honor of sharing the authorship of this book to allow me to write the preface to express what it means to me so many years of study of mountain areas, trying to understand their complexity and how they work, albeit in a simple way. I also want to comment on how we have evolved in our approach to mountains and who have been our best accomplices in this adventure.

I have learned a lot from the mountains and from other fellow geographers, geologists, biologists and historians, and at the same time I ignore almost everything. It is well known that when you are over 70 years old, everything is doubts (many more than certainties), proof that the passage of time has taught us to ask ourselves questions and to be aware that we have few answers. Perhaps that is why I encouraged myself and José Arnáez, Estela Nadal-Romero, Teodoro Lasanta and Juan Ignacio López-Moreno to start this book. Mountains are a distant planet that you can approach to ask about so much beauty and complexity, about the impressive slopes, about the intriguing mark left by human societies over millennia in a context of extreme topographic, geological, climatic and hydromorphological heterogeneity.

My relationship with geography goes back to my childhood, under the influence of a young teacher. I then spent hours and hours looking at maps, discovering continents and countries, rivers and tributaries, the layout of mountains and the presence of large plains and valleys. I imagined the mountains from the descriptions I found in encyclopedias or in the Jules Verne novels that accompanied my summer afternoons.

How necessary geography teachers are in our early ages, our dark ages, who should help us to be part of a very complex world that we yearn to interpret in order to integrate into society and nature. That integration is purely geographical (or should be substantially geographical), both from a social and an environmental point of view. But the prevailing curricula deny this possibility to our young people, perhaps with the complicity of the geographers themselves. Andrés Trapiello, in his prologue to the magnificent book by Jorge Bustos (*Asombro y desencanto*), suggests that “before learning to write or paint or to walk around the city or the place where we live, we should be taught to look” (Trapiello, 2021, p. VII). Little more can be added to this sentence by a geographer: perhaps looking in search of astonishment “is the first condition of knowledge” (Bustos, 2021, p. 5). We are not geographers

because we have a university education and a degree. We are geographers because at a certain moment we learned to look at the world at different scales in a different, integrative way, looking for relationships, processes and structures, trying to explain a visible landscape or one that we imagine in our minds, like invisible landscapes that we construct through complex mental processes that are just waiting to be grasped.

To return to the point I was making. Mountains were far away until I began my studies in geography. There I discovered the importance of the verticality of the Earth's surface, the presence of different cultures, the efforts to cultivate small plots of land, the imprint of livestock farming activities, risks of erosion, transport of coarse materials by rivers and landforms modeled under very different climatic conditions. I especially remember the classes given by Profs. Salvador Mensua and María Jesús Ibáñez and, in geography of Spain, those given by Antonio Higuera on the formation, structure and relief of the Spanish mountains, confirming that he was a much better teacher of physical geography than of human geography. Also, those of Luisa María Frutos and Vicente Bielza. Then, in July 1971, I joined the Institute of Pyrenean Studies, one of the two research centers that the CSIC had in Jaca, in the heart of the southern Pyrenees. There I did my Ph.D. on *Modos de vida y niveles de renta en el Prepirineo del Alto Aragón Occidental*, when I believed in human geography, a good apprenticeship for a still novice geographer who saw more than he interpreted and who interpreted more than he could explain.

I was fortunate. The Director of the Institute of Pyrenean Studies, Prof. Enrique Balcells, trusted me from the beginning, perhaps more than my knowledge and learning ability would have suggested. From him I listened to his almost inextricable advice and that of other colleagues, especially Dr. Pedro Montserrat, always attentive, ready to tell me everything he knew about vegetation and soil conservation, about mountain agro-biosystems and the effects of extensive livestock farming on the evolution of the landscape. They were wise men, among the last wise men I have ever met, always willing to tell me their latest ideas, to share their passion for the mountains (and their inhabitants) and for their global vision of all the environmental problems in which human activity takes place. I have always appreciated very much what these people did for me, so generous, so altruistic, so open-minded and different from what I was used to. At that time, on my many trips to the city of Huesca to gather information for my Ph.D., I met a surprising person, someone who leaves an indelible mark: Aurelio Biarge was, besides being a Magistrate of the Audiencia, secretary of the Chamber of Commerce and Industry of the Province of Huesca, and one of the greatest people who have influenced my life for his wisdom and generosity, for his affable character and his detailed knowledge of Pyrenean society, economy and landscapes. He was an inexhaustible source of ideas that he was always renewing because of his infinite curiosity. I wasted a lot of his time with my visits, but he was always kind to me. Always. He died recently, in January 2021, and the news still pains me.

After my Ph.D. defense, I joined the University College of La Rioja as a teacher, but I maintained a close relationship with some of my former colleagues in Jaca, especially with Juan Puigdefábregas, an exceptional ecologist. On one of my trips, I told him my point of view about the geocological importance of reforestation,

the need to understand the variable evolution of artificial forests and their influence on geomorphological processes, soil erosion, infiltration and runoff generation. We designed a fieldwork program that included outings every weekend, whatever the weather. It was a paradigm shift for both of us, the assumption that we could work on dynamic aspects of mountain areas, delve into the way in which very different aspects are integrated and contribute to understanding the way in which water flows down the slopes and redistributes fertility, the way in which vegetation takes advantage of this diversity to organize itself, and the astonishment of humans when faced by so much richness. We then moved on to the deforestation of the subalpine belt and its effects on erosion in general and shallow landslides in particular; and also the effects of land-use changes on erosion and hydrology at different spatial scales and on river dynamics. All this between 1977 and 1987, at a highly productive time when we benefited from the science and information provided by other scientists from Germany, the UK, the USA, Israel, Italy, with whom we coincided in different commissions of the International Geographical Union. I remember well those field trips, the discussions with Juan Puigdefábregas to interpret what we saw, the ideas that arose like sunbursts in a storm leading to new projects to tackle, and the incorporation of methods that we sensed were improving all the time.

In 1984, the union of the two CSIC research centers in Jaca was renamed the Pyrenean Institute of Ecology (IPE-CSIC), a name that is still used today, and in February 1987, I joined that institution definitively. Juan Puigdefábregas and I believed that those moments of absolute freedom for scientific creation that we had enjoyed until then could continue indefinitely. But it was not possible. A year later, Juan Puigdefábregas moved to the Experimental Station of Arid Zones in Almería (EEZA-CSIC) and I was left in charge of an incipient group of young scientists and lines of work that were then novel, which were at the frontier of research in geomorphology, environmental hydrology and geoecology.

Geography has always been a frontier science, developed by people bordering on irrationality, outlaws who appropriate foreign methods to build their own paradigms in contact with other sciences. We are geographers because we are free to interpret in an integrative way the relationships established in nature and in human societies, and particularly the relationships between social and environmental changes. We are the main observers of these changes and their impacts, on the margins of scientific correctness, acting as explorers of territories that seem familiar but that always allow for a different view. We never see the same mountain, the same river, the same city, we advance through territories that put our fragile knowledge at risk, we are like the pre-Neolithic groups of hunters and gatherers, like the first farmers and herders, like the pioneers whose survival depended on their ability to interpret the (natural and human) environment in which they moved. We are the first inhabitants of regions that have been populated for thousands of years, in search of an almost impossible synthesis.

With this point of view, several doctoral theses were written at the University of La Rioja and at the IPE, taking small steps that seemed big to us despite many difficulties. We have been in the new headquarters that the IPE opened in Zaragoza since

1991, and this has given us the opportunity to attract new profiles of young scientists, and open new lines of research to broaden our temporal and spatial perspective. An experimental station was created in the Aísa Valley (Central Spanish Pyrenees) and four new experimental basins were monitored, which joined the one installed in 1986 by Juan Puigdefábregas in Izas (Upper Valley of the Gállego river), we measured everything we could and increased our interpretation capacity. Those were good times, I would almost go so far as to say brilliant times, with high productivity, focused on the publication of results in international journals. We were recognized as a very dynamic, different group, which in any of its work contributed something new to the knowledge of the mountains and also increasingly incorporated human activities to give a greater globality to our proposals and conclusions. We avoided routine and opened new doors in areas in which we felt comfortable: the management of water resources and reservoirs, the spatial organization of geomorphic processes and erosion modeling, the interpretation of droughts in broad temporal contexts, the identification of paleoenvironmental patterns to explain the current landscape, the dynamics of abandoned lands in a context of vegetation regeneration, the functioning of gully areas or the hydromorphological function of forests. More PhDs and positions were filled by young scientists who, fortunately, left me far behind, while they became part of the world's scientific elite. Those, some physical geographers and environmental geologists.

In recent years I have gone, at least partially, on other paths, but always in the mountains. I cannot easily explain why I have always been interested in glaciers. I have devoted quite a few publications to them in a learning process inspired by Carlos Martí, with whom I shared so many field trips and so many exhausting efforts, by David Palacios and by the "paleo group" of the IPE, with their constant palynological and paleolimnological contributions. Finally, I have become interested in the landscape changes in the mountains and in the factors, especially anthropogenic ones, that explain them. The whole mountain has attracted me, but more so the subalpine belt, that subalpine belt on which I worked with Juan Puigdefábregas, which takes me back to my younger years, to the discoveries, to the moments when we used to pour out our ideas in front of unforgettable landscapes before which we felt overwhelmed; the subalpine belt that was partially deforested from very early on in order to facilitate summer grazing and which, from the Middle Ages onward, saw almost all the woodland disappear as a result of the great expansion of transhumance, unleashing a series of hydrological and geomorphological processes that we have described in several publications. If today I were to take stock of what has satisfied me the most among my scientific work, I would say that the articles on transhumance, landslides on the subalpine belt and major landscape changes in the Pyrenees are the ones that overcome my resistance to believing that I have done something interesting. I consider myself, therefore, a lucky person.

Yes, I have been fortunate, because I have done what I liked best, what made me feel more comfortable and excited about the work plans and their results, and also because I have been accompanied by exceptional people who have made me grow and understand, share and transmit what freedom of choice means in the face of bureaucracy, the greatest enemy of scientific research and of any university project. I

cannot forget the aforementioned Enrique Balcells and Pedro Montserrat, who have been a personal reference point, and Juan Puigdefábregas, the friend who opened so many doors for me and whom I lost not long ago, José Luis Rubio de Francia, the great mathematician with whom I shared a youthful desk at the school and so many hours of rock music and who died so early, Vicente Bernat Claramunt and our university hours in Zaragoza, when we believed that everything was possible, Aurelio Biarge and his brother Fernando, examples of good people in the best sense of the word “good”, Mateo Gutiérrez Elorza, a bold and innovative teacher, generous like few others, Artemi Cerdà, the real “*wild geographer*”, to whom I owe so much for his example of tireless and brilliant worker, and also Francisco Gutiérrez, José Luis Peña, María Asunción Romero, David Palacios, Enrique Serrano, Francisco López Bermúdez, José María Redondo, Javier Santos González, Manuel Seeger and, of course, the great Eduardo Martínez de Pisón, Jack D. Ives and Bruno Messerli, the real men of the mountains. And two of the great Spanish human geographers: Fernando Manero and Manuel Valenzuela, with whom I have coincided on a few occasions, too few, just enough to confirm that we are not always alone.

I have left for the end the people who have shared a large part of my scientific activity, who were able to believe almost blindly in this adventure in which we embarked collectively since 1974, an adventure unimaginable at the beginning, which has led us to let our imagination fly without limits: Luis Ortigosa Izquierdo (whom we suddenly lost very few years ago), Purificación Ruiz Flaño, Amelia Gómez Villar, Santiago Beguería Portugués, Sergio Vicente Serrano, Noemí Lana-Renault, María Pilar Serrano, Penélope González Sampériz, Ana Moreno, Blas Valero Garcés, Luis Carlos Alatorre, Carlos Martí and those who sign this book with me, José Arnáez, Teodoro Lasanta, Estela Nadal-Romero and Juan Ignacio López-Moreno, who have made a decisive contribution to sustaining my latest scientific concerns in what is my last voyage. With all of them I have a priceless debt, because true friendship is priceless, like all the important things in life.

I once wrote that life is a poisoned gift that includes many irreparable losses and too many frustrations. In the midst of the storms, I have always had Mari Carmen and my children by my side, to whom I have now added my grandchildren. This book is dedicated to all of them for so many things that, I hope, my memory will allow me to continue remembering.

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Chapter 1

Introduction



Almost everyone has a close connection with the mountains. Wherever you live. Mountains influence everything that happens on the Earth's surface; they guide the flow of humid air, create drying situations on the leeward side and condition the distribution of rainfall, influence the seasonal regime of river flow, generate large watercourses, provide resources of all kinds, contribute to the creation of cultures and the discriminate exploitation of the territory, have served (and still serve) as a refuge for some human societies, but also for plant and animal species, and are the origin of many foods that have been fundamental in the history of mankind. The mountains show us the great complexity of the Earth's landscapes, from tropical rainforests or Mediterranean environments to polar areas and the world of ice by simply ascending their slopes on a short journey from the base to the summit, which is like moving towards the poles.

It is in the mountains, as well as in the sea or in semi-arid environments, that we discover our many limitations. The moment we become aware of the power of nature, of our individual insignificance and of our strength as a society, then we can say that we have matured, a process that opens horizons we would not have discovered without traveling or reading. We have conquered everything on our planet. Where would we be without the first adventurers, those who dared to climb the slopes of a mountain, to reach the limits of our biological capacities, to the point of exhaustion? Where, without those who threw wooden rafts into the sea, which then represented infinity, to reach the distant coastline that could be glimpsed through the haze? Where without those who ventured into hostile lands, with the uncertainty of the lack of water, the scarcity of food? What would have become of humanity without the curiosity for the most distant and the most difficult, or if climatic changes or hostilities had not forced some groups to go far away, to open roads to unknown areas? We are the heritage of adventurers without a homeland, of people bordering on madness or simply unaware, of groups forced to risk everything, what they had and what they could have. Sometimes we imagine human groups or individuals, on the edge of marginality, going deeper and deeper into the forest, further and



Fig. 1.1 Glaciers have been (and still are in many cases) decisive in explaining the evolution of landforms in many of the Earth's mountains. At the same time, they have been a source of mystery because of their movement, the noises generated by seracs, the falling ice blocks in a landscape dominated by huge precipices. Today, glaciers still captivate visitors to the mountains and remain the focus of much scientific research. Mont Blanc massif, Western Alps (France), Aiguille de Chardonnet (3824 m) and du Tour glacier. *Photo Enrique Serrano*

further away, accessing the rocky areas of the high mountains, treading the snow and sometimes even dying on the edge of the ice, where human life is no longer possible in a reasonable way, like that Ötzi Man, more than 5200 years ago, forced to go into the Alps between present-day Italy and Austria, where only the assumption of risks could guarantee survival (Fig. 1.1).

What was the discovery of the mountains like? What were the feelings of the human groups who entered territories that were increasingly difficult to control, more diverse, no doubt more dangerous? How did they interpret the colossal landscapes they contemplated from a rocky outcrop, from the edge of a glacial shoulder that allowed them to look out over the great vertical escarpments? What made them decide to penetrate a narrow, winding, dark river canyon, full of threats and dangers, not knowing whether other human groups had preceded them?

We think we know everything about mountains, but they still hold great mysteries. They hide almost everything from us: when and how they were populated, how their first inhabitants perceived the enormous diversity of the mountains; how they adapted to their great limitations with only the strength of their arms and poor tools, but with strong social cohesion, and a great ability to interpret nature that was transmitted from one generation to another through routines. Their lives depended on it.

The discovery of the mountains must have meant an unprecedented change in the relationship between humans and nature. The diversity of the landscape, the strong seasonal contrasts, the presence of snow during the cold season, the frost, the risks due



Fig. 1.2 The spectacular landscapes found in mountains have always exerted a special attraction: for the first settlers they must have represented almost insurmountable risks except for the need to survive: the existence of game, of different vegetation levels that provided fruits at different times, the possibility of finding shelter. The mountain, with its contrasts between gentle landscapes and steep, inaccessible slopes. Mount Rainier (4392 m), Washington State, USA, a stratovolcano of the Cascade Range. *Photo* Juan I. López-Moreno

to steep slopes, the harshness of every effort, the abundance of water, the torrential nature of rivers, and the complexity of decision-making. Everything made the occupation and control of the territory more difficult. For the first settlers, they learned to check the delay in the growth of grass and crops, to be aware of the compartmentalization of the relief. They must also have been impressed by how difficult it was to get where they wanted to go, or to dominate this hitherto unknown territory; also, given that in their advance they encountered ravines that were impossible to cross, slopes with escarpments that required frequent, long detours, how hard it was to reach any objective, without knowing what dangers they still had to overcome. These difficulties, these dangers, made them stronger and probably forced them to take decisions that they had not even been able to imagine until then. It was another world, another more insecure landscape, which required a different perspective. The mountain, initially so hostile, but so generous when you get to know it (Fig. 1.2).

The mountain makes us strong when we know it and makes us weak when we exceed the limits of our resistance or when we fail to comply with the laws governing



Fig. 1.3 This image is just a small example of the difficulties that historically (and in some cases still today) the inhabitants of the great mountain ranges have had to overcome. The mighty rivers and steep slopes are obstacles to social and economic relations that have been overcome with ingenuity. Suspension bridge over the Indus River (Karakorum, Pakistan) in Hussaini, 2007. *Photo* Juan I. López-Moreno

the relationships between topography, climate, soil, water, vegetation and exploitation of the territory. Mountain dwellers have always been at the limit: obtaining resources, maintaining a family, growing crops, mastering water and slopes, knowing the advantages of diversity (Fig. 1.3). This means foreseeing where to build settlements for people and places to keep and protect livestock, in order to optimize production and security, where to open up the forest to locate fields for cultivation, far from floods or the abrupt arrival of rock avalanches; where to maximize sunshine, that most precious resource in the mountains.

Almost nothing is completely natural in the landscapes we see. A few people have reached the most inaccessible peaks on Earth. Other mountains have come under heavy demographic pressure at certain points in history, and tourism has transformed landscapes that have taken millennia to build into banal landscapes. Ranchers, farmers, charcoal burners, miners, all have lived from the many resources the mountains offer, all have transformed the landscape and all have influenced the changes in soil fertility, the way runoff is generated, the irregular presence of forests or the varied pattern of crop fields. The mountains are humanized, some more than others, of course, but they all show us difficulties, e.g., dangerous geomorphological and hydrological processes, and also the consequences of social or political crises that have caused disasters for soil conservation and for the presence of the population itself. We have changed mountains according to many factors that will be seen in the following pages, and sometimes we have crossed (or are about to cross) thresholds of what today is called *sustainability*.

It is not easy to imagine what our planet would be like without mountains. It is true that they condition relationships between territories, force us to invest great effort into overcoming topographical difficulties, the effect of gravity, and limitations for crops. However, the mountains have been a determining factor in taking advantage of seasonal contrasts; to enjoy water resources that depend on the higher rainfall and benefit from the presence of snow, to give us a landscape and biological diversity that has helped greatly in the conservation of species. To this conceptual importance of mountains must be added the huge extent they occupy on the Earth as a whole, their strategic position in the face of prevailing winds and their proximity or remoteness with respect to oceanic masses. Mountains are omnipresent elements, even if we only see them in the distance, far from the lowlands, where they also exert their influence in the form of drying air currents or rivers that alleviate water shortages on inland or coastal plains. That is why, because they are always present, we need to rethink our relationship with the mountains. We must not only protect soils from erosion or promote diversity. Above all, we need to know what the relationships between the different parts of the mountain are; where the risks are and the limits beyond which exploiting the territory introduces changes affecting the circulation of water, spatial distribution of fertility, the dynamics of rivers and recovery of vegetation when human pressure diminishes. By improving our information on these aspects, we can help reorganize landscapes and land use patterns, recreate the way in which the efficiency and quality of human work can be increased and our ability to coexist with other species, even those we have long considered competitors.

All of this is discussed in the book. We will do it from a perspective that, we hope, the reader will find different, integrating physical, biological and social aspects characterizing mountains, knowing that a large part of the landscapes and geomorphic processes are partly the consequence of current or inherited human activities. Our interest is to synthesize the scientific experience of numerous researchers specialized in mountain environments, and also in sharing our own. For decades, the authors of this book have worked on a wide variety of topics, including soil erosion, environmental hydrology, snow hydrology, landscape evolution and land-use change. For this reason, we have been particularly interested in conveying how we see the complexity of mountain areas, the interactions between physical and human factors, the influence of vegetation and land use changes on runoff generation and geomorphological processes. We will try to clarify that, except for catastrophic situations related to wars and invasions, there is a historical continuum in the way in which human societies have used the territory and transformed the landscape, leaving direct and indirect traces that scientists must identify and interpret. And, above all, we will try to explain why mountain areas are so complex, why their diversity of plants, animals and landscapes is so rich, why the land use patterns are so peculiar and what their environmental consequences are. We do not want to leave aside the interactions between mountains and lowlands and their mutual interdependencies. And finally, why and in what way the mountains are changing and how we should look at them. Many changes are taking place in the mountains; some are related to the so-called global change, but others are a consequence of the evolution of population and land use. They are living mountains, affected by seismic movements, major landslides

and floods, rapid thaws, alterations in the regime of snow accumulation and melting, abandonment of farmland and pastures in some cases, intensification of agriculture in others, erosion and soil conservation. There are no mountains alike, all are different, and yet all with common features. Such is the world of mountains, so diverse, so difficult to encompass.

We are indebted to many excellent books that have opened up unexplored avenues for us, especially in the field of geography. We would like to recall some of those that have had a major impact on our vision of the mountains: The impressive *Arctic and alpine environments* [1] is an excellent contribution that still surprises us with its quality and advanced and holistic perspective; *Geoecology of the Colorado Front Range: A study of Alpine and subalpine environments* [2] delves into an emblematic sector of the Rocky Mountains and provides exhaustive information on different geoecological aspects of the high mountains; *Mountains and man* [3] is the work of a mountain lover, with an intense knowledge of the difficulties they pose and the societies that inhabit them, *The Himalayan dilemma: Reconciling development and conservation* [4] is an invaluable book for understanding the problems faced by developing mountain ranges in a scenario of strong demographic growth. In this case the authors focus their study on the Himalayas, where they have produced other monumental works, *Hautes montagnes. Passion d'explorations* [5] directs the study towards high mountains, in glacial and periglacial environments, with numerous examples taken from the Andes and the Himalayas, *Mountains of the World. A global priority* [6] is an extensive and complex contribution on the societies living in mountains and the risks they face; *Cuadernos de montaña* [7] and *La conservación de las montañas* [8] constitute a personal view on the variety of mountains, and particularly on the need for conservation of their landscapes, *Mountain Geography. Physical and human dimensions* [9] is a comprehensive and modern study of the most salient aspects characterizing the world of mountains. Other more specialized books have also been of transcendental importance in our adventure. Among them we would like to highlight the following: *Mountain weather and climate* [10] is an impressive study of the wide variety of factors involved in mountain climates and their diversity, *Floods in Bangladesh* [11] explains the relationships between land use/land cover in the High Himalayas and the hydrological dynamics of the Ganges and Brahmaputra rivers, *Steepland Geomorphology* [12] analyses structural aspects and different geomorphic processes in the evolution of landforms in mountain areas; *Climate and hydrology in mountain areas* [13] is a compendium of knowledge on snow, hydrology, ground ice and climate change in mountains. The ecological overview provided by Ozenda [14] in *Perspectives pour une Géobiologie des montagnes* has also been very useful, including in-depth studies on the altitudinal belts of the main mountain ranges.

A large number of books and scientific articles have been published on physical and human aspects of mountains (see, for example, the list of bibliographical references at the end of this book), but there are still many outstanding questions, and a wide field of work for future scientists with sufficient enthusiasm for interpreting mountain landscapes and their complexity. We are confident that we will have been able to answer some of those questions that the great pioneers in mountain studies

raised decades ago. We have only been the links in a long chain of people who, years ago, were captivated by the beauty of the mountains. Fascinated, we first asked questions that tried to interpret the complexity of interactions between slopes and rivers, cultures and landscapes, human activities and erosion and sediment transfer processes; later we tried to answer those questions and more questions arose; and thus we have continued until today without seeing the end of our questions or having found all the answers.

Therefore, the objectives of this book are the following:

- (i) To show the diversity of the world's mountains from an environmental and social point of view, and especially the contrasts between the mountains of developed and developing countries.
- (ii) To present the main features of the occupation of mountains by mankind and the relevant role of Alexander von Humboldt in the scientific progress on mountains.
- (iii) To analyze the most salient features of mountains, including particularly the heterogeneity and altitudinal organization of climate, vegetation, geomorphological processes and land use.
- (iv) To show the similarities and contrasts in land uses of the world's mountains and their environmental consequences, highlighting the types of crop fields and seasonal movements of livestock.
- (v) To emphasize the idea that mountains are subject to constant change at different temporal and spatial scales, with particular emphasis on the consequences of global change for river regimes, patterns of snow accumulation and melting, and the spatial distribution of vegetation.
- (vi) Convey to the reader the planetary importance of mountains, on which much of the quality of life in the lowlands depends, and the need to maintain a population that cares for the current crop fields, protects soils and facilitates extensive livestock farming to ensure proper pasture management. Humanity needs living mountains, with a population that knows its limitations; mountains protected to ensure the quality of water, the diversity of agricultural products, the beauty of humanized landscapes.

* * *

This book is divided into 14 chapters. After the Introduction, Chap. 2 discusses in simple terms what mountains are, how they have been defined, and what factors distinguish them from lowlands or high plateaus. It is striking that, contrary to what one might think, it has not been so easy to establish clearly the boundaries of what mountains are.

Chapter 3 discusses the major changes that have occurred in mountains on two time scales, including their formation through major tectonic movements over millions of years, and the climatic changes that have occurred during the Quaternary, with temporal fluctuations over 100,000 years in duration. It is a chapter that helps us to situate the evolution of mountains as a permanently changing phenomenon when we

move to geological time scales; nothing is stable on planet Earth, and even less so in the mountains.

Chapter 4 looks at how mountains have been discovered and colonized by humans on different continents. It shows that mountains have been, often seasonally, frequented by Neanderthals and Denisovans and, of course, by *Homo sapiens* in their expansion throughout the mountains of the Earth. Chapter 4 also briefly discusses Herodotus' perspective on mountains and Alexander von Humboldt's contribution to the knowledge of mountain climate, altitudinal zonation and vegetation.

Chapter 5 discusses mountain climate, with its decisive altitudinal organization in terms of temperature and precipitation, the diversity of oceanic influences, the thermal inversions in valley floors that disrupt the usual temperature gradients, the irregularities in precipitation gradients, the originality and planetary significance of monsoon rains, the local and regional varieties of mountain winds, and topoclimates that are essential to understand the heterogeneity of the Earth's highlands.

Chapter 6 is devoted to the study of snow in the mountains and its importance in explaining the phenology of plants and the functioning of mountain rivers. The spatial and temporal variability of snow and the influence of topographic factors are analyzed, as well as the behavior of snow within the forest. A brief section is also devoted to the study of snow avalanches.

Chapter 7 looks at ice and glaciers in mountains. It is well known to specialists in different branches that mountains have been and still are places where large and small glaciers developed and had an enormous influence on mountain landforms and sediment load of rivers. Even today, glaciers are still of great importance for the flow of many rivers, ensuring the water supply of numerous settlements and irrigation systems. In particular, the evolution of mountain glaciers during the Holocene is analyzed as further evidence of the instability of changes affecting the highlands of the Earth, whose consequences extend to the lowlands.

Chapter 8 focuses on mountain vegetation and its altitudinal organization, perhaps the most defining feature of mountains, as a consequence of temperature and precipitation gradients. This altitudinal organization marks much of the relationship between human societies and the mountains, and explains the distribution of crops and live-stock movements. The authors have tried to highlight the most salient features of mountain vegetation, including, for example, ecophysiological adaptations, the importance of forests, and diversity of soils as a factor explaining the diversity of vegetation. Special emphasis is placed on the great *timberline* boundary, which separates the montane and alpine belts, two very different worlds from a climatic, biogeographical, geomorphological and land use point of view.

Chapter 9 is devoted to river hydrology and morphology. Mountain rivers are very important for their biogeographic influence and supplying water to the lowlands, which in much of the Earth depend on the water resources they provide. These rivers have significant flow fluctuations throughout the year, due not only to the distribution of precipitation but also to cycles of snow accumulation and melting. They also have a great capacity to produce abrupt changes in flow (extreme precipitation events) and transfer large volumes of sediment which, in many cases, contribute to fertilizing the floodplains. In this chapter, special emphasis is placed on the importance of