1 · Introduction

In the six decades since Sir Arthur Tansley first coined the word *ecosystem*, an enormous amount of ecological research has been carried out in every imaginable habitat on earth. Forests, grasslands, deserts, tundra, wetlands and oceans have all been mapped in their distribution on the earth’s surface and have revealed their structure and some aspects of their function to ecologists. Until recently, however, vertical cliffs have been almost completely overlooked as subjects for ecological study, even though some workers in Europe have included areas of steep rock in analyses of vegetation communities. For example, McVean and Ratcliffe (1962) described plant communities for the Scottish highlands but only a handful of stands had slopes greater than 60° and only one had a slope value of 80°. In other words, cliffs as defined in this book were not really included even if subsequent authors said that they were. McVean and Ratcliffe were also aware of the difficulty in dealing with cliff vegetation at the community scale. They stated:

To many botanists this heterogeneous cliff vegetation is the most interesting of all but to the phytosociologist it is easily the most baffling. The larger, stable ledges usually bear tall herb communities and are amenable to the normal method of analysis but the open and patchy vegetation consisting of small herbs, sedges, grasses and bryophytes is very difficult to describe. . . . We have therefore analyzed only those cliff communities which provided stands of at least the normal minimal area of $2 \times 2$ m. . . . Description of the micro-communities naturally confined to open rocks is best reserved for detailed studies of individual rupestral species. (McVean & Ratcliffe, 1962, p. 88)

These words reinforce the idea that even something simple like the biological description of cliffs as habitat has been difficult for ecologists to accomplish. Cliffs simply do not fit into conceptual models that work well for other habitat types.
The available literature is scattered over a wide variety of journals, monographs and books, and much of it dates from the early part of the twentieth century. Cliffs have rarely been investigated from an ecological viewpoint and even when some individual workers have shown that many important ecological problems could be addressed by focusing on cliff vegetation (Oettli, 1904), subsequent workers for the most part have ignored their contributions. In most of the literature on geology, geomorphology or hydrology that is reviewed in the following chapters, no mention is made of the vegetation or fauna of cliffs. Equally, studies of the flora and fauna rarely try to interpret the relationship between the biota and the physical characteristics of the cliff habitat.

This lack of scientific interest is in striking contrast to how common cliffs are around the world, and to the attraction cliffs have had for humans throughout history. Cliffs are present on every continent and in virtually every country on earth. In some jurisdictions (such as Utah, USA, or Madagascar), cliffs are so common that they structure the agricultural or industrial development of the entire landscape. Even regions such as the American Midwest or Bangladesh, which are perceived as flat landscapes, have isolated cliff fragments or long sections of cliff carved by the actions of rivers or coastal tides. As an example of this, the state of Iowa (USA) is well known for its flat agricultural landscape. But the entire northeast quarter of the state is a massive palaeozoic limestone plateau through which more than a dozen large rivers have cut their channels. All of these rivers have vertical limestone cliff faces somewhere along their courses, and the total length of these faces is likely to be in the hundreds of kilometres. Paullin (1932) clearly understood this fact, and also noted that these cliff-lined river courses were locations that supported virgin forest. We will return to this point frequently in subsequent chapters.

While cliffs are common, the exact area covered by them is not known because vertical surfaces do not show up on aerial photographs and maps. In the following chapters, we will present evidence that cliffs represent some of the least disturbed habitats on earth and contribute more to the biodiversity of a region than their actual surface coverage would indicate. In Europe cliffs can represent the primary habitat for species of Saxifraga, Draba, Sorbus, Daphne, Dianthus, Campanula, and Androsace. In addition, Ellenberg (1988) reports that 35–40 per cent of the endemic taxa of alpine regions of Europe grow only in rocky crevices on steep slopes and cliffs, while Wardle (1991) reports that this figure is 66 per cent for New Zealand. This evidence suggests that it may be impossible to establish the
full extent of biodiversity in different parts of the world without careful sampling and inclusion of these vertical habitats.

Cliffs also represent a habitat that is relatively free from human disturbance. This characteristic together with the abundance of scenic vistas common in cliff environments provide the incentive for anchoring parks or nature preserves around them. Examples include the Lake District National Park in the UK (Fig. 1.1), Yosemite National Park and the Grand Canyon in the USA (Fig. 1.2), New River Gorge National Park in the USA (Fig. 1.3), the Niagara Escarpment Biosphere Reserve in Canada (Fig. 1.4), and Las Ruinas de Tulum National Historic Site in Mexico (Fig. 1.5). All these areas have large cliffs that form the focal point for the entire management unit.

The natural appeal of cliffs has led many companies and organizations to use them to advertise their products. The Apple Computer Corporation initially marketed its series of Powerbook laptop personal computers by showing the image of a person sitting on the edge of a cliff, working on an open laptop computer. Similarly, the Chrysler Corporation (Fig. 1.6), the Bell Telephone Company, and Cathay Pacific Airlines have all recently used cliffs as marketing images. Table 1.1 illustrates the frequent use of cliff images in magazine advertising for the years 1994 and 1995. Out of 221 advertisements surveyed in four different magazines, 31.2 per cent used cliffs as the context, 25.8 per cent with the cliffs in the foreground. Such advertising exploits the degree to which humans are attracted to the dramatic views that are derived from cliff tops, and the danger associated with being very close to cliff edges. In a gruesome but effective item of marketing, the Canadian Automobile Association recently advertised its death and dismemberment insurance programme by showing a pair of hikers standing on an overhanging rock at the edge of a 150 m cliff in northern Ontario. There is probably no habitat on earth that has received so much attention from the general public but so little attention from scientists.

This book is about the ecology of cliffs and the primary objective for writing it is to ignite an interest in all aspects of cliff research. It is interesting to speculate on the reason why ecologists have been so completely ‘cliff-blind’. Vertical surfaces are difficult to sample, but so are ocean floors. Cliffs are considered hostile, lifeless and therefore not worth investigating: but why have deserts and antarctic regions, which can be equally bare, escaped the judgement of being ecologically uninteresting? The truth may be that while cliffs are in everyone’s backyard, they are rarely viewed as ‘places’ in their own right. A good example of this is the book...
Figure 1.1 Cliffs such as this one in the Lake District, UK, have usually been viewed as habitat barren of life, and useful only for rock climbing or as an element of attractive scenery. Photo by Alan Charlton.
Figure 1.2 View of a series of cliff faces, terraces and talus slopes in the Grand Canyon, Arizona, USA. Differential weathering rates of strong and weak strata, combined with intense erosion over long periods of time, have produced this series of cliffs. Photo by P.E. Kelly.

Figure 1.3 View of 30 m high limestone cliffs along the New River, Virginia, USA. These cliffs support a population of presettlement Juniperus virginiana. Photo by D.W. Larson.
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Figure 1.4 View of 25 m high limestone cliffs of the Niagara Escarpment near Milton, Ontario, Canada. These cliffs line the edge of the Michigan Basin that runs northward to Manitoulin Island, Canada, westward through Michigan, USA, and south along the Door Peninsula, Wisconsin, terminating near Chicago, Illinois, USA. Photo by P.E. Kelly.

Figure 1.5 View of 10–15 m high cliffs along the Atlantic coast of Mexico, near Tulum. Stunted Yucca and a variety of cryptogams and succulents occur on the cliffs. Photo by A. Haig.
Figure 1.6  Cliffs are used abundantly in commercial advertising, as illustrated in this 1996 advertisement for a sport-utility vehicle. Note the stunted cliff-edge tree to the rear of the truck. Photo courtesy of W. McCall, Chrysler Canada.

Table 1.1. Summary of the extent to which cliffs form the image or the background image in commercial advertising

<table>
<thead>
<tr>
<th>Magazine (no. of issues)</th>
<th>Type of setting</th>
<th>In cliff</th>
<th>Forest</th>
<th>Lake or ocean</th>
<th>Field</th>
<th>Other</th>
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<td></td>
<td></td>
<td>In</td>
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<tr>
<td>Equinox (12)</td>
<td></td>
<td>22</td>
<td>4</td>
<td>3</td>
<td>18</td>
<td>3</td>
</tr>
<tr>
<td>Discover (12)</td>
<td></td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>11</td>
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<tr>
<td>Canadian Geographic (11)</td>
<td></td>
<td>19</td>
<td>6</td>
<td>2</td>
<td>10</td>
<td>4</td>
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<tr>
<td>Time (16)</td>
<td></td>
<td>11</td>
<td>0</td>
<td>2</td>
<td>13</td>
<td>8</td>
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<td>12</td>
<td>9</td>
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<td>26</td>
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<tr>
<td>Percentage of total</td>
<td></td>
<td>25.8</td>
<td>5.4</td>
<td>4.1</td>
<td>19.0</td>
<td>11.8</td>
</tr>
</tbody>
</table>

Note: All 1994 and 1995 issues of three different natural history magazines (Equinox, Discover, and Canadian Geographic) and one news magazine (Time) were surveyed. The 221 such advertisements found which presented the product in some kind of natural setting were placed into one of five categories based on the type of setting: field, lake or ocean, forest, cliff, or other (such as snow, roads, sky or lawn). The group in which the context was a cliff was subdivided further into advertisements in which the cliff was in the foreground, and those in which the cliff formed the background. The number of advertisements in each category is shown below for each magazine.
entitled *The Vegetation of Wisconsin* by Curtis (1959), in which an entire chapter is devoted to cliffs and in which it was claimed that ‘a cliff is a geological feature, not a biotic community type’. Curtis then contradicted this claim by stating that the cliff environment supported a specialized group of plants that included many endemics and rare species such as *Rhododendron lapponicum* that normally occur many thousands of kilometres north along the arctic shores of the Northwest Territories in Canada.

1.1 What is a cliff?
The word *cliff* in the English language is of Teutonic origin and defined as ‘a high, steep, or overhanging face of rock’ (Onions, 1968). It is similar in meaning to the word *precipice*, which is of Old French and ultimately Latin origin and given as ‘an extremely steep or overhanging mass of rock’. In some countries, the word *bluff* or *rock wall* is used in an equivalent manner to *cliff*. In contrast, a *rock outcrop* is ‘a portion of bedrock protruding through the soil level’. Thus, all cliffs are rock outcrops, but rock outcrops are not necessarily cliffs. We do not think it is necessary to specify the degree of consolidation of the rock. Thus, cliffs formed of sand, gravel or loess should be included in this discussion, as well as cliffs formed of igneous rock or hard sedimentary rock. For an outcrop to be called a cliff, three essential elements must be present: a level or sloping platform, or *plateau*, at the top; a *pediment* consisting of baserock at the bottom; and a vertical or near-vertical part, called the *cliff face* or *free-face*, in between (Fig. 1.7b). In addition, the face must be both tall and steep. Figure 1.7 illustrates that tallness and steepness are relative terms and are subject to interpretation. Tallness is relative to the observer and therefore introduces a species bias. Figures 1.7a and 1.7b show two rock outcrops that are equal, except in height, but only the second would be considered a cliff by the human observer, whereas both might function as cliffs to small insects. The minimum height at which an outcrop is called a cliff is not defined, but an intuitive definition is ‘high enough that falling off will kill you’ and this height is probably more than 3 or 4 m. From the viewpoint of the processes that produce the rock face and the organisms colonizing the surface, however, the height may be irrelevant. In fact, we have found no literature that demonstrates that cliff height per se influences the organisms that live on cliffs.

The relationship between the angle of the slope and the appropriateness of the term cliff is illustrated in Fig. 1.7. Overhangs or undercuts
What is a cliff? 

Figure 1.7 This diagram illustrates the difficulty in defining the word ‘cliff’. The strict wording of the definition includes relative words such as ‘high’ and ‘steep’ that are subject to interpretation. Comparison of the structures shown in (a) and (b) illustrates the effect of height relative to a human observer. Both structures are the same except for height, but only (b) would be described as a cliff by most people. The effect of slope angle on the concept of ‘cliff’ is seen by comparing the structures in (b), (c) and (d). The term ‘cliff’ applies to both (b) and (c); overhangs or undercuts make the cliff appear more extreme compared to a vertical free-face. Conversely, the structure shown in (d) appears less extreme and would probably be described as a steep slope.

(Fig. 1.7c) represent more extreme cliffs than vertical faces (Fig. 1.7b), while steep slopes such as that shown in Fig. 1.7d challenge the definition of a cliff. The critical distinction between a cliff and a slope may be that objects falling from cliffs usually fall through the air before they hit solid ground, whereas objects falling down slopes normally maintain at least sporadic and probably painful contact with the ground. The point here is that it is impossible to define a critical angle that separates cliffs from other structures. Furthermore, from a scientific perspective, we gain little by trying to make such strict definitions. What we can do is recognize that slope angles from 180° (the underside of an overhang) to 90° (a vertical wall) are all strictly ‘cliff’, whereas slope angles less than 90° are less
so. The maximum angle of repose of tightly interlocked scree composed of large blocks is typically 43–45° (Ritter, 1978), and subsequent weathering or land movements result in lower angles. Thus, it seems compelling to argue that a cliff should have a minimum angle that is significantly greater than the maximum slope for scree.

The word escarpment is sometimes used to indicate the precipitous face along a line of cliffs. This word is defined as ‘a steep slope or long cliff separating two relatively level areas of different elevations’. Geomorphologists also often use the term terrace or bench to describe steep but short slopes and cliffs on riverbanks and shorelines.

Figure 1.8 adds another component to the definition of cliffs. A cliff in the narrowest sense is just the vertical part of the structure, i.e. the cliff face. But cliffs in the broad sense include a cliff edge at the top, and a talus at the bottom of the face. The cliff edge is a zone extending from the face back an arbitrary distance. It consists of rock in the process of weathering, whereas the talus or talus slope is the accumulation of loose rock fragments and slabs derived from weathering on the cliff face. In some settings, large blocks of talus can create a mosaic of hundreds of small cliffs at the base of a larger cliff. Both cliff edge and talus share some of the physical characteristics of the free-face, support many of the same plants and animals, and are linked by the same ecological processes. Therefore, this book is about cliffs in the broader sense of the definition, i.e. cliff edge, free-face, and talus slope as a single unit.

Some other frequently encountered features of cliffs are also illustrated in Fig. 1.8. The toe is the point where the talus slope meets the pediment. Whereas the idealized cliff face is a solid vertical surface, in reality there is heterogeneity on multiple spatial scales in the form of ledges, overhangs, cracks, crevices and caves. Ledges are sections of the cliff face that are more or less horizontal and may be undercut, thus forming overhangs. Depending on the type of rock, there may be few or many fractures in a continuum of sizes from invisible microscopic cracks to large crevices. Caves may be formed by the expansion of these openings through the dissolution of rock. Lastly, it is entirely possible for each of these individual microsites to be immediately adjacent on a single rock face. In other words, an unfractured vertical face with no rooting space for higher plants but abundant habitat for heat-resistant and desiccation-tolerant lichens can be immediately adjacent to a small fracture plane or ledge that accumulates either liquid water or organic matter (or both) that permits the growth of grasses, sedges or small trees. The compression of all of these microhabitats in a small space leads to the peculiar (and, to some, the