# Assessment of Forest Karst Resources of Haida Gwaii:

## A Strategic Overview

Project SFM08-2008

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All photos were taken by the authors and on Haida Gwaii except where noted otherwise.

# Foreword

This publication is about *karst.* Mention the word "karst", and many people immediately think of caves. In fact, there is a common perception that karst is only valuable in its potential to host caves. Such a perception can only be based on a lack of information.

Unfamiliar karst terminology can be intimidating, and many karst texts are written for highly specialized audiences. Nevertheless, while the linkages between the various components of karst systems can be complex, the basic notions of what karst is, how it functions, and its many values are relatively straightforward.

Karst is a distinctive type of soluble rock landscape with closely interconnected surface and subsurface components. It is most accurately conceptualized, and most effectively managed, as a unique three-dimensional system. Haida Gwaii, Canada's most remote archipelago, is endowed with valuable karst resources, many of which reside within the globally scarce coastal temperate rainforest biome. Other such occurrences are limited mainly to Vancouver Island and some smaller coastal BC islands, Southeast Alaska, the State of Tasmania in Australia, New Zealand's South Island, and southern Chile. Despite the rarity and sensitivity of this resource, practically no formal karst inventory work or research has been conducted on Haida Gwaii.

The many natural and cultural values of karst resources on Haida Gwaii include, but are not limited to, water, fish, wildlife, timber, heritage, recreation and tourism. Recognizing that karst landscapes are highly inter-connected, complex ecosystems is the first step in properly managing and protecting these valuable resources.

On September 15, 2006, the Haida Gwaii Forest District became the first district in BC to legally require protection of most categories of karst resource features, including all karst caves, from the damaging effects of forestry activities. Achieving and maintaining effective karst management practices requires the full support, cooperation and vigilance of the wider public. Meaningful public engagement and support for karst best management practices are more forthcoming when people have a good working knowledge of karst values, the sensitivity of the resource, and the rationale behind protective strategies.

As stewards of their karst resources, Haida Gwaii residents need to understand the terminology, processes and values associated with karst systems. The public can play a key role in determining the level and quality of management and protection that karst resources receive. Decision makers are ultimately accountable to the public, and it is their responsibility to become adequately informed about karst and understand how their decisions may impact the karst resources entrusted to their care.

The purpose of this publication is to promote a greater awareness, understanding and appreciation of Haida Gwaii's karst resources.

*Paul Griffiths* *Carol Ramsey*

This publication intentionally omits detailed information about the specific location of sensitive karst features on Haida Gwaii.

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# Background

## What is Karst?

The term "karst" refers to a distinctive type of soluble rock landscape, occurring most commonly in carbonate bedrock.[1] The distinguishing feature of any karst landscape is subterranean drainage, which develops when water dissolves and enlarges cracks, fractures and joints in soluble bedrock (Ford and Williams 2007; Williams 2004b).

Karst can potentially develop on any type of bedrock with a relatively high solubility, including limestone, marble, dolomite or gypsum. The presence of soluble rock in and of itself does not guarantee the presence of karst, but it does indicate the potential for karst to form, given the right conditions. The majority of Haida Gwaii karst is associated with limestone, which is the most important of the karst rocks globally.

Dissolution of carbonate bedrock by water is the driving or dominant force shaping the karst landscape both above and below the surface (Ford and Williams 2007). The wide variety of surface landforms typically associated with karst can be a product of bedrock dissolving either at or below the surface. Individual features can range in size from centimeters, through hundreds of meters, to tens of kilometers in a few cases (Ford and Williams 2007). Surface karst landforms include fluted or grooved rock surfaces, sinkholes, natural arches, shafts, canyons, dry valleys and springs.

The epikarst and endokarst zones form the two basic components of the karst landscape in profile. The epikarst zone extends from the upper surface of the bedrock to, at most, 10-30 meters below; in Haida Gwaii a depth of a few meters is normally all that will be encountered because of geologically recent glacier scour. The bedrock in the epikarst zone is riddled with many solutionally enlarged vertical openings or fractures because it is the first to be impacted by acidic rain water. The endokarst lies below the epikarst and may also have abundant void spaces ranging in size from tiny cavities to larger cave passages and conduits.

The feature that differentiates karst landscapes from all others is that part or all of the natural run-off from rain and snow becomes diverted underground in solutionally enlarged channels ('caves' when they become big enough for human entry). No other type of landscape possesses such a varied subsurface component (Jennings 1973). Numerous connections between surface and subsurface void spaces can produce a highly permeable and porous landscape (Ford and Williams 2007; Jennings 1973; Veni *et al.* 2001; Kiernan 1988). These conditions allow for movement of air, water, energy and living things between the surface and subsurface.

Karst cavities can range in size from minute cracks and fissures to larger conduits and extensive cave systems. Collectively, all karst cavities play an important role in the functioning of an overall karst system. Connected surface and subsurface domains, as well as the water, air, soil and living things that move and interact throughout them, form the "karst system" (IUCN 1997). The main "movers" of matter in karst systems are water and gravity. Karst systems function as ecological units and can encompass topographic relief and drainage catchments extending well beyond the boundaries of the karst itself.

1 Carbonate rocks are primarily made up of carbonate minerals (e.g., calcite ($CaCO_3$) in the case of limestone and marble).

Caves are only one type of subsurface karst feature. The term "cave" is typically defined as "a cavity containing a zone of total darkness and large enough to admit a human".

The term "karst" is often taken to be more or less synonymous with "caves", but caves are not necessarily diagnostic karst features. Caves can occur in non-karst landscapes; examples include lava tube caves (Williams 2008b) or wave-cut sea caves.

## What Values Are Typically Associated With Karst?

Karst landscapes are associated with a diverse array of natural and cultural values.

One of the most important values associated with karst on a global scale is water. An estimated one-quarter of the world's population obtains its water from karst aquifers (IUCN 1997; Hamilton-Smith 2006). The permeability of karst landscapes and the extensive networks of fissures and cavities beneath the surface are responsible for karst's unusual and unique hydrology.

Karst contributes to the earth's geological and biological diversity (IUCN 1997). The complexity of karst landscapes can provide highly variable microclimatic conditions and/or moisture regimes (e.g., see Gillieson 2004; Whiteman *et al*. 2004; Bárány-Kevei 1999a; Bárány-Kevei 1999b), as well as isolation for some species or biological communities (e.g. Gillieson 2004; Kruckberg 2004). To some extent, these factors may account for the high incidence of endemic species associated with karst globally.

While cave ecosystems provide some of the best-known examples of biodiversity in karst, increasing attention is now being paid to lesser known karst habitats, including epikarst and surface karst landforms, such as sinkholes and springs (e.g., Pipan 2005; Pipan and Culver 2007; Van der Kamp 1995).

Karst landscapes can have great significance for First Nations cultures, extending to their spiritual beliefs and particular usages of specific karst features (e.g., caves as places of refuge, spring waters for drinking, healing or ritual bathing, etc.) Even if there are no visible signs of use, certain karst sites or categories of sites may be of cultural significance.

Karst landscapes often contribute to outstanding scenery, attracting tourists and outdoor enthusiasts of all types, ages and fitness levels. They are amongst the most frequently selected sites for UNESCO World Heritage status. Fine examples of karst trails and interpretation sites exist throughout the world. (See "Karst Recreation and Tourism" section.)

**Photo: Karst landscape on Haida Gwaii.** *Surface karst landforms and sites are often very scenic.*

Karst landscapes attract researchers from a wide variety of disciplines including ecology, geography, geology, hydrology, climatology, zoology and botany, to name a few. Recognized as a standalone discipline in many parts of the world, the multi-disciplinary study of karst systems is called "karstology".

Karst caves draw a following of specialized researchers, including speleologists, ecologists, climatologists, earth scientists, palaeontologists, archaeologists, and even pharmacologists. The scientific study of cave biology is a specialized field known as "biospeleology".

Many karst caves house a variety of secondary mineral deposits. Speleothems, comprised chiefly of calcium carbonate, can take many forms, the most well known being stalactites and stalagmites.

Caves may also contain significant palaeontological remains that can reveal information about past vegetation, fauna, climates and environments (IUCN 1997). Karst caves in particular can provide conditions uniquely conducive to the preservation of bone material. These conditions include protection from weathering, the higher pH of cave substrates, and stable environmental conditions, including constant, relatively cool temperatures, and constant high humidity (Baichtal *et al.* 1996; Schulte and Crocker-Bedford 1998).

**Photo: Fragile stalactites and stalagmites in a Haida Gwaii cave.** *Certain types of stalagmites can be dated and, through isotopic analyses, can provide valuable information about past climates (Ford and Williams 2007).*

The benefits of scientific knowledge gained through palaeontological, archaeological or other research activities in karst caves must be carefully weighed against the potential risks such activities pose to other cave values (Williams 2008b; Ramsey 2004; Buchanan and Maguire 2002).

**Photo: Bear bones deep in a Haida Gwaii cave.** *Preliminary palaeontological investigations in the karst caves of Haida Gwaii produced bear bones dating to 14,400 radiocarbon years before present. (Ramsey* et al. *2004)*

# Karst Processes and Controlling Factors

In karst systems, the bedrock dissolution process is controlled or mediated by many factors, including climate, soil cover and vegetation. Impacts to any one of the mediating factors in a karst system can affect the system as a whole (Kruckeberg 2004; Ford 2004; Williams 2004b).

An important factor contributing to karst development on Haida Gwaii is the high purity of some of its limestone. The calcium carbonate ($CaCO_3$) content for Sadler Formation limestone exceeds 95% (Sutherland-Brown 1968). Most carbonate rocks susceptible to karst development will have a $CaCO_3$ content of 70% or greater (Ford and Williams 2007).

Moderate coastal temperatures and abundant precipitation contribute to high rates of limestone dissolution on Haida Gwaii. The annual precipitation on the east coast of the islands average about 1300 mm, while the west coast averages 4000 mm (BC Ministry of Forests 1994a).

**Photo: High rainfall on Haida Gwaii's west coast contributes to development of karst landscapes.** *The planet's wettest places generally have the fastest rate of limestone dissolution (Williams 2004b). Haida Gwaii is rated amongst the wettest karsts known anywhere (D. Ford, pers. comm. 2009).*

The forest vegetation and associated soils of Haida Gwaii play an especially important role in enhancing dissolution through the "Carbon Dioxide Cascade". While rainwater absorbs some carbon dioxide ($CO_2$) as it falls through the atmosphere, it picks up much more $CO_2$ when it infiltrates the forest floor and percolates through soil. The decaying organic litter and respiration from tree roots and soil microbes produce concentrations of $CO_2$, as much as 1000 times higher than are measured in the open air. The more $CO_2$ water absorbs, the more acidic it becomes. The increased acidity results in greater dissolution rates.

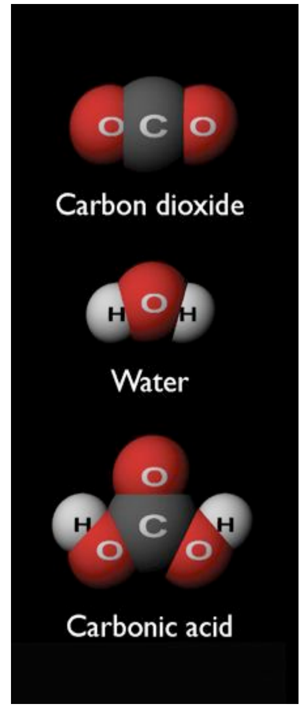
## The "Carbon Dioxide Cascade"

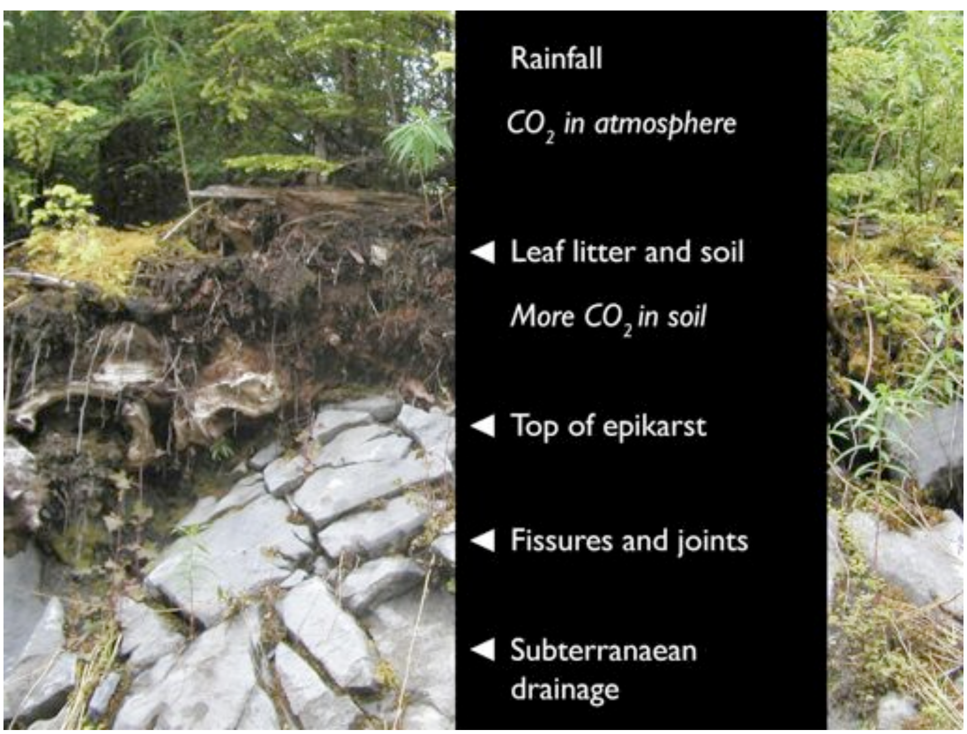
The potential for water to dissolve limestone is greatly enhanced through a process known as the "carbon dioxide ($CO_2$) cascade". The $CO_2$ is obtained either by dissolving into rain drops in the open air or from greater concentrations of the gas found in many soils. It forms a weak solution of carbonic acid.

Reading to the right, the following equation represents the dissolution of calcium carbonate:

$$CaCO_3 + CO_2 + H_2O \rightleftharpoons Ca^{++} + 2HCO_3^-$$

The acidic water then flows into or along existing cracks, joints or fractures, gradually dissolving them and creating larger subsurface openings and flow paths.




Tree roots can penetrate the bedrock along joints, fissures and bedding planes, contributing to the enlargement of subsurface openings and influencing karst dissolution and erosion processes.

Significant karstification can occur at higher elevations where soil may not be present because cooler water is capable of dissolving more $CO_2$ than warmer water at a given partial pressure (Ford and Williams 2007).

Photo: Karstification at higher elevations on Haida Gwaii.

Haida Gwaii's tectonic history has included uplifting and tilting of limestone beds and structural deformation of bedrock. These factors often provide greater opportunity for more energetic groundwater circulation, and for unrestricted dissolution and removal of dissolved material.

The karst on Haida Gwaii has likely been affected by glaciation. Clague (1989) notes that the archipelago was glaciated many times during the Pleistocene, though perhaps not so extensively as on the mainland. More research is needed to determine the effects of glaciation on Haida Gwaii's karst. The effects can be highly variable, ranging from complete obliteration of smaller scale karst landforms and infilling of subsurface conduits, to the stimulation and acceleration of karst development via the focusing of glacial meltwaters (Ford 1987).

**Photo: Glacial erratic on a higher elevation Haida Gwaii karst landscape.**

# Karst Geology, Geomorphology and Hydrology

## Karst Geology of Haida Gwaii

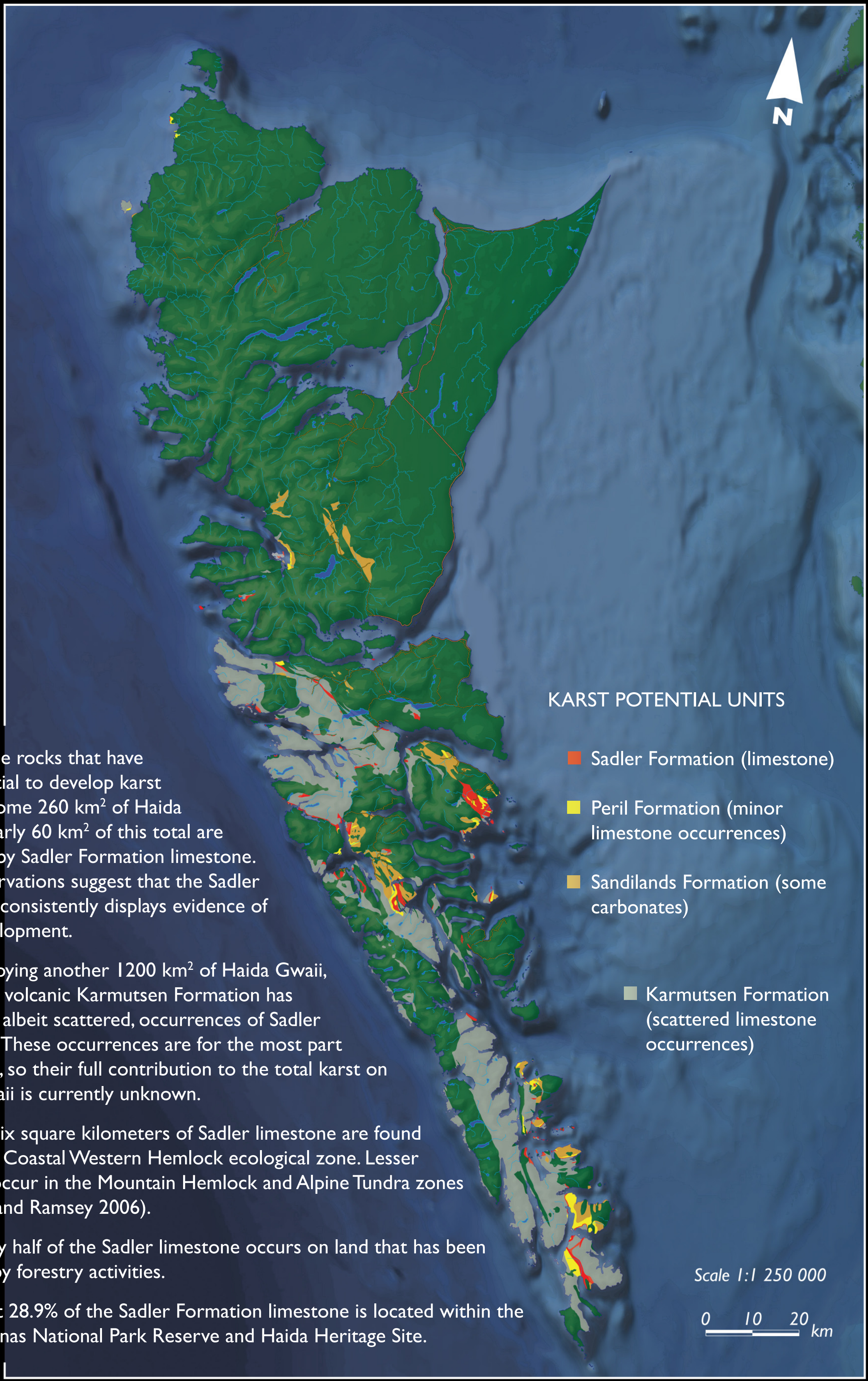
The main soluble rocks on Haida Gwaii are limestones of the Sadler, Peril and Sandilands formations (Haggart *et al*. 1995). Together, these three formations make up the Kunga Group of sedimentary rocks (Sutherland Brown and Yorath 1989). The Sadler limestone is the oldest (Haggart *et al.* 1995) and attains a thickness of 180 meters (Fischl 1992). Geologists (e.g., Sutherland Brown 1968) describe it as grey, massive to thickly bedded limestone that was deposited directly on top of volcanic rocks of the Karmutsen Formation. Due to its high calcium carbonate content most of the karst development on Haida Gwaii occurs in the Sadler Formation.

The Sandilands and Peril formations lie on top of the Sadler limestone (Haggart *et al*. 1995) and tend to be darker in colour and very thinly bedded when compared to the Sadler limestone.

The karst development potential on these formations is not well established. However, well-developed karst sites and caves are not expected to develop in them as frequently as in the Sadler limestone due to the discontinuities in bedding and insoluble impurities that can resist or inhibit dissolution.

**Photo: Karst developed in Sadler Formation limestone.** *This high purity limestone is thickly bedded.*

# How Much Karst Is On Haida Gwaii and Where Is It Located?




Soluble rocks that have the potential to develop karst underlie some 260 km² of Haida Gwaii. Nearly 60 km² of this total are underlain by Sadler Formation limestone. Field observations suggest that the Sadler limestone consistently displays evidence of karst development.

Occupying another 1200 km² of Haida Gwaii, the mainly volcanic Karmutsen Formation has significant, albeit scattered, occurrences of Sadler limestone. These occurrences are for the most part unmapped, so their full contribution to the total karst on Haida Gwaii is currently unknown.

Fifty-six square kilometers of Sadler limestone are found within the Coastal Western Hemlock ecological zone. Lesser amounts occur in the Mountain Hemlock and Alpine Tundra zones (Griffiths and Ramsey 2006).

Nearly half of the Sadler limestone occurs on land that has been modified by forestry activities.

About 28.9% of the Sadler Formation limestone is located within the Gwaii Haanas National Park Reserve and Haida Heritage Site.

## Where Does Haida Gwaii's Limestone Come From?

The sediments that make up the limestone on Haida Gwaii are largely composed of shells of marine organisms.[2] Clams, corals, and tiny plants and animals, such as coccolithophores and formanifera, extracted calcium from seawater to secrete calcium carbonate (CaCO3) for their shells (Skinner *et al.* 1999).

### *"A Little Piece of Paradise"*

The Sadler limestone is thought to have accumulated in warm tropical seas somewhere in the vicinity of what is now the southwestern Pacific Ocean (Sutherland Brown and Yorath 1984). Around 230 million years ago undersea volcanoes began to erupt basaltic lavas on the seafloor. The resulting thick unit of basaltic lavas is what geologists call the Karmutsen Formation. The volcanic activity lasted for about five million years, resulting in an extensive and relatively shallow undersea platform on which molluscs, corals and other shelly organisms could grow (Yorath 1990; Yorath and Nasmith 1995; Haggart *et al.* 1995).

As the marine organisms grew and died over millions of years, masses of their calcium carbonate shells and skeletons accumulated in pockets and hollows on the volcanic platform. In time, these accumulations were buried by other sediments and gradually transformed into what is now called the Sadler Formation (Yorath 1990; Yorath and Nasmith 1995).

As these sediments accumulated, the region of the earth's crust on which they rested was slowly moving by plate tectonic processes towards the ancient coast of North America. That piece of the earth's crust is now known as the Wrangellia Terrane.[3]

By about 100 million years ago, the terrane had collided with the North American continent (Yorath and Nasmith 1995.) The effect of this accretion was that parts of Wrangellia were squeezed, folded and pushed up to form large parts of what we now know as Haida Gwaii and Vancouver Island (Clague 1989).

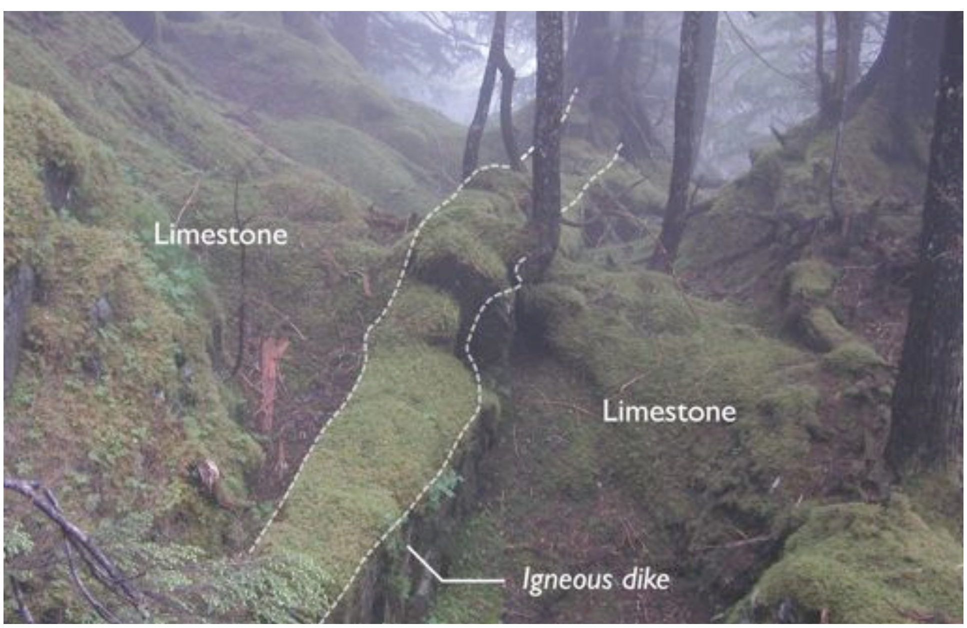



**Photo: Non-carbonate molten rock moved upward along fractures and weakened joints in the limestone to become igneous dikes.**

3 A terrane is a piece of the earth's crust made up of distinct groups of rocks that differ from those of adjacent terranes. Most of the rocks associated with the Wrangellia Terrane in BC are found on Haida Gwaii and Vancouver Island.

The tectonic and seismic forces of uplifting, tilting, folding and faulting that raised Haida Gwaii's limestone above sea level also fractured the rock and created the pathways needed for water to exploit and dissolve the bedrock – the beginnings of subterranean drainage systems.

As noted earlier, how significant a role glaciation played in shaping Haida Gwaii's karst is not currently known. The karst systems on Haida Gwaii may have already been well developed prior to the onset of the Pleistocene glaciations, if Southeast Alaska is a valid analogue (Aley *et al*. 1993; Baichtal and Swanston 1996). Evidence suggests that well-developed karst landscapes in Southeast Alaska predated glaciation which significantly modified existing karst landforms (Baichtal and Swanston 1996).

## Karst Soils

The inorganic sediments that make up karst soils can be assigned to one of two broad categories: autogenic or allogenic (Boyer 2004a).

Inorganic autogenic sediments are those that originate in carbonate bedrock and are mostly made up of the insoluble "leftovers" from the dissolution process – that portion of the parent bedrock that isn't calcium carbonate and won't dissolve easily. Because carbonate bedrock has a high calcium carbonate content, a great deal of the parent bedrock must be dissolved over a long period of time to provide even a small amount of insoluble autogenic sediments over the landscape. For this reason, autogenic karst soils often tend to be shallow or negligible (Aley 2004; Boyer 2004a). Scouring glaciers, rain and wind on Haida Gwaii would also carry any accumulations of autogenic sediments away unless they were protected by surface topography or vegetation.

Inorganic soils of allogenic origin are those derived from sources other than carbonate bedrock. In many cases, these sediments have been transported onto (and into) karst landscapes by glaciers, streams, and, to a lesser extent, by mass wasting and wind. Allogenic glacial sediments (e.g., till) in coastal BC can form very thick deposits, which, in some cases, are deep enough to completely mask or cover surface karst landforms.

**Photo: Soils covering well-developed epikarst.** *These shallow karst soils are often predominantly organic.*

## Karst Geomorphology

Many types of surface karst landforms have been observed on Haida Gwaii. These include sinkholes, karst canyons, dry valleys, karst springs, shafts, grikes[4], and varied microrelief features on epikarst exposures.

Subterranean drainage is the defining attribute of karst, but it is difficult to directly observe from the surface. It can be inferred, however, from other aspects of the karst landscape, such as the presence of sinking streams, springs, sinkholes and other distinctive surface karst landforms (Ford and Williams 2007).

Some of the surface characteristics typically associated with karst, such as fluted or grooved rock surfaces, are a direct result of water acting on the soluble bedrock surface. Other karst landforms, such as sinkholes, can result from dissolution beneath the surface of the karst. The presence of sinkholes and other negative relief features implies subterranean drainage, and hence karst.

Dense clusters of karst landforms often contribute to the distinctive "roughness" of well-developed karst topography.

Sinkholes are among the most common karst landforms found on Haida Gwaii. These sinkholes can range in size from a few meters to many hundreds of meters in diameter.

**Photo: Sinkholes are enclosed depressions, typically round to elongated ovals in plan view, ranging from conical to shallow, and dish shaped in cross-section.** *Most sinkholes (and many other surface karst features) form as a result of processes directly or indirectly linked to the karst system's internal drainage. Sinkholes concentrate and channel surface water into the subsurface (Ford and Williams 2007; Williams 2004a; Kiernan 2002).*

4 A grike is a narrow solutional slot with vertical or near-vertical sides. In plan view, it is longer than it is wide. Grikes at least 7-10 m deep have been observed on Haida Gwaii.

## Karst Hydrology

Water that enters the karst system as precipitation that infiltrates the soil and flows down vertical openings in the epikarst is referred to as "diffuse" or "autogenic" recharge (Ford and Williams 2007; Williams 2004b).

During the $CO_2$ Cascade, water droplets pick up carbon dioxide, causing them to become progressively more acidic as they fall through the atmosphere and percolate through the soil. Autogenic recharge water therefore has the greatest ability to dissolve carbonate bedrock at the soil-bedrock boundary. When the water encounters carbonate bedrock, the chemical reaction of dissolution causes the water to become progressively less acidic, thus reducing its potential to dissolve bedrock as it flows downward from the surface through enlarged openings in the epikarst.

The development of the epikarst zone in a karst system both results from and facilitates this aspect of autogenic recharge. The solution openings in the epikarst zone are larger at the surface than they are at depth, reflecting the decreasing potential of water to dissolve the bedrock (Ford and Williams 2007; Williams 2004c; Williams 2008a). Larger openings at the epikarst surface allow larger volumes of water to quickly penetrate the epikarst zone, while the characteristically smaller openings at depth restrict the flow of water, releasing much smaller volumes to percolate downward at a much slower pace. The net result is a slowly draining aquifer within the bedrock mass of a karst system that can be "suspended" above the surrounding water table (Williams 2008a). The ability to temporarily store water in the suspended aquifer is one of the epikarst zone's most important values and functions. Such aquifers also serve as important habitats for small subterranean fauna (Pipan 2005; Pipan *et al*. 2008).

Surface water can also enter the karst system from non-karst portions of the catchment. This so-called "allogenic recharge" flows overland as a river or stream, disappearing into caves or other sink points where soluble bedrock is encountered downstream (Williams 2004b). From the sink points, the water can rapidly transit the karst system, possibly emerging at one or more springs.

**Photo: Allogenic stream on Haida Gwaii disappears underground at geological contact.** *Limestone is visible to the left of waterfall; the sinking stream flows over igneous bedrock.*

Subsurface drainage patterns in karst are not necessarily defined and delineated by surface topography (Aley and Aley 1993; Huntoon 1992; Elliot 1994). For example, a river or stream sinking in one valley can reappear at a spring several drainage basins over and many kilometers away, passing under one or more topographical divides. Subsurface flow paths may change as subterranean water levels rise and fall seasonally, or during isolated heavy precipitation events.

Recharge areas and subsurface drainage patterns in karst can be investigated by water tracing using fluorescent dyes (e.g., Goldscheider et al. 2008; Prussian and Baichtal 2007).

# Flora, Fauna and Karst

A single karst system can contain a remarkable variety of surface and subsurface habitats that possess one or more extreme or unusual conditions that may limit or inhibit colonization by some species and exert strong selection pressure on others (Gillieson 2004).

Karst habitats can be divided into three broad categories: surface karst environments, karst transition zones (the "ecotones" between surface and subsurface), and subterranean karst environments. Each of these categories can potentially have aquatic and terrestrial components.

Karst is often associated with greater biodiversity than is found on adjoining terrains worldwide (Hamilton-Smith 2004b; Hamilton-Smith 2007), and can display a high degree of endemism and/or karst-specific biological communities (IUCN 1997; Gillieson 2004; Williams 2008b).

## Surface Karst Environments

The surface component of karst landscapes receives solar radiation ranging from full sunlight to deep shade, and exhibits similar diurnal and annual temperatures, and temperature fluctuations, as nearby non-karst environments. Areas of greater topographical roughness[5] tend to provide greater habitat diversity in terms of microclimates, aspect, shade, moisture, and opportunities for isolation and protection (Hamilton-Smith 2004b; Kruckeberg 2004; see also Viles 1988).

**Photo: Negative relief features, such as sinkholes, can be large and deep enough to develop distinct microclimates.** *Sinkhole on Haida Gwaii measuring approximately 750-m long, 450-m wide, and 150-m deep.*

5 Topographical roughness can be defined as a high ratio of positive to negative surface relief.

Varied surface karst topography, typically coupled with thin, well-drained calcium-rich soils, can present favourable colonization opportunities for rare, endemic or specialized flora and fauna or biological communities. Roemer and Ogilvie (1983:2579-2580), for example, have reported that endemic and disjunct plant species distributions occur more frequently on Haida Gwaii limestones than on other rock types:

"*…these results must not be viewed as more than first indications of an interesting phenomenon. But the fact that a brief survey…produced so much new information should alert future collectors to two situations in the Queen Charlotte Islands* [Haida Gwaii], *limestones and high elevations, which appear to deserve very special attention in future botanical explorations*".

High-elevation limestones tend to yield above-average numbers of rare and unusual plants. This was confirmed in recent years on Vancouver Island (H. Roemer, pers. comm. 2009).

**Photo: "Grike gardens" can host lush and diverse flora.** *The widespread effects of browsing by introduced deer on Haida Gwaii forest understory vegetation are somewhat moderated by the presence of plant refugia in some surface karst landforms. For example, habitats such as "grike gardens", karst canyon walls, and other karst features, are effectively inaccessible to the deer (R. van der Zalm, pers. comm. 2006; Anthony* et al. *2006)*

The rainforests on karst landscapes of coastal BC are examples of uncommon biological associations with karst. Productive old-growth forests on karst can be found even in landscapes where bog-forest complexes would otherwise occur. The remaining stands of old-growth rainforests may not be especially rare in and of themselves, but combined with karst landscapes, they represent naturally rare occurrences.[6] The limited amount of undisturbed Sadler limestone karst in old-growth rainforest on Haida Gwaii can be classified as exceptionally rare ecosystems.

Deer and other mammals on Haida Gwaii may exploit surface karst landforms. For example, the authors have observed Sitka black-tailed deer (*Odocoileus hemionus sitkensis*)

6 The BC Conservation Data Centre (CDC) has not identified these occurrences as rare ecosystems where they exist in association with common site series (sites capable of producing the same mature or climax plant communities within a biogeoclimatic subzone or variant) (Pojar 2002). Currently, the CDC focuses on ecosystems that are uncommon ecological communities based on the Vegetation Classification component of the BC Ministry of Forests and Range Biogeoclimatic Ecosystem Classification, which focuses on the terrestrial plant associations of BC's native plants.

and, in one case, a black bear (*Ursus americana carlottae*) seemingly to favour sinkholes as resting places. Similar behaviour is reported in Southeast Alaska (J. Baichtal, pers. comm. 2008). Research is needed to determine whether these observations indicate purposeful use of sinkholes. Karst depressions may provide some concealment (or sense of concealment) and in certain cases, these animals may be using sinkhole microclimates.

Research conducted in Southeast Alaska suggests that karst systems may have important implications for aquatic productivity in streams and therefore salmon populations. (Bryant *et al.* 1998; Wissmar *et al.* 1997)

## Karst Transition Zones

Karst transition zones in a broader sense are "ecotone" (transition) environments between the surface and subsurface components of the karst landscape. They can be influenced by both surface and subsurface conditions (e.g., see Van der Kamp 1995; Wood 2004), and exhibit higher humidity, gradations of incident sunlight, and temperature regimes influenced or moderated by the mixing of surface and subsurface air.

Cave entrances, sinkholes and shafts with distinct microclimates, sinking streams, springs, or deep solution openings in epikarst exposures are examples of biologically important karst transition habitats (e.g., Culver and Sket 2002; Gibert 1997; Pentecost 2004; Kiernan 1988; Camassa 2004; Peck 1988; Pipan *et al*. 2008). Cave entrances have been identified as karst habitats where relictual plants are likely to persist (Pentecost 2004; Kiernan 1988; Schulte and Crocker-Bedford 1998).

**Photo: Cave entrance on Haida Gwaii.** *Cave entrances and other transition zone habitats receive the widest range of solar radiation – from full sunlight to near constant total darkness, with corresponding zonation of associated flora and fauna (Pentecost 2004; Sket 2004).*

Caves can be divided into three distinctive ecological zones: entrance zone, twilight zone, and dark zone. The entrance zone in particular can host thriving and biologically diverse "edge" communities of plants, fungi, protists and animals (e.g., see Culver and Sket 2002; Danielopol *et al*. 1997). The results of a study of invertebrate cave fauna at cave entrances in Ontario are typical:

*"The fauna is most abundant in individuals and richest in species diversity within the first 10 meters of the entrances, just inside the dark zone, and at 12-14°C."* (Peck 1988:1197; see also Wood 2004:707)

Surface karst landforms with open connections to the subsurface can be subject to the moderating influence of subterranean climates, which typically render them warmer in winter and cooler in summer than unprotected surface settings (Baichtal and Swanston 1996; see also Eberhard and Humphreys 2003:137). Such moderating effects often occur in cave entrances and at karst springs (e.g., Van der Kamp 1995). Karst transition zone habitats with horizontal parts, such as some cave entrances and springs, can benefit from additional structural protection from wind, rain, snow and sunlight.

Many of the biological studies of cave entrance zones around the world have focused on use of these transition zone habitats by plants and/or invertebrate fauna (e.g., Peck 1988; see also Pentecost 2004). No such biological studies have been conducted on Haida Gwaii. Baichtal and Swanston (1996) and Elliot (1994) have reported the occasional use of karst caves and their entrances in Southeast Alaska by larger mammals. For example, deer and bear reportedly rest in or close to ventilating cave entrances in both winter and summer (J. Baichtal, pers. comm. 2008).

Sidebar: Karst transition zones can be important routes for organic matter entering the nutrient-poor subsurface environment. Some animals that live underground forage in the transition karst zones or on the surface, and "shuttle" organics and other sources of nutrients between the zones of sunlight and constant total darkness (Camassa 2004:365).

## Subterranean Karst Environments

Subterranean karst environments are characterized by constant and total darkness, often very high humidity, stable temperatures, and meager food resources. Air temperatures in the deep zones of caves ordinarily vary less than one degree from the average annual temperature on the surface (Moore and Sullivan 1978). Since photosynthesis cannot occur without sunlight, food resources can be meager. Hypogean fauna (organisms that live underground) must subsist on organic matter transferred from the surface by air currents, water, other animals or gravity (Eberhard and Humphreys 2003; Elliot 2004; Kiernan 1988; Sket 2004).

Animals that live underground can be classified in three general categories: troglophiles, trogloxenes, and troglobites. Troglophiles are "cave-loving" animals that are adapted to life in constant total darkness but can also survive on the surface. An example of a troglophile on Haida Gwaii is the centipede. Trogloxenes are animals that are adapted to life on the surface, but may visit or use caves for part of their life cycle. The black bear is an example of a trogloxene on Haida Gwaii.

An animal living permanently underground in the dark zone of caves and only accidentally leaving is called a troglobite or troglobiont.[7] Hypogean fauna, such as some invertebrates, may have evolved in their underground karst habitats since isolation or separation from their surface ancestors (Clarke 1997). These fauna often have physical adaptations to subterranean environments, such as reduced pigment and eyesight (Eberhard and Humphreys 2003).

To date, no troglobitic taxa have been identified on Haida Gwaii. Comprehensive biological inventories of subterranean karst environments will likely produce some interesting results, as has been the case on Vancouver Island to the south and in Southeast Alaska to the north. The research in Southeast Alaska has already revealed a

7 The prefix 'troglo' can be used with reference only to terrestrial fauna and the prefix 'stygo' used for aquatic species. Thus, for aquatic species, troglobite becomes "stygobite" or "stygobiont".

significant number of karst-associated species and unique faunal communities (Carlson 1996). Collections of invertebrates from karst caves on Vancouver Island have revealed 192 taxa, including a minimum of 10 new species and new distributional records (Shaw and Davis 2000). A troglobitic amphipod crustacean (*Stygobromus canadensis*) is known only from 20-km long Castleguard Cave in the Rockies (Holsinger 1980). Canada's longest cave system on record, it has been described as the only one in the world explored beneath an active ice sheet – the Columbia Icefield (see Ford 1983).

Small or microscopic organisms (mostly invertebrates, fungi, protists and bacteria) usually make up the great majority of hypogean populations in terms of biomass (D. Culver, pers. comm. 2009). These organisms can easily be missed if people don't look closely enough, look in the wrong places, or fail to modify standard observational or biological collection techniques for use in subterranean karst environments[8] (e.g., see Culver and Sket 2002; Culver 2003). In caves, fauna can also easily be overlooked when observers' interests are focused on other cave resources and values.

A wide assortment of invertebrates have been observed in karst caves on Haida Gwaii, including flatworms, snails, centipedes, millipedes, spiders, moths, and beetles, yet little is known of their adaptations, biogeography, ecology and evolution. Scudder and Cannings (1994) identified karst caves in British Columbia as a priority for systematic studies on invertebrate communities because of likely endemic species occurrences and the vulnerability of the cave habitats to disturbance.

*Stygobromus quatsinensis* - a blind, unpigmented freshwater crustacean found in the underground pools of glaciated karst caves on Vancouver Island (Holsinger & Shaw 1987) has also been identified in karst on Heceta Island (Southeast Alaska) to the north of Haida Gwaii (Baichtal and Swanston 1996; Elliot 1994). The occurrence on Coronation Island, Southeast Alaska, represents the high latitude record for any troglobitic species in this hemisphere (Holsinger *et al.* 1997).

**Photos: Centipede (left) and snail (right) from the dark zone of a Haida Gwaii karst cave.**

The number of troglobitic species decreases in higher latitudes (e.g., see Peck 1988; Peck 1997), and are more often found in caves in areas that remained ice-free during the last glaciation (Pielou 1992). A number of endemic taxa are already known to exist in non-karstic habitats on Haida Gwaii (examples of this extensive body of research include Foster 1965; Moodie and Reimchen 1973; Schofield 1989; Kavanaugh 1988; Byun *et al.* 1997; Reimchen, T. and S. A. Byun McKay 2005).

The lack of unique or rare taxa in a given cave does not necessarily obviate the need to protect its biological communities because, although made up of more common organisms, in the whole they contribute to the biodiversity of the cave. As Peck

*"Speciation among invertebrates may progress rapidly in caves, which often provide a refuge for relic life-forms"* (Kiernan 1988:38; see also Eberhard and Humphreys 2003; Peck 1997).

8 Elliot (2006:37) identifies the "Vertebrate Bias" as one of the most important stumbling blocks to the effective inventorying and conservation of cave fauna. This bias is a tendency by some to show more interest in the conservation of vertebrates, especially mammals and birds, than of invertebrates.

(1997:61) notes, *"There is certainly a need to work towards the protection and conservation of this special part of the world's biodiversity"*.

Subterranean karst environments are often automatically equated with caves, whereas the vast majority of life-supporting cavities within karst landscapes are *not* large enough to be enterable by humans. The living space of an organism is normally limited only by its body size (Harris 1993).

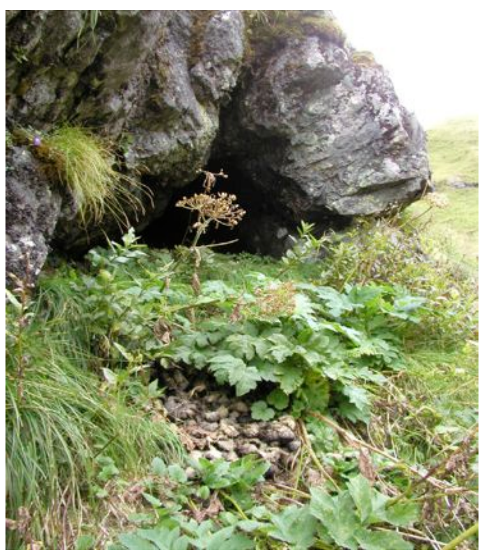
Minute cracks, joints, fissures and other voids in the epikarst zone, for example, can serve as important habitats and dispersal routes for communities of small organisms, such as amphipods and copepods (both tiny freshwater crustaceans) (e.g., Pipan 2005; Culver 2003; Pipan and Brancelji 2003).

The uppermost epikarst and its solution openings could be considered an ecotone environment because it is subject to variations in climate (Pipan 2005; Gibert *et al*. 1990). Lower parts of the epikarst zone that are not subject to variations in climate form part of the subterranean karst environment.

Epikarst provides habitats for both terrestrial and aquatic organisms (Brancelj 2004). In addition to distinctive epikarst taxa, assemblages can also include both epigean (surface) and hypogean (subsurface) fauna (Pipan 2005; Pipan *et al*. 2008). While aquatic fauna in epikarst can drift down fissures and can therefore be readily sampled in cave drip water, obtaining samples of terrestrial epikarst fauna is more difficult (Sket *et al*. 2004).

As in other surface and subsurface karst environments, epikarst fauna studies tend to show high levels of endemism and enhanced biodiversity (Pipan 2005). Moldovan *et al*. (2007) point out that there is still much to learn about the diversity and ecology of epikarst fauna.[9]

The subterranean karst environment can provide habitat for a wide variety of larger animals, including amphibians, birds and mammals. On Haida Gwaii, the authors have observed one instance in which a bear used the interior chamber of a small cave as a denning or resting site in a sub-alpine/alpine karst setting.



Reporting on karst caves in Southeast Alaska, Elliot (1994:11) notes: "… *bats hibernate to an extent not seen so far north, and large mammals such as bears, deer, wolves, and otters use caves to an extent no longer seen in the rest of the nation."*

To date, the use of karst caves by bats has not been reported for Haida Gwaii. Caves on Vancouver Island and Southeast Alaska are used by varied species of bats, including the Keen's long-eared bat (*Myotis keenii*), a red-listed species in BC first described from specimens collected on Haida Gwaii in 1893 (Burles & Nagorsen 2004). In BC, hibernacula (hibernation sites) for the Keen's long-eared bat are only known from

9 Epikarst faunal distributions have the potential to serve as environmental indicators (Pipan 2005) and water tracers (Pipan and Culver 2007).

Epikarst has an important biological function as habitat for aquatic and terrestrial organisms, in addition to its hydrological functions in terms of infiltration and the storage, mixing, and lateral redistribution of recharge (Williams 2004c). Epikarst is characterized by fracturing and enhanced solution, but unlike other karst habitats, much of the epikarst cannot be directly observed or sampled. This may be one reason why epikarst fauna have seldom been studied in North America (e.g., see Pipan *et al.* 2006 as an example). More research on epikarst habitats has been conducted in Europe (some recent examples include Pipan *et al.* 2008; Moldovan *et al.* 2007; Pipan 2005; Pipan and Brancelj 2003).

**Photo: Small karst cave on Haida Gwaii used by black bear.**

karst caves. The deep zone of caves can be especially important hibernacula for these trogloxenes because the temperatures remain low enough to maintain torpor but do not reach freezing during the winter.

At least two karst caves in Southeast Alaska provide shelter for salmon during their annual spawning run (Elliot 1994), and salmon have also been observed in or moving through karst systems on Vancouver Island and on Princess Royal Island. On Haida Gwaii, the authors have observed Dolly Varden char (*Salvelinus malma*) inside a karst cave far from the nearest entrance.

The study of the condition factors, feeding, residence time and reproduction of non-troglobitic fishes such as those encountered in the karst caves of coastal BC, including Haida Gwaii, may help to shed light on the evolutionary biology of troglobitic fishes (G. Proudlove, pers. comm. 2009).

## Karst Recreation and Tourism

"Karst tourism" may seem to be an odd concept at first glance, but many famous karst landscapes, such as the tower karst of Guilin (China) and Vietnam's Ha Long Bay; the limestone pavements of the Burren, Ireland and the United Kingdom; the surreal Tsingy de Bamaraha karst of Madagascar; the cenotes of Mexico's Yucatan Peninsula; and the spectacular lakes, waterfalls and tufa dams of Croatia's Plitvice Jezera attract tourists from all over the world (see also Hamilton-Smith 2004b).

**Photo: The Dachstein Plateau Nature Trail in Austria.** *An 8-km long trail circuit allows visitors of all ages to view pristine alpine karst landscapes. With permission of Hallstatt Tourist Office.*

A very fine example of a karst tourist attraction is found closer to Haida Gwaii - the Beaver Falls Karst Trail on Prince of Wales Island, Southeast Alaska.

Recreational tourism opportunities pursued on karst landscapes include interpretive/hiking trails, scenic viewing platforms, "canyoning", kayaking and caving.[10]

The karst resources of Haida Gwaii present both opportunities and challenges for recreation and tourism development. While Haida Gwaii has outstanding karst resources, the majority of the most impressive sites and features are isolated and scattered over a wide geographical area. Several of these karst areas are only accessible by helicopter or long drives on industrial forestry roads, many of which have been decommissioned. This situation presents significant challenges for developing environmentally sound and economically viable karst-related recreation and tourism opportunities. Other current limiting factors for developing on-site karst tourism opportunities on Haida Gwaii include the lack of comprehensive inventories and assessments of karst resources, and a

10 Aspects of cave management, including cave tourism and recreation, are dealt with in the Appendix - Karst Cave Management.

lack of site management plans.

The inherent sensitivity of karst resources makes developing sustainable karst recreation or tourism opportunities very demanding (e.g., see Williams 2008b). Providing environmentally sound on-site karst recreation/tourism infrastructure can be complex and costly. Factors such as viability, access, safety hazards, interpretive concept plans, infrastructure materials and design, visitor carrying capacity, and the assessment of potential impacts associated with developing karst sites must be very carefully considered in the early planning stages of a karst recreation or tourism project.

Karst recreation/tourism projects also require adequate funding for proper interpretation, and ongoing site maintenance and surveillance.

When considering karst recreation/tourism opportunities, preserving the pristine qualities of untouched, natural karst sites should be a top priority. On karst landscapes that have been subjected to some form of previous land use activity, efforts should be made to prevent further damage and remediate any degradation before developing the site for recreation or tourism (Williams 2008b).

Interpretive and safety information at designated karst recreation or tourism sites are important considerations.

Employing remote appreciation techniques can help to preserve karst resources with tourism potential, while making information about them accessible to the public in a safe, sustainable, and cost-effective fashion. Remote appreciation techniques can encompass video and photography, mixed media presentations, and educational exhibits. The Bat Cave Teleview Centre, a unique remote bat viewing facility installed at the Naracoorte Caves, Australia, allows visitors to view the bats via high-definition infrared cameras.

**Photo: The Beaver Falls Karst Trail in Southeast Alaska.** *The site makes excellent use of remote appreciation for a number of sensitive karst resource features, including caves, without entering them.*

Fostering public awareness and education through remote appreciation techniques is one of the most successful ways of familiarizing large numbers of people with karst features. When people understand the sensitivity of karst resources, many will voluntarily choose to avoid behaviours that could damage or degrade them (NZDOC 1999).

The varied karst resources of Haida Gwaii afford residents an opportunity to develop a unique vision for sustainable and innovative karst tourism. Tapping into local reservoirs of traditional knowledge and creativity will help to ensure that any karst tourism activities are distinctive and appropriate for Haida Gwaii.

## Why Are Karst Systems Sensitive?

Karst landscapes can attract a wide variety of human pursuits (e.g., timber and limestone extraction, recreation and tourism, research, etc.) which can place added pressure on karst ecosystems, increase disturbance levels, and elevate land-use conflicts.

In karst systems, the complex inter-connectedness between the various system components – bedrock, water, gases, soils and living things – is such that disturbance to any one will often result in disturbance to the system as a whole (IUCN 1997; see also Hamilton-Smith 2006; Kiernan 1988). Inappropriate land-use activities at the surface can bring about immediate and, at times, irreversible impairment of subterranean karst environments (Gillieson 1996). The environmental risk is often compounded because many land managers and decision makers are unfamiliar with how karst systems function, and subsurface disturbances are not readily observable from the surface.

Subterranean karst environments are most likely to be directly affected by surface activities where adequate protective cover in the form of stable surficial sediments or intact vegetation is lacking, and where connections between surface and subsurface elements of a karst system are particularly well-developed (Gillieson 1996). The effects of surface disturbances on hypogean karst fauna can be potentially more severe because of the limited mobility of some species to avoid impacts and the spatial limits of the habitat, together with naturally low nutrient input levels.

While groundwaters in general are less easily polluted than surface water (Dermer *et al.* 1980), karst aquifers are potentially more vulnerable. Karst aquifers can be sensitive to pollution, unlike some other porous media aquifers (e.g., sand aquifers) where natural processes can benefit from lengthy residence times and more intimate contact with the media (Kiernan 1988). Effects of disturbances occurring on the surface of the permeable karst landscape can be readily transmitted to the subsurface (e.g., fuel spills, soil erosion). Natural purification processes are often much less effective in karst systems, where flow velocities are comparatively high, residence times are short, and filtration and dispersion are sometimes negligible (European Commission 1995). Pathogenic bacteria and other contaminants (e.g., pesticides and fertilizers), can rapidly infiltrate porous karst landscapes and circulate in karst channels and other subsurface voids, surviving the travel times and reaching all parts of the karst system and output features (i.e., karst springs) very quickly (Kiernan 1988).

The highly publicized incident at Walkerton, Ontario provides an example of how karstified carbonate bedrock with rapid groundwater velocities may be highly vulnerable to contamination. In May 2000, the municipal wells became contaminated with pathogenic bacteria, resulting in seven fatalities and illnesses in 2300 people (Worthington *et al.* 2002).

Karst soils – especially shallow soils atop irregular bedrock surfaces – are particularly vulnerable to erosion (Boyer 2004b: Gillieson 1996; Kiernan 1988; Kiernan 2002). The term 'karst' itself is derived from the Serbo-Croat 'krs' meaning 'stony ground' which described regions in the Dalmatian coastal areas that had lost their soil to the subsurface due to deforestation and over-grazing.

The many vertical openings in epikarst offer numerous opportunities for disturbed or displaced soil particles to be washed or carried by gravity into the subsurface (Gillieson 1996; Baichtal and Swanston 1996). Increased or altered surface runoff due to soil disturbance or deforestation is one way soil loss can occur on karst landscapes, particularly on steeper slopes (Boyer 2004b). Soil loss can also occur independently of slope gradient and surface runoff, with soil particles eroding directly into the epikarst from the bottom of soil profiles (Kiernan 1988; Kiernan 2002). The first indication that this is happening may be the gradual exposure of bedrock displaying fluted or grooved rock surfaces, such as rundkarren, which develop beneath soil cover (Kiernan 1988). More dramatically, 'catastrophic collapse' sinkholes (so-called because they appear in minutes or seconds and may enlarge quickly to swallow entire trucks, drilling rigs, homes, etc.) can appear due to the failure of a soil arch formed by sapping into a karst cavity beneath it.

Once soil loss has occurred on karst, it can be exceedingly difficult to reestablish vegetation to arrest further loss and restore site productivity to former levels (Harding and Ford 1993; Boyer 2004b; U. Vilhar, pers. comm. 2009). Harding and Ford (1993) provide a case study from northern Vancouver Island that compares impacts of timber harvesting on karst terrain versus non-karst terrain. This study is analogous to karst landscapes on Haida Gwaii as the Quatsino limestone on Vancouver Island is geologically equivalent to the Sadler Formation on Haida Gwaii. [11]

**Photo: Soil loss on a Haida Gwaii limestone karst landscape.**

Barring those cavities with active running water for all or part of the year, many subterranean components of karst systems tend to be very stable low energy environments, compared to those on the surface. For example, tracks made on sediments on a cave floor may be there for a very long time – human footprints thought to be nearly 30,000 years old have been found in Chauvet Cave in southern France (Tattersall and Schwartz 2001). These lower energy subsurface environments and the values associated with them tend to be less resilient to disturbance (NZDOC 1999).

11 In addition, the non-karst terrain in the study occurred on Karmutsen basalts on Vancouver Island, which also occur on Haida Gwaii.

# Karst and Forests

The majority of the natural vegetation cover on the karst landscapes of Haida Gwaii is coniferous forest. A typical old-growth forest karst site is covered by a multi-layered stand, usually dominated by western hemlock (*Tsuga heterophylla*) and western red cedar (*Thuja plicata*), with lesser amounts of Sitka spruce (*Picea sitchensis*). The age of these stands can exceed 250 years and the largest trees commonly attain heights of 35-45 m as an average, and 50-60 m as a maximum range. Similarly productive forests occur on limestone karst of the north coast of BC (Kranabetter and Banner 2000).

**Photo: A typical productive old-growth forest stand on a Haida Gwaii limestone karst landscape.**

Forests and their soils play an important role in the dissolution of underlying soluble bedrock (e.g., see Gillieson 1996; Gillieson 2004). In addition, well-developed karst sites on Haida Gwaii provide biophysical conditions favourable to productive old-growth forests. Free vertical drainage on karst promotes aerobic conditions in soil and ready diffusion of oxygen and carbon dioxide from tree roots (Gillieson 1996; Gillieson 2004; Aley 2004; Pojar 2002). Aerobic soil organisms depend on this enhanced aeration, which in turn influences the availability of plant nutrients, such as nitrogen and sulphur (Kranabetter & Banner 2000; also Banner *et al.* 2005). While limestone soils are often thin and do not readily retain nutrients, their higher pH values can enhance bacterial action which breaks down nutrient-retaining organic matter such as forest litter through decomposition (D. Gillieson, pers. comm. 2009).

Root masses and associated soil fauna contribute via respiration to the Carbon Dioxide Cascade, which is a key factor in the dissolution process (Viles 1988; Gillieson 2004). In non-karst settings where drainage is impeded, the downward growth and penetration of roots are often restricted, and the depth of soil from which moisture and nutrients can be drawn is effectively reduced (Banner *et al.* 2005). In karst, roots can often extend into and enlarge epikarst fissures, helping to anchor trees, enhance

The underlying epikarst zone promotes free vertical drainage in autogenic karst soils (Gillieson 1996; Boyer 2004a). The water-holding capacity may be greatly enhanced by the addition of organic materials provided by vegetative cover (Boyer 2004a). Autogenic karst soils are often prone to drought in many parts of the world, but this characteristic does not preclude lush forest growth on karst on the northwest coast where rainfall is abundant (Aley 2004).

drainage, and allow for the uptake of moisture and nutrients directly from epikarst bedrock (Gillieson 1986).

Contrasting productive forested karst sites are conditions found in the bogs (muskegs) of Haida Gwaii, where non-decomposed organic matter and excess water can severely limit the growth of forest vegetation.

The ability of forests to store water buffers the flashy hydrology of associated karst systems, attenuating peak flows during storms, while helping to maintain water yields during occasional dry spells via a number of different mechanisms including interception[12], transpiration[13] and shading (Gillieson 1996).

Forest cover plays a critical role in controlling soil erosion in karst landscapes (Gillieson 1996: Boyer 2004b). Forest floor organic matter enhances the water storage capacity of forest soils, making them less prone to erosion (Boyer 2004b). Large root masses and fallen trees help to maintain and stabilize the soil mantle atop karst.

The dominant natural disturbance associated with forested karst landscapes on Haida Gwaii is likely to be small-scale canopy gaps resulting from mortality of one or more trees. Other natural disturbances include fire, wind, insects and pathogens, as well as landslides and other geomorphic disturbances.

Few large natural fires occur in the cool, wet climate of Haida Gwaii, and the topographical roughness of many karst sites likely makes them less susceptible to fire spread and major damage. Fire return intervals in coastal temperate rainforests are in the range of several thousand years. (Lertzman *et al.* 2002; Gavin *et al.* 2003)

Natural catastrophic wind events are comparatively rare on the forested karst landscapes of Haida Gwaii. Pearson *et al.* (2005) have calculated that stand-replacing wind disturbances on Haida Gwaii overall could account for 0.3% of the forested landscape and have a rotation period of nearly 35,000 years. Here too, the very nature of karst can make sites less susceptible to wind effects. Deep rooting in epikarst may make some of the forest stands somewhat more resistant to windthrow. Small-scale windthrow events can influence tree productivity positively by mixing organic matter with mineral soil horizons to improve soil aeration and nutrient uptake and cycling (Banner *et al.* 2005).

Landslides and other geomorphic disturbances are rare events on well-developed karst landscapes with thin cover deposits, and are more likely to occur in adjacent or upland non-karst areas.

Carbon dioxide is released into our atmosphere when carbon-containing fossil fuels, such as oil, natural gas and coal, are burned in air. The rising levels of $CO_2$ in the atmosphere from these anthropogenic sources are likely to influence karstification on Haida Gwaii. The pH of precipitation water will be lowered, increasing its acidity and dissolution power. On soil-covered limestone karst landscapes in high rainfall areas like Haida Gwaii, more plant activity due to elevated atmospheric $CO_2$ levels would lead to more soil $CO_2$ and enhanced dissolution rates at the soil-epikarst interface (J. Mylroie, pers. comm. 2009).

This century is expected to witness greater climatic changes than any other since the end of the last Ice Age about 12,000 years ago. Under predicted climate change scenarios for coastal BC, including Haida Gwaii, the role of forests in precipitation water storage and karst system recharge is likely to gain importance. Among the possible effects of changing climate on karst are variations in the amount, intensity and timing of rainfall, and changes in evaporation, which is closely related to temperature. Other possible effects of climate change will be associated with wind speed, vegetation characteristics, and soil properties (Spittlehouse 2008).

12 Interception is the capability of trees, especially conifers, to trap and store water on their surfaces due to adhesion forces

13 Transpiration refers to the process in which plant roots absorb water, which moves through the plant and is finally returned to the atmosphere via evaporation from leaves and sometimes stems. Evaporation is the transformation of water from a liquid state to a gas.

# Forestry Activity Impacts

Forestry activities can modify the structure, function and ecological integrity of karst landscapes. The general impacts of forestry activities on karst landscapes have been described extensively in karst literature reviews by B.A. Blackwell and Associates (1995), Stokes (1996), and others.

Much of the karst on Haida Gwaii occurs with productive old-growth forests. Two silviculture systems that manage stands on an even-aged basis have predominated on the islands – clearcuts with reserves, and retention (von Schilling 2003). A clearcut is an area where trees, within an area larger than one hectare and greater than two tree lengths in width, are removed in a single harvest (BC Ministry of Forests 1999). The retention system retains individual trees or groups of trees to maintain structural diversity over the area of the cutblock for at least one rotation. Retention can be dispersed throughout a cutblock as single trees or aggregated groups of trees.

While the net resulting effects of forestry activities may be less important at the site level (e.g., in relation to an isolated smaller scale karst landform), they may constitute a major disturbance at the karst system level when imposed repetitively over a given landscape.

Impacts on the integrity of the climate-vegetation-soil system on carbonate rock terrain are perhaps the most important aspect of forestry activities on karst landscapes because forest cover influences or mediates dissolution (Viles 1988; Viles 2004) and karst system recharge processes. (Bárány-Kevei 2003)

While there is a substantial amount of literature available on best practices for conducting forestry activities on karst landscapes, there have been few ongoing research efforts to gain a better understanding of the full environmental impacts. The extent to which natural or forestry-related disturbances lead to changes in karst ecology, either temporally or spatially, has not yet been evaluated on Haida Gwaii karst.

By recognizing potential forestry activity impacts, responsible authorities can apply proven best practices and mitigation measures to reduce the risk of significant impairment of karst resources. (See **Planning and Management Considerations** section).

## Timber Harvesting

Timber harvesting will modify localized microclimates, soil properties, the quantity and quality of water available to recharge karst systems, and increase inputs of organic matter and sediment into the subsurface. The removal of mature trees can also affect nutrient cycling. With the removal of moisture-absorbing trees on the surface, the extra influx of water can leach more nutrients and other dissolved substances from the soil.

Removing the forest canopy changes the evaporation and transpiration regime, and increases the distribution and amount of rain or snow reaching the karst surface. Radiant energy balances are altered, and incident solar radiation at ground level is substantially increased. The consequent warming and reduced capacity of the landscape (without its forest litter layer) to retain water can cause biochemical changes in the soil, and influence the amount and dissolution strength of percolation water reaching the epikarst.[14]

Removal of the forest canopy can also modify the microclimates of karst transition zone habitats and shallow subsurface cavities. Air temperature and relative humidity ranges in these habitats thus altered will more closely resemble those of surface climatic regimes, and surfaces that were once perpetually moist due to stable high humidity

14 Greater aggressivity of seepage waters can occur under deforested karst surfaces (Gillieson 1996).

conditions can be subjected to periodic desiccation.

The topographical roughness of some karst landscapes can cause increased breakage of felled timber, resulting in the deposition of more harvesting residue (logging slash and related debris).[15] The introduction of harvesting residues above the natural load on epikarst exposures and other karst features can alter the pattern of air currents and infiltration patterns for water and organic nutrients.

**Photo: Timber harvesting at Haida Gwaii karst site.** *Harvesting residue on or adjacent to a karst microsite can result in the following types of direct or indirect physical alteration, disruption or destruction of surface habitat: a) burial, displacement or smothering of surface flora and fauna, and their associated habitats; b) reduction of sources of suitable food, increasing the risk of starvation and predation; and, c) alteration of site drainage patterns by settlement and compaction of residue.*

Excessive harvesting residue deposits in karst transition zone environments can obstruct atmospheric connections to subsurface karst habitats, limiting their usability by troglophiles or trogloxenes. Damage or destruction of rare plants or plant assemblages or the surface habitat for epigean or troglophilic fauna (e.g., bats) can also result.

Harvesting residue, once exposed to air, water, and soil microbial activity, breaks down and releases dissolved organic substances, including humic and fulvic acids. These compounds begin to leach immediately from the residue upon contact with precipitation water, infiltrating surface water or groundwater.[16, 17]

Where there are no confining layers in the soil, leachates are transferred rapidly by gravity percolation into the epikarst. Underground, the leachate can be recognized by its dark colour, foam and occasional iridescent sheen. It can appear in drip waters and surface films inside karst cavities, and leave persistent stains on speleothems in caves. Turbulent flow conditions in underground streams containing leachate can add to foam

15 In timber harvesting, only the bole or log is extracted from the forest, while the crown (consisting of foliage and branches) is treated as residue or waste. The wood residue can also include broken logs, decadent timber and stumps.

16 The wood residue from freshly cut trees initially generates a more concentrated leachate than that from weathered wood residue. Breakage of timber felled on rough karst landscapes can reduce the particle size of residue and increase the exposed wood surface area available for leaching.

17 Other classes of compounds in leachate include tannins and lignin, phenolics, tropolones and resin acids.

formation, leaving its residue on surfaces well above the normal mixing zone.

If excessive amounts of particulate organic matter, and soluble and non-soluble organic compounds associated with harvesting residues, are introduced underground through cracks, fissures or open solution features, they can modify subsurface habitats to the detriment of existing organisms or populations, and/or influence the behaviour of organisms. Impacts may include an overall decrease or partial loss in species diversity, abundance and biomass, particularly with regard to hypogean invertebrate communities. The diversity and density may shift toward a less complex community and ecology as more opportunistic heterotrophic epigean (surface-dwelling) species utilize the surplus food source. Anoxic conditions (a reduction in molecular oxygen supply in the system) brought on by the simple decomposition of the harvest residue and its more mobile oxygen-demanding leachate may result in immediate and widespread mortality and/or a decrease in the rate of growth of hypogean organisms. Contamination of karst groundwater by residue and leachate can also impact fish if they are present in underground streams or if the karst aquifer discharges into surface fish habitat.[18]

Timber harvesting increases water inputs into the karst system that in turn can accelerate erosion and sedimentation rates (Boyer 2004b). The groundbreaking forces associated with timber harvesting invariably disturb, compact or remove the often thin soil cover on karst landscapes. Where thin soil mats cover bedrock projections of epikarst, they can easily become detached, or desiccate and slough off. Ground disturbance can also occur when logs are dragged without full load suspension over the surface.

**Photo: With most harvesting methods, soil erosion can occur even on gently sloping or flat terrain on well-developed epikarst, whereas erosion is not normally an issue on a non-karst landscape of similar slope gradient.**
*(Harding and Ford 1993)*

The negative impacts of soil erosion are not limited to the surface of the karst landscape. Once underground, eroded sediments can obstruct passages and conduits,

18 Aqueous wood extractives are known to be acutely toxic to fish and aquatic invertebrates at relatively low test concentrations in ambient water.

alter air and water flow patterns, and smother hypogean habitats, particularly for species and communities in the saturated zone of the karst (Clarke, 1997; and Kranjc 1979, as cited in Gillieson 1996). The introduced waterborne sedimentation can also impact aesthetic values in caves by soiling or staining speleothems and relief features.

Removing forest cover can also change wind patterns, often increasing wind speeds at ground level, exposing trees along clear-cut edges to greater wind speeds and making them more susceptible to blowdown. Post-harvest windthrow on karst landscapes can impact the soil-epikarst system interface by dislodging bedrock and soil, disrupting natural infiltration patterns and solution processes, obstructing subsurface pathways, and affecting the biology of subsurface karst environments and/or downstream aquatic resources. The accompanying soil losses can reduce long-term site productivity as well.

The level of windthrow impact on karst landscapes is closely related to soil thickness and the level of epikarst development. Where the level of epikarst development is low and the soil cover is thick, the magnitude of windthrow is often less severe.

Harding and Ford (1993) found that clearcutting on sampled northern Vancouver Island limestone karst sites (some with prescribed burning) led to an average soil depth reduction of 25% five years after harvest, increasing to 60% after 10 years.

**Photo: Harvest-related tree windthrow on Haida Gwaii karst site.**

**Chronosequential photos: Soil-covered karren forms can be exposed by accelerated soil erosion following timber harvesting or post-harvest windthrow.** *(Northern Vancouver Island.)*

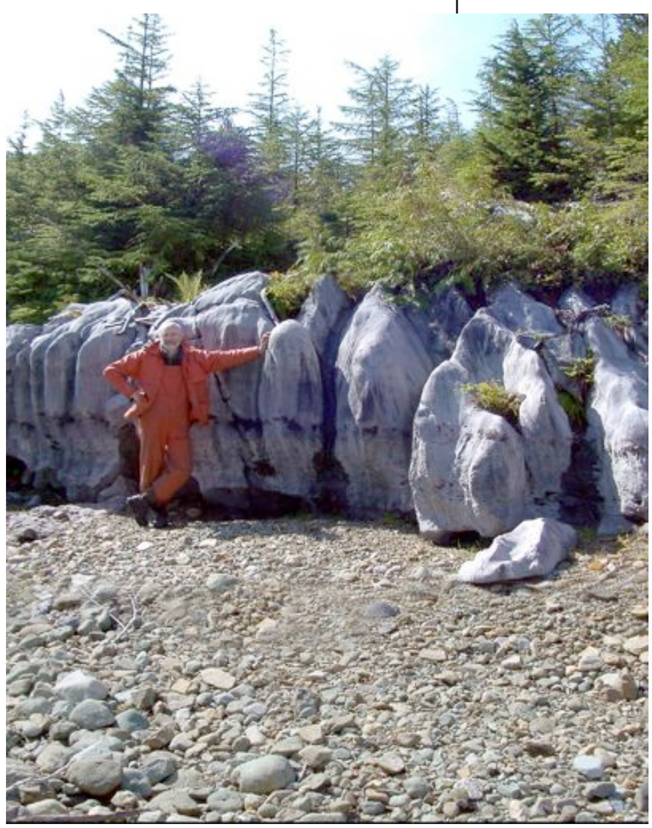


**Photo: Positive-relief features, such as residual karst hums and bedrock projections, can be impacted by the mechanical forces that accompany timber harvesting.**

Removing forest cover can profoundly modify microclimatic conditions and the composition of plant communities within features such as sinkholes. Extreme temperature fluctuations can result within larger sinkholes after removal of forest cover (Bárány-Kevei 2003).

Sinkholes with steep inner slopes are particularly susceptible to ground disturbance caused by timber harvesting. Eroded soils and sediment can often pass through the base of these solution features into subsurface karst environment.

**Photo: Riparian forest cover removed along a karst stream channel.**



Removing the forest cover in the riparian zones of sinking streams, inadequate protection of stream banks and channels, and poor location and design of stream crossings, can introduce soil and sediment into sinking streams (Clarke 1997), and modify water temperatures and flow regimes. More energetic sinking streams can carry harvesting residue into subsurface openings. Excessive, unnatural inputs of conifer needles and sawdust are easily entrained even by low energy watercourses, and associated dissolved organic substances can lead to de-oxygenation of the receiving karst waters. These finer organic particulates and dissolved organics can coat or smother subterranean habitats and impact nutrient regimes for hypogean faunal communities.

Eliminating or reducing the forest cover along sinking streams can also fundamentally alter hypogean faunal communities dependent on downstream drift of organic matter and epigean (surface) aquatic fauna.

## Road Construction, Maintenance and Deactivation

The use of heavy machinery for grubbing and pulling stumps, excavating, and grading during the subgrade preparation of forest roads will disturb the soil cover, and alter natural surface water movements and infiltration pathways (Clarke 1997).

Surface karst landform elements and shallow subsurface cavities can be intersected and destroyed during road construction.

**Photo: The presence of underlying karst cavities is difficult to detect from the surface and can result in subsidence or collapse even in the later stages of road use.**

The construction of forest roads imposes a semi-impermeable surface on naturally porous karst landscapes and can significantly impact water availability and water quality in karst systems. The provision of excavated ditches along forest roads can disrupt natural infiltration patterns on permeable karst landscapes. Roads have been linked to a reduction in density, abundance and diversity of macro-invertebrates and aquatic fauna in downstream locations (Barton 1977; Cline *et al*. 1982). Surface fines in road runoff can easily pass underground and impact hypogean faunal communities. The runoff flow may also contain hydrocarbons, oils and heavy metals originating from vehicle emissions and leaks.

**Photo: Road-related impacts can also occur where over-steepened fill slopes are permitted adjacent to sinkholes and other infiltration features.**

Quarrying for road ballast and surfacing materials in karst landscapes can lead to changes in groundwater quality and subsurface hydrology, as well as changes in erosion rates and sediment deposition regimes. The use of explosives and heavy equipment in quarry development and road building can directly impact the immediate karst surface, and produce noise, vibration, and air and water quality impacts that are transferred underground.

**Photo: Quarrying on a Haida Gwaii karst landscape.**

In addition, roads can increase public access to sensitive karst sites (BC Ministry of Forests 1991).

## Silvicultural Treatments

Pruning and spacing debris introduced into surface openings or sinking streams can clog infiltration points or pass into subsurface karst systems.

Although broadcast slash burning on karst landscapes with sensitive soils is no longer an accepted forest management practice, spot burning or fire escapes may lead to localized impacts. Prescribed burns can incinerate forest floor materials, expose and calcine the limestone bedrock (convert the bedrock to powder by heating), and change soil structure. Burning makes soil more water repellent, resulting in higher surface flow and soil erosion rates during precipitation events (Scott 1993; Hubbert *et al.* 2006).

**Photo: Burning on limestone karst can convert bedrock to powder.**

Salvage logging of windthrow can further disturb soil and rock in well-developed karst landscapes. The new openings created by windthrow salvage logging operations can increase the windloading for the remaining trees along boundaries and lead to further windthrow.

# Planning and Management Considerations

The surface and subsurface components of karst landscapes are generally recognized as environmentally sensitive areas. Their protection must therefore be a key planning and management objective.

For many decades, logging of karst landscapes in coastal BC occurred without much regard for karst systems or their ecology. Existing guidelines were not well researched, and often not well applied or understood. Knowledge of actual karst site conditions was often insufficient to render informed management decisions, and in many cases, appropriately qualified professional assistance was not sought or relied upon. This was especially true with regard to assessing the vulnerability of karst terrains and delineating recharge areas for karst systems. There was no significant change in practices until the late 1990s, when the call for sustainable karst resource management based on ecological precepts became particularly acute.

In 1997, the Ministry of Forests in BC moved toward an ecologically based approach to karst designed to help ensure sustainable management of karst systems. The *Karst Inventory Standards and Vulnerability Assessment Procedures for British Columbia* (RISC 2003) is now an accepted protocol. The inventory methodology is complemented by the *Karst Management Handbook for British Columbia* (BC Ministry of Forests 2003), which describes recommended best practices for karst management primarily in a forestry context, and where the major goals of karst management include the continuance of timber production for economic benefit.[19] While these documents remain important sources of guidance, approaches to vulnerability classification, and sinkhole protection in particular, have evolved since their publication based on the recommendations of many practicing karst resource professionals in BC and members of the karst academic and scientific community.

If extraction of natural resources from the surface or subsurface of a karst landscape is proposed, karst resources must be professionally inventoried and evaluated, and planned activities carefully assessed to ensure ecological sustainability of the karst system. Consideration must be given not only to the protection of discrete landform elements and structures, but also to the maintenance of karst processes, habitat characteristics, and surface and subsurface geodiversity and biodiversity at both site and landscape levels (IUCN 1997).

Sustainable land-use activities above and below the surface must follow protection strategies based on karst inventories and vulnerability assessments completed by qualified and competent karst resource professionals (Griffiths *et al*. 2002)

Karst resource professionals are expected to have a very solid understanding of how various aspects of karst systems – ecology, geology, physical geography, hydrology, chemistry, etc. – work together and how different land-use activities can affect karst ecosystems, supporting processes and values. A professional can only undertake and accept responsibility for professional assignments when qualified by appropriate training and/or experience. Professionals have an ethical obligation to practice within their areas of expertise and to call in and defer to specialists from other disciplines when appropriate (Professional Reliance Task Force 2006).

Professional reliance is one of the cornerstones of the current results-based

While the provision of safe drinking water from karst aquifers is one of the main karst management objectives in many foreign jurisdictions (25% of the world's population drinks karst water), objectives in coastal BC must focus holistically on the protection of karst as an ecosystem with many natural and cultural values. The protection of karst aquifers on Haida Gwaii for domestic water supply is not particularly urgent where alternative sources are currently available. Nevertheless, the vulnerability of karst aquifers to possible contamination remains very high, and appropriate management is important for the protection of other aquatic karst resource values such as fisheries.

19 These protocols have been recommended for adoption worldwide, in the leading textbook (see Ford and Williams 2007:473).

approach to forest resource management in BC, and is entirely applicable to karst (Coast Region FRPA Implementation Team 2006). The effectiveness of the professional reliance model to adequately conserve karst resources has not been evaluated.

Special safety precautions are needed when working in karst landscapes as they often have hazards completely different from other types of landscapes.[20]

## Ecosystem-Based Management

Ecosystem-based management (EBM) is an integrated, science-based approach to the management of natural resources that aims to maintain key characteristics of ecosystems in a manner that sustains species and ecological processes but also supports some human activities for economic or social purposes. EMB emphasizes the protection of ecosystem structure, function and key processes over the long term.

The EBM approach represents a shift from a management strategy of protecting individual karst elements to one where protection of landform elements requires landscape-level considerations.

Maintaining the ecological integrity of the karst landscape as a whole over the long term is the desired objective of EBM applied to karst. This integrity can be defined as the ecological condition characteristic of the landscape in its natural setting, and within the range of natural variability[21], and likely to persist in the absence of human disturbance. The ecological condition of karst landscapes encompasses the surface and subsurface living and non-living components of the karst system, and can include composition and abundance of native species and biological communities, rates of change, and supporting processes. (Bárány-Kevei 1999a)

The presence of distinguishable surface karst landforms (e.g., sinkholes and similar infiltration features) or caves is one of the basic indicators of a high vulnerability karst landscape (e.g., see Kiernan 2002).

**Photo: A high vulnerability karst site on Haida Gwaii typically has a relatively thin soil cover, closely spaced infiltration features, and some topographical roughness.**

20 Irregular surface micro-topography and epikarst exposures often include enlarged solution openings that can act as foot traps. In other areas forest litter and root masses can hide dangerous solution openings, such as small crevices and grikes. The presence of logging slash on irregular surface micro-topography, and around karst features and cave entrances in logged karst landscapes, poses an additional safety hazard. Workers must be aware of dangerous surface openings (e.g., deep shafts, grikes) that may be hidden by the logging slash.

21 The range of natural variability can be defined as the range of dynamic change in natural systems over historic time periods (~500 years before present) (BC Ministry of Forests and Range 2008).

As a rule, it is unnecessary to determine the precise relationships between individual karst features that populate a karst system. In the EBM approach, the management unit of concern is the total karst catchment rather than discrete features, and the unit can extend to contributing non-karst (i.e., allogenic) recharge components.

Maintenance of a continuous mature forest cover of native species is a desired natural condition in forested karst landscapes and an essential element of the EBM approach. As noted in earlier sections, intact vegetation and soil cover are pivotal to the maintenance of critical soil properties, and the natural hydrological processes and dissolution rates on karst landscapes (Gillieson 1996; IUCN 1997). Maintaining sufficient intact vegetation cover is also the best way to prevent soil erosion on karst landscapes (Boyer 2004b; Gillieson 1996), which can lead to denudation of the karst surface and degradation of karst ecosystems both on the surface and subsurface (Gams 2003).

Maintenance of continuous forest cover also favors enhanced water storage capacity and balances underground water flows and spring discharges (Gillieson 1996; Vilhar, in press).

If EBM is to be achieved on forested karst landscapes, harvesting wood should only be carried out in such a manner as to resemble the natural structural diversity of forests following natural disturbance events (Vilhar *et al.* 2005). Understanding the nature and frequency of natural disturbances on karst landscapes within coastal temperate rainforests, and their effects on karst systems, is therefore a basic prerequisite of EBM and requires in depth research. Full retention of forest cover with appropriate preventative windthrow treatment in surrounding areas is often the most effective strategy for meeting the ecological objective for managing karst sites.

Development of comprehensive karst-specific EBM guidelines for Haida Gwaii will require establishing baselines for comparative analysis of natural disturbances and native species composition in logged versus unlogged forested karst landscapes. Status maps showing the existing forest cover condition of allogenic and autogenic karst catchments, supplemented by hydrological mapping derived from dye tracing, are essential tools for EBM land use planning on karst. In addition, local research and monitoring are needed to evaluate the impacts of various land uses on habitats in high vulnerability karst sites and identify the species associated with karst systems that are sensitive to microclimatic changes. The results of these studies can be used to help refine the EBM methodology.

Disturbed or degraded karst sites that would otherwise require centuries to recover their native old-growth forest characteristics may be candidates for planned rehabilitation (e.g., planting, thinning, etc.) under EBM. A reliable inventory of degraded forested karst sites on Haida Gwaii would be required to develop priorities for site rehabilitation.

Comprehensive knowledge of local karst resources forms the basis of a karst management system within an EBM framework. This allows for informed planning, and the development and application of appropriate land use practices (e.g., forestry methods and practices). Evolving EBM methodologies for minimizing disruption of karst systems will benefit from knowledge derived from research and monitoring.

The Appendix presents more detailed information on requirements, and recommended management strategies and practices for karst caves.

Restoration of a late succession or climax forest community on an old-growth forested karst site may not be seen for centuries if the silvicultural system is mostly by clearcut and the harvesting cycle (‘rotation’) on the site is shorter than the natural life span of the dominant tree species.

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# Glossary

*Accretion* – the process of continental growth by the addition of successive rock formations.

*Allogenic* – meaning generated or coming from elsewhere; principally allogenic drainage, which is drainage to karst from runoff originating on non-carbonate rocks upstream.

*Amphipod* – a small crustacean.

*Anoxic* – the condition of oxygen deficiency.

*Anthropogenic* **-** resulting from human manipulation or activities.

*Aquifer* **-** a saturated, permeable geologic unit of sediment or rock that can transmit significant quantities of water under prevailing hydraulic gradients.

*Archaeological site* **-** defined as a geographical location that contains physical evidence of past human activity for which the application of archaeological methods of inquiry (e.g., site survey, excavation, data analysis) are the primary source of information.

*Archaeology* – the scientific study of the physical evidence of past human cultures.

*Aspect* – the direction toward which a slope faces; its exposure in relation to the sun.

*Autogenic* **-** the precipitation falling directly on the karst portions of karst catchment areas that infiltrates the ground surface and enters the karst system.

*Biomass* – the dry weight of all organic material, living or dead, above or below the soil surface.

*Biome* - life zones, all plants, animals, and other organisms, as well as the physical environment in a particular area. A biome is characterized by its plant life, the types of which are determined by a location's climatic conditions, latitude, and altitude.

*Biospeleology* - the study of subterranean living organisms, particularly in caves in limestone regions.

*Calcine* – to convert bedrock to powder by heating, normally to temperatures above 800° C.

*Canyoning* - traveling in canyons using a variety of techniques that may include walking, scrambling, climbing, jumping, abseiling, and/or swimming.

*Carbonate bedrock* – rock consisting mainly of the carbonate minerals, aragonite and calcite, ($CaCO_3$) and dolomite ($CaMg{\cdot}2CO_3$).

*Catchment* – the surface area drained by an integrated set of watercourses upstream of a given position such as a river mouth, tributary junction, etc..

*Cave* - a natural cavity in the earth that connects with the surface, contains a zone of total darkness, and is large enough to admit a human. For the purposes of cave management, this term should also include any natural extensions, such as crevices, sinkholes, pits, or any other openings, that contribute to the functioning of the cave system.

*Caving* – the recreational exploration of caves.

*Clearcut* - an area of forest land from which all merchantable trees have recently been harvested.

*Conduit* – underground channel for water.

*Copepod* – an animal in the order Copepoda, minute crustaceans.

*Cutblock* - a specific area, with defined boundaries, authorized for tree harvest.

*Disjunct* - refers to the absence of a connection as in the geographical distribution of a taxon or a community.

*Disturbance* - a significant change in the structure and/or composition of ecosystems, communities, or populations through natural or human-induced events.

*Diurnal* – daily cycle; may refer to daytime in contrast to nocturnal.

*Dolomite* – a mineral composed of calcium magnesium carbonate. Rock is chiefly composed of the mineral, dolomite ($CaMg{\cdot}2CO_3$). Also called 'dolostone'.

*Dike* – a wall-like or tabular body of igneous rock that cuts across or intrudes into the structure of adjacent rocks.

*Ecotone* - a transition area between two adjacent ecological communities usually exhibiting competition between organisms common to both.

*Endemic species* - a species that is indigenous to a particular area; not introduced and often with a limited geographical range.

*Endokarst* - the part of a karst system that is beneath the surface. It includes the full spectrum of underground voids and the dissolutional features that are present on the rock surfaces surrounding them.

*Epigean* – pertaining to, or living on, the surface of the earth.

*Epikarst; epikarst zone* - the upper surface of karst, consisting of a network of intersecting fissures and cavities that collect and transport surface water and nutrients underground. Epikarst depth can range from a few centimetres to a few tens of metres; it is normally limited to the top few beds in a limestone or dolomite sequence.

*Evaporation* - the transformation of water from a liquid state to a gas.

*Evapotranspiration* - the sum of evaporation andtranspiration.

*Flowstone* – a precipitate from seeping water in a cave that forms a roughly uniform layer on the floor or down a wall. Usually of calcite in a limestone or dolomite cave. Usually associated with stalactite and stalactite deposition on or adjoining it.

*Geomorphic* – pertaining to the form and/or origin and development of landforms and landscapes.

*Grike* - a deep, narrow, vertical or steeply inclined rectangular slot in carbonate bedrock, developed by solution along a joint or similar fracture.

*Gypsum* – the mineral, hydrated calcium sulfate ($CaSO_4 \cdot 2H_2O$).

*Heterotrophic* – refers to an organism in which complex materials, especially organic foods, are the chief source of nutrition.

*Hypogean* – living below ground.

*Interception* - the capability of trees, especially conifers, to trap and store water on their surfaces due to adhesion forces.

*Invertebrate* – any animal lacking a backbone.

*Karren* – channels or furrows separated by ridges resulting from solution on bedrock surfaces; the term is also used broadly to describe a variety of superficial solution forms on the surface of bedrock, including grikes.

*Karst* - a terrain, generally underlain by limestone, dolomite or gypsum, in which the topography is chiefly formed by the dissolving of rock, and which is commonly characterized by karren, closed depressions, subterranean drainage, and caves.

*Karst hum* - a small residual hill of soluble rock standing above a recently eroded soluble rock surface.

*Karst resources* - refers to all components of a karst system, including the physical, biological, and aesthetic aspects of a karst landscape.

*Karst spring* – the outlet of an underground stream, where it emerges at the surface; also known as a 'rising' or 'resurgence'.

*Karstology* - The scientific study of karst, embodying all the earth science disciplines as applied to the study of karst in the four dimensions. Includes speleology – the scientific study of caves.

*Landform* - any physical, recognizable form or feature of the earth's surface, having a characteristic shape, and produced by natural processes.

*Limestone* – a sedimentary rock comprised primarily of calcite or (more rarely) aragonite.

*Marble* – limestone that has been hardened and partially or entirely recrystallized by heat and pressure.

*Microflora* – microscopic plants.

*Palaeontology* – science that studies fossil remains, both plant and animal, from past geological ages.

*Pathogenic* – able to cause disease.

*Permeability* – the capacity of a rock for transmitting a fluid.

*Protists* – members of Protista, a group of comparatively simple organisms that have characteristics of both plants and animals. The protists include such familiar organisms as seaweeds, amoebas, and slime molds.

*Recharge* - water added to an aquifer. For instance, rainfall that seeps into the ground. Recharge area - the surface area in which water is absorbed into an aquifer, eventually to reach the zone of saturation (phreatic zone).

*Refugia* – climatically stable areas; and areas whose climate remains habitable, when that of the surrounding areas has changed. Geographical refuges of plant and/or animal species destroyed in surrounding areas by the arrival of adverse physical conditions such as glacier cover or aridity.

*Riparian area* – riverbank; an area of land adjacent to a stream, river, lake, or wetland that contains vegetation that, due to the presence of water, is distinctly different from the vegetation of adjacent floodplain or higher areas.

*Rundkarren* - solutional pits or channels having intervening rounded ridges; if exposed on the open surface, probably exhumed after formation beneath soil.

*Seismic* - relating to or caused by an earthquake or earth tremor.

*Silvicultural treatments* - activities that ensure the regeneration of young forests on harvested areas, enhance tree growth, or improve wood quality in selected stands. Activities include: site rehabilitation and preparation, planting, spacing, fertilization, and pruning.

*Sinkhole* (or *'doline'*) – a topographically closed karst depression, wider at the rim than it is deep; commonly of a circular or elliptical shape with a flat or funnel-shaped bottom. Diameter ranges from a few meters to more than 500 meters, and diameter:depth ratios normally range 0.1 -1.0

*Solutional cavities* – cavities formed primarily by the solution action of water on carbonate or other soluble bedrock.

*Speleology* – the scientific study of caves.

*Speleothem* - secondary mineral deposits formed in caves, such as stalactites or stalagmites. Also known as cave formations or cave decorations; chiefly of calcite or aragonite in limestone regions.

*Stalactite* - a cylindrical or conical precipitate hanging from the roof of a cave, generally calcite formed by dripping water and often having a hollow canal at its center.

*Stalagmite* - a candlestick-, cone- or dome-shaped precipitate formed on the floor of a cave and building up above it; in limestone and dolomite, usually a precipitate of calcite. May have a source drip from a stalactite above it.

*Subgrade construction* – removal of obstacles and materials necessary for the construction of a road.

*Taxa* – in biology, a major category, or taxon, of organisms with a common design or organization.

*Tectonic* – relating to the forces that produce movement and deformation of the earth's crust.

*Terrane* – a geologic province in the earth's crust that has geologic features distinct from those around it.

*Till, moraine* – heterogeneous mixture of clay, sand, and rock fragments of all sizes, ranging from small pebbles to boulders deposited by a flowing glacier.

*Transpiration* - process by which water that is absorbed by plants, usually through the roots, is evaporated into the atmosphere from the plant surface, such as leaf pores.

*Troglobite (troglobiont)* - an animal living permanently underground in the dark zone of caves and only accidentally leaving it. The prefix 'troglo' can be used with reference only to terrestrial fauna and the prefix 'stygo' used for aquatic species. Thus, for aquatic species, troglobite becomes "stygobite" or "stygobiont".

*Troglophile* - a facultative cave-dwelling animal that may complete its life cycle in a cave, but can also survive in above ground habitats (e.g., beetles, millipedes).

*Trogloxene* - an animal that enters caves for various reasons, but does not live there permanently (e.g., bats, bears).

*Windthrow (blowdown)* - tree or trees felled or broken off by the wind.

# Appendix – Management of Karst Caves

Cave resources within karst systems must be managed to protect fundamental physical and biological processes, as well as individual features, species, and animal and plant communities and the habitats that support them. They must be managed along with the karst system as a whole (Williams 2008b).

Responsible authorities are entrusted to actively pursue rigorous measures to protect cave resources from damage or destruction. This objective entails managing surface land-use activities that could damage or degrade cave resources (Williams 2008b). It also calls for preventing damage to cave resources caused by visitor abuse, misuse, or incompatible research activities (e.g., see Buchanan and Maguire 2002; Kiernan 1988).

The sensitivity of all but high energy cave passages is usually such that caves will invariably suffer some amount of degradation every time humans are introduced – damage that is cumulative (Hamilton-Smith 2004a; Williams 2008b). "Managing caves" is therefore more about managing people, whether they are tourists, scientists or recreational cavers, and attempting to foresee, avoid and mitigate any damage they might cause (B. Clark, pers. comm. 2009).

Karst caves often contain outstanding examples of natural resources and processes, some truly unique, some with purely intrinsic values (e.g., see Ramsey 2004). As a general rule, the ecological integrity of the cave is a reasonable proxy indicator for other values; if the cave's biology and ecology are intact, chances are good that other natural resource values are also adequately protected.

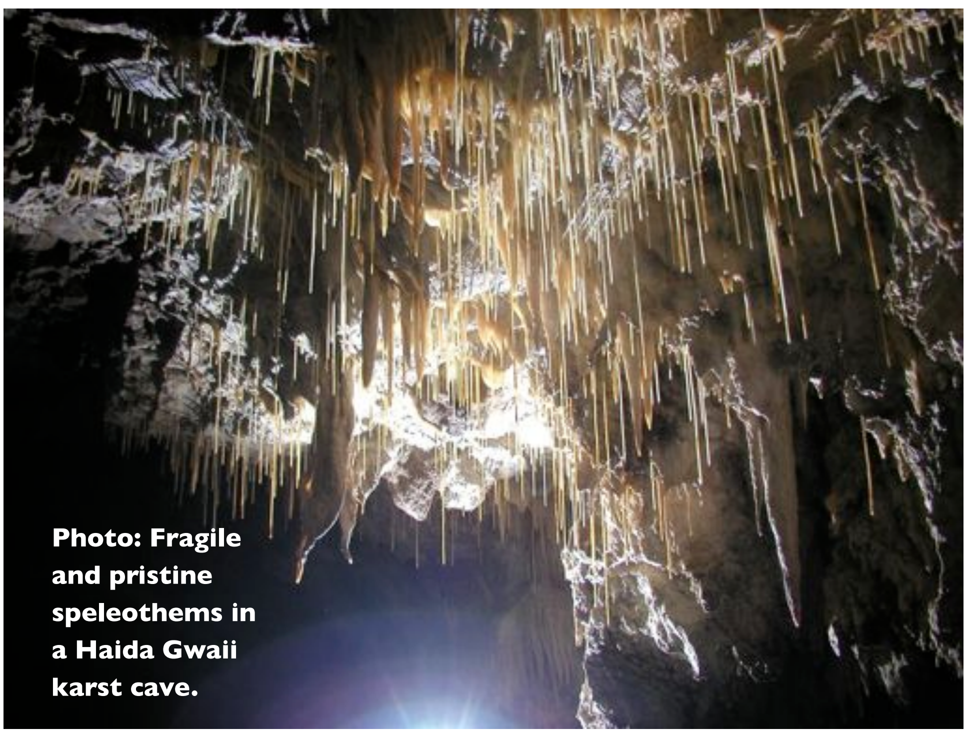

**Photo: Fragile and pristine speleothems in a Haida Gwaii karst cave.**

**Maintenance of the ecological integrity of a cave is paramount** and must not be confused with more specific management objectives based on single goals or uses (e.g., managing caves for recreation). The ecologically based approach to the

"Conservation of caves is a very short-sighted preoccupation unless it is accompanied by energetic attention to conservation of karst as a whole" (Gillieson 1996:268; see also IUCN 1997:5).

The designation of "no use" or "reference caves" is growing in popularity around the world. All would-be users, including scientists, are excluded from visiting these caves to ensure that their resource contents are preserved.

The strategy of keeping people out of caves can often result in the installation of gates to control access. Gating caves can be fraught with problems ranging from diminishing the aesthetics of the natural entrance to altering the cave's natural airflow, and even attracting vandals. Improperly designed gates can impede movement of bats and other fauna that use the cave.

protection and management of karst systems must be applied in all instances, including the evaluation of proposed uses of natural and cultural cave resources. Preventative management is the preferred approach to maintain the natural condition of caves and avoid costly rehabilitation or restoration efforts.[22]

In addition to preserving natural cave resources, the responsible authority must consider and protect any cultural resources associated with a cave, including First Nations cultural uses of a cave both ancient and current, and maintain less tangible qualities such as "pristineness" and/or "sacredness" (see Hamilton-Smith 2004b). Caves can also hold resources that have value for long-term or future scientific observational studies, or as control or reference cave environments.

Government policy statements and guidelines for managing provincial Crown land cave resources specify that important or priority caves should be inventoried and evaluated for the full spectrum of cave resources or values (e.g., see BC Ministry of Forests 1981, 1983, 1986, 1990, 1991 and 1994b). A cave must be inventoried and evaluated before the cave management authority can decide on the relative significance of the cave, the appropriate management directions to take, and resulting implications for confidentiality.

Cave inventories and evaluations identify the susceptibility of the cave to accidental or deliberate damage by visitors. Without an accurate inventory, the responsible authority may not know whether a cave contains hazards or sensitive resources.

The inventory process catalogs cave resources and collects ecological data, whereas the evaluation process analyzes and interprets the inventory data. Together, the inventory and evaluation processes provide critical information for identifying the features or elements that need to be protected and addressed in a cave management plan. Inventory and evaluation information can be particularly useful in developing management decisions for those caves that require more intensive and precautionary management.

An interdisciplinary approach is often needed to define the level of protection and management intensity needed for cave resources, as each resource type is often most closely associated with a particular field of study. An assessment can often require the collaboration of multiple specialists depending on the nature of the cave and identified resource contents.

The overall cave inventory must be coordinated by a qualified professional competent to design, organize, supervise, and undertake a cave inventory. Subsurface inspection and mapping tasks performed by other members of the inventory team should only be conducted by individuals with specialized knowledge, training and experience. The overall coordinator must be capable of identifying any potential or actual danger to human health or safety in the cave environment, and any sensitive, unusual or unique cave resources. This person must also be familiar with the provisions of prevailing best practices and the regulations, standards, policies and procedures that may apply to caves in British Columbia.

It may be appropriate to confine the inventory or evaluation of a cave only to those critical factors that need to be known in relation to a planned land use. For example, when primary forestry activities are planned in the vicinity of a karst cavity in a provincial forest on Haida Gwaii, normally no more than an undemanding subsurface

22 The natural condition of a cave can be defined as the condition that would occur in the absence of human presence in the cave, or human activities on the land surface above the cave that could change the cave.

Cave environments can hold very long and precise records of past climatic variations in their geographic region. Their study may be of great benefit in predicting impacts of future climate change (see Ford and Williams 2007:271-320). Such cave resources must not be lost or compromised through incompatible cave uses.

Archaeological investigations in private and provincial Crown land caves require a heritage permit issued by the Archaeology Branch under the authority of the Heritage Conservation Act if there is to be any alteration or disturbance of the site. Qualified and competent archaeologists should be called in to investigate the archaeological potential of caves and their surrounds on Haida Gwaii, where there is strong evidence or indicators of such potential.

inspection conducted by an experienced, qualified person is needed. By regulation and ministerial order, a cavity in a provincial forest on Haida Gwaii is automatically protected from primary forestry activities if it is definable as a karst cave. The cave must not be damaged or rendered ineffective by these activities, irrespective of the nature of the associated cave resources or values. Simple knowledge of the cave's position beneath the ground surface will enable the responsible authority to identify the extent of the protection zone required above the cave. Under these circumstances, it is not necessary to investigate the natural or cultural resources of the cave, especially if these human interventions are potentially damaging to the cave.

Haida Gwaii is endowed with significant cave resources, many of them sensitive, and with varied appeal and hazard levels. Making caves known and available for use by the public can lead to degradation of natural and cultural cave resources, or risks of personal injury. Responsible authorities can attempt to control undesirable visitations of caves by maintaining confidentiality of information. Such information management is particularly effective for protecting caves in remote locations on publicly managed lands (Griffiths and Ramsey 2008a).

The strategy of keeping people out of caves can often result in the installation of gates to control access. Gating caves can be fraught with problems ranging from diminishing the aesthetics of the natural entrance to altering the cave's natural airflow, and even attracting vandals. Improperly designed gates can impede movement of bats and other fauna that use the cave.

## Cave Tourism and Recreation Management Considerations

Cave tourism goes back at least as far as the 17th century in Europe (Hamilton-Smith 2004a). Worldwide, approximately 20 million people visit caves as tourists each year (IUCN 1997). There are some 650 tourist caves with lighting systems in the world, not counting caves used for "wild" cave tours where visitors carry their own lights (IUCN 1997:7).

The tourism and recreation potential of karst caves must be carefully weighed against each cave's sensitivity. Caves can be sensitive in terms of not only tangible resource values or contents, such as water, cave formations, biology or palaeontology, but also in terms of less tangible cultural values such as traditional use, sacredness or aesthetics. Publicity about specific sensitive caves often draws unwelcome public attention to those caves and other nearby sensitive caves that might otherwise remain undisturbed for hundreds and possibly thousands of years (Griffiths 1997). Visitor impacts to sensitive caves can be persistent and, in some cases, permanent.

Caving is the recreational sport of exploring caves, whereas speleology is the scientific study of caves and the cave environment. In Canada, the practice of caving in organized groups began in the 1950s (Thompson 1976). With areas of known limestone geology reported by Sutherland Brown (1968), loggers' first-hand descriptions of caves, and the promise of other karst features concealed in the rainforest, Haida Gwaii drew the interest of organized cavers beginning in the 1970s.

The islands saw the first group of cavers from Vancouver Island arrive for a brief reconnaissance visit in 1979 (Griffiths 1979). In the 1980s and 1990, small numbers of ardent cavers and speleologists from other parts of Canada and abroad made visits to Haida Gwaii (Griffiths 2001). Benefitting from helicopter access, speleological

The Nakimu Caves in the Selkirk Mountains of BC, first explored in 1904 and one of the Canada's most extensive cave systems, was used for tourism in the early part of the twentieth century. A carriage road brought visitors up to a teahouse near the cave entrance though the 1920s. Visitation eventually declined and the cave was closed to the public in 1935 (Marsh 1973).

Unrestricted access by unsupervised visitors will lead to cumulative damage and/or rapid degradation of sensitive karst caves even in established protected areas.

investigations on Haida Gwaii resumed in earnest in 2000.

Pursuing caving as a personal challenge without sufficient regard for the fragile nature of cave contents can put sensitive caves at significant risk of damage. The commercial marketing of cave tours as a form of "extreme" adventure experience can also be damaging to sensitive karst caves. This type of recreational caving is best confined to high energy cave passages, which are less sensitive to visitor impacts. While the degradation of cultural values, such as the intrusion or defiling of sacred spaces, or impacts to aesthetic appeal, can be harder to quantify, this type of impact is an equally serious concern.

Replica caves and remote cave appreciation techniques can offer more sustainable, practical, and affordable cutting-edge alternatives to visiting real caves. Replica caves are designed and built to withstand wear-and-tear while providing visitors with an experience that very closely approaches that of visiting a real cave. They can be made incredibly realistic and can be designed and located with convenience, safety and accessibility in mind – either as stand-alone attractions or as part of larger remote appreciation exhibits.

Opened in 1983 in southwestern France, "Lascaux II" is an outstanding example of a replica cave that could be mistaken as the real thing. It accurately duplicates the first 40 m of the famous Grotte de Lascaux, which contains some of the finest prehistoric cave paintings in the world. The real cave was closed to the public in 1963 after visitors changed the $CO_2$ and water vapour levels in ways that could have resulted in damage to the paintings.

## Palaeontological and Archaeological Research Activities in Caves

Without question, the scientific knowledge derived from palaeontological and archaeological research activities in karst caves can occasionally rank high among the suite of cave resource values. On the other hand, the potential exists for a conflict between a protection mandate and potentially damaging research activities where cave environments are fragile and basically non-renewable (Williams 2008b; Buchanan and Maguire 2002; Kiernan 1988).

Caves have few if any natural restorative processes – the pace at which nature varies the cave environment can easily be overwhelmed by human-caused disturbances. The enhanced preservation of bone material and its contextual cave environment tend to be associated with the lower energy sections of karst caves, which in turn are inherently more sensitive to disturbance. Bone material can often survive undisturbed in karst caves for many thousands of years, and will continue to do so if the caves themselves are not put at risk.

Unfortunately, some palaeontological or archaeological research activities may only add to impacts in more sensitive caves, when there is possibly already a need to mitigate and curtail use. The identification of palaeontological and archaeological resources can help to establish the protection strategy required for a specific cave, but this information is only one part of the overall cave inventory. The full range of other cave resources or values must also be appropriately inventoried and evaluated, and the information gathered used to support the management plan for the cave.

Baseline data on the nature and type of cave resources and the cave environment must be obtained before research can be approved and activities commence. Where necessary, the data must be reviewed by the responsible authority in consultation with cave resource specialists who have relevant expertise in the specific subject area. The baseline data can be used to set indicators of change to monitor and identify ways to address and monitor unacceptable impacts. When approved research uses are operational, the cave should be monitored anew and independently of the research party to detect changes relative to the baseline data obtained prior to approval of the research.

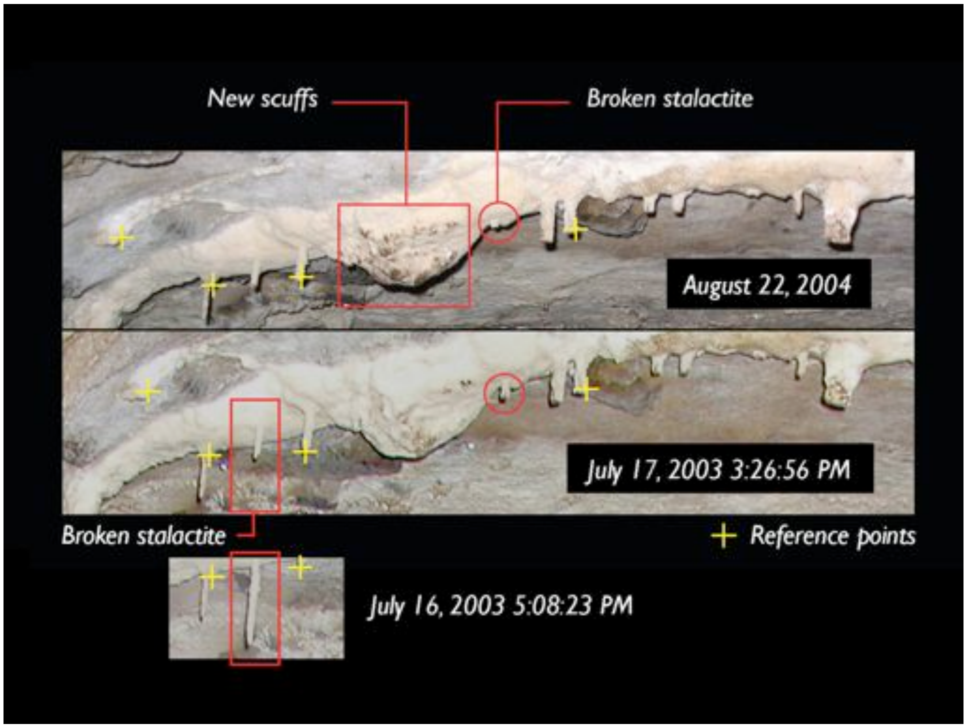


**Photo: Photo-monitoring results for a Haida Gwaii Cave.** *Even the relatively modest level of research activity in some karst caves on Haida Gwaii to date has had a detrimental impact on the cave environments.*

The specific problems posed by palaeontological and archaeological research activities in karst caves were examined as part of *Palaeontological and Archaeological Cave Resources in British Columbia: A Discussion of Management Issues* (Ramsey 2004). This discussion paper led to the development of the *Best Management Practices for Palaeontological and Archaeological Cave Resources* (Griffiths and Ramsey 2005), which were published and widely circulated in BC. The published best practices are based on the Precautionary Principle, which upholds preventive conservation as the most effective means of promoting the long-term protection of a cave. Granting of access to a cave for consumptive research uses must only be contemplated for approval if it can be demonstrated that cave resources and natural conditions will not be significantly impaired.

<u>Provincial Crown Land – Outside of Parks and Protected Areas</u>

Caves outside of the established national or provincial protected areas on Haida Gwaii have no form of legal protection from potentially damaging palaeontological and archaeological research activities. *Heritage Conservation Act* (HCA) provisions aimed at protecting archeological sites may have some limited application to the protection of the environment surrounding archaeological resources in caves, but only if the non-archaeological cave resources are considered for protection. Condition 5 of the General Terms and Conditions of a heritage inspection or investigation permit granted under the HCA requires the permit holder to make reasonable efforts to ensure all sites are restored as nearly as possible to their former condition upon completion of any inspection or investigation involving excavations.

Palaeontological and archaeological research activities in provincial Crown land caves are guided by the 1981 *Crown Land Cave Policy and Administration Statement* (BC Ministry of Lands, Parks and Housing 1981), and regional policies and guidelines for cave management developed by the BC Ministry of Forests in 1983, 1990, 1991 and 1994b. The Haida Gwaii Forest District of the Ministry of Forests and Range encourages observance of the *Best Management Practices for Palaeontological and Archaeological Cave Resources* (M. Salzl, pers. comm. 2009). Since 2005, the Archaeology Branch of the BC Ministry of Tourism, Culture and the Arts has encouraged observance of the best practices document and recommends that investigators engage qualified cave specialists (J. Batten, pers. comm. 2009).

More current guidance applicable to conducting these research activities is found in *Recommendations for Policy and Administration of Palaeontological and Archaeological Research in Caves*. These supplementary recommendations were made following the case-specific review of compliance with recommended best practices at a Vancouver Island karst cave used for research purposes (Griffiths and Ramsey 2008b).[23] Exclusion of certain research uses is recognized by the responsible authorities as the more desirable action to take if the overall objective of protecting the cave system without significant impairment cannot be met by permitting even limited research-driven use.

The Recreation Sites and Trails Branch of the BC Ministry of Tourism, Culture and the Arts will encourage the observance of the *Best Management Practices for Palaeontological and Archaeological Cave Resources* should any karst caves be found in designated recreation or interpretative forest sites (P. Tataryn, pers. comm. 2008).

Provincial Crown Land – Parks and Protected Areas

Provincial protected area laws apply to caves on Haida Gwaii found in provincial parks or ecological reserves. The *Park Act* and the *Ecological Reserve Act* usually mean that damaging activities are prohibited in designated protected areas. By legislation, a permit is required for research activities that take place in parks and ecological reserves designated under the *Park Act*, the *Environment and Land Use Act* or the *Protected Areas of British Columbia Act*. Permit applications are subject to review under the BC Parks Impact Assessment Process.

As the responsible authority, BC Parks recognizes through its Geological Management policies that the conservation of caves as 'geologic features' in the park and ecological reserve system is to take precedence over their use by people, including researchers. For each cave system within parks and ecological reserves, a cave management plan is to be formulated that outlines how the cave resources will be protected and perpetuated, and any opportunities for scientific study and research. In addition, an inventory of cave resources must be prepared, including factors that could lead to use restrictions in particularly fragile cave systems. A process of impact monitoring is to be implemented in each cave accessible by the public, and recognized cave management standards are to be adhered to for most purposes, including research (BC Parks Conservation Program Policies 1997).

BC Parks also has a specific Palaeontological Site Management policy statement whereby it is committed to the protection and preservation of palaeontological features within the parks and ecological reserve system. BC Parks recognizes that palaeontological features have value to society merely through their existence – this policy and concept would extend to palaeontological features found in caves.

*"Unless its existence, and thus its value to society, is threatened by natural forces such as erosion or by public extraction, removal of any palaeontological feature from parks or ecological reserves will not be permitted."* (BC Parks Conservation Program Policies 1997)

23 Following the Precautionary Principle, this guidance recommends that research uses of a cave as a rule be disallowed until a proper inventory (including baseline photo-documentation) and evaluation are undertaken, possible impacts to the cave are assessed by qualified persons independent of the proponent, and a cave management plan is prepared and approved by the responsible authority.

Potentially destructive research, inventory or monitoring activities are considered by BC Parks to be generally inappropriate within a provincial park or ecological reserve, and will be permitted only if they result in information that provides for increased protection of the feature or scientific knowledge not otherwise available. It is recognized that there is normally no pressing need to authorize potentially destructive research activities in karst caves unless there is a need to document cave resources in imminent danger of being vandalized or otherwise damaged, stolen or destroyed.

Gwaii Haanas National Park Reserve and Haida Heritage Site

The *Canada National Parks Act* (CNPA) and related federal guidance make it clear that primary objectives in the national parks are linked to "ecological integrity" and "ecosystem management". A commitment to maintaining the ecological integrity of karst caves would therefore appear to subscribe to these general objectives.

Parks Canada has a standing policy of meeting or exceeding the protection and management standards set by other jurisdictions – this would presumably extend to effectively managing palaeontological and archaeological research activities in karst caves. Another Parks Canada policy of working with jurisdictions bordering national parks on shared ecosystem matters could apply to trans-boundary cave systems and their particular management concerns. Parks Canada participates in land-use planning and management initiatives sponsored by other jurisdictions to encourage the understanding and cooperation of other agencies in protecting park ecosystems, and for Parks Canada staff to better understand the management concerns of those other agencies.

Under Regulation 8 of the CNPA's General Regulations for the Control and Management of National Parks (Government of Canada 1978), entry to a cave in a national park is not permitted without the permission, in writing, of the superintendent, except where it is indicated by a notice posted by the superintendent at the entrance to the cave.

Proponents of conducting research in a national park cave must apply for a research permit unless the proponent is Parks Canada itself. Research activities proposed for karst caves in the Gwaii Haanas National Park Reserve and Haida Heritage Site have been the subject of a federal Environmental Assessment Project (EAP) process. As the responsible authority, Parks Canada identifies the potential environmental effects, measures to mitigate those effects, and decides whether adverse environmental effects of the proposed research activities on the cave environment are likely to be significant. An initial step in the EAP process is to screen the project to determine whether it is likely to cause significant adverse environmental effects that "cannot be justified in the circumstances" or whether there are other reasons to conduct a more detailed assessment. The project may proceed if Parks Canada determines that there is no need for a more detailed assessment after considering any comments from the public.

The research activities screened and subsequently approved by Parks Canada on Haida Gwaii since 2001 have included excavations inside caves and at cave entrances. Parks Canada has consistently rendered an opinion that projects of this nature are not likely to cause significant adverse environmental effects.

Parks Canada has been urged to adopt the principles and practices embodied within the *Best Management Practices for Palaeontological and Archaeological Cave Resources*, and *Recommendations for Policy and Administration of Palaeontological and Archaeological Research in Caves*.