Submission for the Old Growth Strategy Review: Old Growth Karst

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1. What is karst?

Karst landscapes develop when water dissolves relatively soluble bedrock such as limestone, marble, dolomite or gypsum. Existing fractures and crevices in the bedrock are enlarged by the dissolving action of water. Over time, extensive complex underground flow paths linking the surface and subsurface can develop. On the surface, landforms typically associated with karst, such as dolines (also known as karst "sinkholes"), dry valleys, vertical shafts, fluted bedrock surfaces, sinking streams and springs, may be present.

In the upper layers of the karst, or "epikarst", fissures and conduits enlarged by the dissolving action of water render the karst essentially porous. Instead of pooling or flowing on the surface, water falling directly onto the karst in the form of rain or snow typically infiltrates any existing surficial cover and enters the karst bedrock where it may be stored for some time. This water input is known as "autogenic recharge". Such water eventually drains into the "endokarst" – deeper regions of the karst containing fewer voids, but larger ones. Eventually, the water resurfaces at springs.

Surface watercourses, especially those that originate off the karst, often sink soon after they encounter karst, flowing into caves, swallets or ponors. Streams that originate off the karst and sink only after they flow onto the karst are classified as "allogenic recharge". Even though they themselves are not karstic, allogenic recharge areas are deemed to comprise part of karst systems for management purposes, because land-use activities that occur on these areas can affect karst systems downstream.

Since drainage is internal, karst hydrological systems are not necessarily constrained by topography as with non-karst hydrological systems. In karst, water can disappear in one drainage basin and re-emerge in a completely different system many kilometers away, after passing under or through one or more topographic divides. To further complicate matters, flow pathways within karst may vary with hydrological conditions. For example, the places where water may emerge during dry summer conditions may differ from those where water emerges during peak flow storm events.

Although some subsurface conduits in karst may meet the provincial definition for caves (i.e., natural cavities large enough to admit humans and contain zones of perpetual darkness (see, for example, Resources Information Standards Committee, 2003, p. 72), the majority of subsurface void spaces are too small to meet this definition. Nevertheless, these voids still permit the transfer of air, water and small particles, and in many cases serve as habitat. For example, the small water-filled cracks and pores in epikarst provide important habitats for diverse communities of small aquatic organisms (see for example, Pipan, 2005; Pipan & Culver, 2007; Papi & Pipan, 2011). The *Canada Fisheries Act* appears to cover (or at least does not exclude) freshwater and anadromous fish and the subterranean karst environments they occupy or transit as spawning routes (see Section 2 definitions in the Act). Since the Act also defines crustaceans as “fish”, karst cavities inhabited by freshwater crustaceans may be defined as “fish habitats”. The surface-subsurface connections in karst that serve as food supply routes for the crustaceans may also be considered as fish habitats.

The ability to transmit and store water in small subterranean voids in the epikarst (see, for example, Williams, 2008a) accounts for the inclusion of karst as a special type of subterranean wetland, as first proposed in 1993 (see Ramsar Convention on Wetlands, 1993). Canada and the other Contracting Parties to the 1971 Ramsar Convention extended the definition of wetlands to include karst in 1996 (see Ramsar Convention on Wetlands, 1996, Resolution VI.5).

2. What values are associated with karst?

BC’s *Karst Management Handbook for British Columbia* observes that, “Karst is a unique, non-renewable resource with significant biological, hydrological, mineralogical, scientific, cultural, recreational, and economic values.” (British Columbia Ministry of Forests, 2003, p. 6).

One of the most important resource values associated with karst on a global scale is water. Although karst covers only about 7-12% of the earth’s surface, it provides drinking water to about 25% of the world’s population. (Ford & Williams, 1989; IUCN 1997; Hamilton-Smith, 2006, Ford & Williams, 2007; and many others).

Karst makes a significant contribution to the earth’s geological and biological diversity (see, for example, IUCN, 1997). A single karst system can contain a remarkable variety of surface and subsurface habitats, possessing 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). 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; Kruckeberg, 2004). These factors likely 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 dolines (karst "sinkholes") and springs (e.g., Pipan, 2005; Pipan & Culver, 2007; Van der Kamp, 1995). Karst transition zone environments or "ecotones", such as cave entrances, dolines and shafts with distinct microclimates, sinking streams, springs, or deep solution openings in epikarst exposures (e.g., Culver & Sket, 2002; Gibert, 1997; Pentecost, 2004; Kiernan, 1988; Camassa, 2004; Peck, 1988; Pipan *et al*., 2008), can be influenced by both surface and subsurface conditions, and hence may exhibit higher humidity, gradations of incident sunlight, and temperature regimes influenced or moderated by the mixing of surface and subsurface air (e.g., see Van der Kamp, 1995; Wood, 2004). Cave entrances have been identified as karst habitats where relictual plants are likely to persist (Pentecost, 2004; Kiernan, 1988; Schulte & Crocker-Bedford, 1998).

Opportunities for colonization and protection for rare, endemic or specialized flora and fauna or biological communities on or in karst may be further enhanced by the presence of thin, well-drained calcium-rich soils. On Haida Gwaii for example, Roemer and Ogilvie (1983:2579–2580), report that endemic and disjunct plant species distributions occur more frequently on limestones than on other rock types. High-elevation limestones in particular also tend to yield above-average numbers of rare and unusual plants on Vancouver Island (H. Roemer, pers. comm., 2009).

Karst attracts researchers from a wide variety of disciplines, including ecology, palaeontology, geography, geology, hydrology, climatology, archaeology, zoology and botany. Karst caves, for example, provide conditions uniquely conducive to preserving palaeontological material that can yield information about ancient fauna, climates and environments.

Karst landscapes can have special significance for Indigenous 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.) or other traditional uses such as places for gathering certain plants that might be associated with the karst. Other cultures around the world have also attached special or spiritual significance to karst landscapes or features through time and up to the present.

Karst landscapes can also attract a wide variety of other human pursuits (e.g., timber and limestone extraction, recreation and tourism, research, etc.). For example, 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 and have often been used as film-making locales due to their unusual or dramatic scenery.

Karst presents both opportunities and challenges for recreation and tourism development which can place added pressure on karst ecosystems, increase disturbance levels, and elevate land-use conflicts.

Other land-use activities, such as forestry, farming, quarrying and mining, can negatively impact karst systems. 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).

3. Why are karst systems sensitive to anthropogenic disturbances?

Environmental risks to karst are often compounded because: 1) many land managers and decision makers are unfamiliar with how karst systems function and unaware of the porous nature of the karst; and 2) the effects of surface disturbances on the subsurface component of karst may not easily or immediately observable and hence, are essentially "out of sight and out of mind".

Karst system components – bedrock, water, gases, soils and living things – are so inter-dependent and interlinked 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 can bring about immediate and, at times, irreversible impairment of subterranean karst environments as well as those on the karst surface (Gillieson, 1996). The effects of surface disturbances on hypogean (i.e., subterranean) karst fauna can be particularly 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.

The term 'karst' 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 initially to deforestation and compounded by subsequent over-grazing. The name is appropriate because karst soils – especially shallow soils atop irregular bedrock surfaces – are particularly vulnerable to erosion (Boyer, 2004: Gillieson, 1996; Kiernan, 1988; Kiernan, 2002; Kranjc, 2009; Harding, 1987; Harding & Ford, 1993; and many others).

The many vertical openings in epikarst offer numerous opportunities for disturbed or displaced soil particles/sediments to be washed or carried by gravity into the subsurface (Gillieson, 1996; Baichtal & Swanston, 1996). Increased or altered surface runoff due to soil disturbance or deforestation is one way that soil loss can occur on karst landscapes, particularly on steeper slopes (Boyer, 2004). 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). More dramatically, 'catastrophic collapse' dolines (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 mechanical failure of bedrock or compacted soil bridging an underlying karst cavity.

Once soil loss occurs in karst areas it can be difficult to re-establish vegetation needed to arrest further loss and restore site productivity to former levels (Harding & Ford 1993; Boyer 2004; U. Vilhar, pers. comm., 2009). Harding & Ford (1993) provide a case study from northern Vancouver Island that compares impacts of timber harvesting on karst terrain versus non-karst terrain. Harding found that post-harvest soil loss was greater on the Quatsino Formation limestone sites than on the Karmutsen Formation volcanics. Soil loss on the limestone further increased with slope gradient and with post-harvest burning. Although routine intentional post-harvest broadcast burning has been discontinued in coastal BC since Harding completed her research, post-harvest wildfires on well-developed karst sites with relatively thin soils have become an increasing concern in recent years (Ramsey & Griffiths, 2017a; Ramsey & Griffiths, 2017b), and they are almost always followed by rapid and catastrophic soil loss.

Evidence of soil loss on karst may not be visible on the surface initially since it tends to occur at the bottom of the soil profile into the underlying porous surface of the epikarst (see, for example, Boyer, 2004; Gillieson, 1996; Kiernan, 1988; and many others). Soil loss may only be detected on the surface when subaerial karren forms (i.e., distinctive types of rocky relief that form on the surface of karst) begin to emerge from the lowering soil profiles. Evidence of post-harvest soil erosion can sometimes be observed underground in the form of newly sediment-clogged cave passages and sediment-stained speleothems, as well as occurrences of recently formed post-harvest suffosion-type dolines where none previously existed.

Evidence of post-harvest soil loss from some karst sites on northern Vancouver Island is only now becoming apparent on the surface, decades after the first pass harvesting. Current Forest and Range Evaluation Program (FREP) monitoring is unlikely to capture evidence of post-harvest soil loss on karst because of the length of time it takes to become evident to surface-based monitoring.

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 key to retaining soil on karst is retaining vegetative cover, as well as maintaining levels of shade so that the soil doesn't dry out.

Karst aquifers can be very sensitive to pollution in comparison to some other porous media aquifers (e.g., sand aquifers) (e.g., see Kiernan, 1988; IUCN, 1997, and many others). In karst, where flow velocities are comparatively high, residence times are short, and filtration and dispersion are sometimes negligible, natural purification processes are often much less effective (European Commission, 1995).

Subsurface flows within karst can be extremely rapid (see for example, Ford & Williams, 1989; Ford & Williams, 2007; and many others). Pathogenic bacteria and other contaminants (e.g., herbicides, fuel spills, pesticides and fertilizers) introduced on the surface can rapidly infiltrate porous karst landscapes and circulate in subsurface channels and voids, surviving relatively short travel times and reaching all parts of the karst system and output features (i.e., karst springs) very quickly (see, for example, Kiernan, 1988). As the 2000 tragedy in Walkerton, Ontario showed, this can have serious implications for human health, especially when karst is used as a source of drinking water (see, for example, Worthington *et al*., 2002). It can also have serious implications for fish and wildlife that depend on such water sources.

Griffiths (in progress), provides an interesting historical example involving biologist-author Rachel Carson, who described a lethal DDT spraying incident and resultant fish mortality on northern Vancouver Island in her 1962 best-selling book *Silent Spring*. Carson used this spraying incident to illustrate the detrimental effects of DDT and the interconnectedness of natural systems. Unbeknownst to Carson (and very likely those designing and supervising the spraying) nearly one-quarter of the area sprayed with DDT in 1957 is karst. Given the porous nature of karst landscapes, merely avoiding introducing contaminants into standing and flowing surface water (see, for example, Dermer *et al*., 1980) is <u>not</u> a sufficient precaution to ensure contaminants will not infiltrate the karst and be rapidly transported elsewhere. In retrospect, the northern Vancouver Island DDT spraying incident of described by Carson serves as a cautionary tale about how a "business as usual" approach is often not adequate for effectively managing the biology and ecohydrology of karst systems.

Delineating contributing non-karst catchments and understanding subsurface flow paths are basic karst management tools listed among the recommended best practices in BC's karst management guidance documents. This is done primarily through carefully designed dye-tracing work that should be designed and supervised by specially trained karst hydrologists. Unfortunately, BC's karst management guidance documents are almost never followed (see for example, Ramsey & Griffiths, 2018). There are few, if any instances, in which karst catchment delineation supported by dye tracing has been used to plan or guide forestry activities on karst in coastal BC.

4. What is the connection between karst and forests?

In BC's temperate rainforest karst landscapes, a complex biological relationship exists between the forest cover and the karst. Tree roots often extend into and enlarge epikarst fissures, helping to anchor trees, enhance drainage, and allow for the uptake of moisture and nutrients directly from epikarst bedrock (Gillieson, 1996). By comparison, in non-karst settings where drainage is impeded 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). Productive old-growth forests on karst can be found even in landscapes where bog-forest complexes would otherwise occur. Contrasting productive forested karst sites are conditions found in bogs (muskegs) where non-decomposed organic matter and excess water can severely limit the growth of forest vegetation.

In coastal BC, the relative purity of the limestone, coupled with moderate temperatures and abundant rainfall are important factors that contribute to karst development. However, factors, such as climate, soil cover and vegetation, also influence the dissolution process in karst. Impacts to these factors can affect the karst system as a whole (Kruckeberg, 2004; Ford, 2004; Williams, 2004b).

Forest vegetation and associated forest soils play an important role in the development of karst on carbonate rocks such as limestone and marble (e.g., see Gillieson, 1996; Gillieson, 2004). Carbonate bedrock dissolution rates increase with the acidity of water. The more CO_2 water absorbs, the more acidic it becomes. Although rain becomes mildly acidic when it absorbs carbon dioxide (CO_2) as it falls through the atmosphere, decaying organic litter and respiration from tree roots and soil microbes produce concentrations of CO_2 that can be as significantly higher than those measured in the open air. Water that infiltrates the forest floor and percolates through soil therefore picks up much more CO_2 than it does falling through the atmosphere. This is only one of many ways forest vegetation and its associated soils directly influence the karst dissolution process (Viles, 1988; Gillieson, 2004).

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

Well-developed karst sites 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 CO_2 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).

Natural catastrophic wind events are comparatively rare in old-growth forested karst landscapes. Deep rooting in epikarst may make some of the forest stands somewhat more resistant to windthrow.

5. How do forestry activities impact karst?

To date, relatively few karst scientists have attempted studies aimed at quantifying changes to karst systems resulting from forestry activities. There are a few examples of research done outside of BC that directly address how forestry activities affect water quality and quantity. Hartmann et al. (2016), for example, quantified windthrow-related impacts to dissolved inorganic nitrogen (DIN) and dissolved organic carbon (DOC) in a forested karst setting using a model based on data obtained from karst springs. Tissier (2012) monitored pre- and post-harvest changes to precipitation, infiltration and water chemistry parameters under a cutblock on karst in the French Pre-Alps (see also Tissier *et al*., 2013). Kovarick (2007) undertook a baseline water balance study in temperate rainforest karst at two different karst watersheds on northern Prince of Wales Island in southeast Alaska. Vilhar *et al*. (2010) assessed the relative utilities of two different water balance models in relation to virgin forest and managed forest settings in Slovenia’s Dinaric karst.

Although the extent to which natural or forestry related disturbances lead to changes in karst ecology or hydrology, either temporally or spatially, has not yet been quantified or even much studied in BC, it is known that forestry activities modify the structure, function and ecological integrity of karst landscapes. 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.

Impacts on the integrity of the climate-vegetation-soil system on carbonate bedrock terrain are likely 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 (e.g., Bárány-Kevei, 2003). In particular, soil loss on karst following deforestation has been observed in many locales around the world, and is a growing concern in coastal BC.

While the net resulting effects of forestry activities, such as soil loss, diminished biodiversity, and changes to water quality and quantity within karst systems, 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. Some of the different ways broad categories of primary forestry activities may impact karst systems at both the feature and landscape scales are summarized below.

Timber Harvesting

- Timber harvesting results in changes to localized microclimates, soil properties, and the quantity and quality of water available to recharge karst systems and increases inputs of organic matter and sediment into the subsurface.

- The removal of mature trees can also affect nutrient cycling within karst systems. 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 regimes, 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 karst 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.

- Removal of the forest canopy can 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 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). 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.

- Excessive deposition of harvesting residue in karst transition zone environments can obstruct atmospheric connections to subsurface karst habitats, limiting their usability by troglophiles (animals that typically spend all or most of their lives on the surface, but can also survive underground) or trogloxenes (surface dwellers that use caves periodically for such purposes as shelter, sleep or hibernation, but that cannot survive full life cycles underground). Damage or destruction of rare plants or plant assemblages or the surface habitat for epigean (surface) or troglophilic fauna 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 can begin to leach immediately from the residue upon contact with precipitation water, infiltrating surface water or groundwater.

- 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 (calcite formations) in caves. Turbulent flow conditions in underground streams containing leachate can add to foam 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 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 groundwaters by residue and leachate can impact fish in underground streams or in rising streams if the karst aquifer discharges into surface fish habitat.

- Timber harvesting increases water inputs into the karst system that in turn can accelerate erosion and sedimentation rates (Boyer 2004).

- Ground-breaking forces associated with timber harvesting invariably disturb the often-thin soils in 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. The accompanying soil losses can also reduce long-term site productivity.

- 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, alter air and water flow patterns, and smother hypogean habitats (Clarke, 1997; and Kranjc, 1979, as cited in Gillieson, 1996). Introduced waterborne sediments can also impact aesthetic values in caves by soiling or staining speleothems and relief features.

- Removing forest cover can change wind patterns, often increasing wind speeds at ground level, exposing trees along clearcut 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 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, 1987 (see also Harding & 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.

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

- Dolines 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 the subsurface karst environment.

- 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. Fine 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 disturbs the soil cover and alters 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.

- 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 in 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.

- 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 surface karst, and produce noise, vibration, and air and water quality impacts that are transferred underground.

- Roads can increase public access to sensitive karst sites (British Columbia 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 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 (i.e., 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).

- 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.

6. Is it possible to remediate the effects of forestry activities on karst systems?

It may be possible to remediate some aspects of forestry-related damage and degradation to karst systems and karst features, but not in our lifetimes. Damage to karst biodiversity might as well be considered permanent.

The most effective and economical way to manage karst is to avoid damaging or degrading it in the first place. The remaining unlogged old-growth temperate rainforest karst in coastal BC is, for all practical purposes, a rare and non-renewable resource. It should be valued and protected accordingly.

7. How much old-growth temperate rainforest karst is left in coastal BC?

Griffiths & Ramsey (2006) reported that 64% of the 843.9 km^2 considered to be higher potential Karst Potential Areas (KPAs) in the Coast Forest Region, *and not in protected areas*, had been modified by logging by 1999. The data were obtained by GIS spatial analysis using available baseline thematic mapping to establish forest status, and the set of reconnaissance-level KPAs derived from 1:250,000 scale digital bedrock data of the BC Geological Survey and the Geological Survey of Canada.

Griffiths & Ramsey (2006) found that the proportion of the higher potential coastal western hemlock (CWH) zone karst modified by logging by 1999, *and not in protected areas*, in five of the Coast Forest Region districts was:

- Chilliwack – 78.3%
- North Island – Central Coast – 76.0%
- South Island – 74.6%
- Campbell River – 57.5%
- Sunshine Coast – 51.3%

The only available source of karst potential data for this 2006 study was the set of reconnaissance-level KPAs derived in 1999 from 1:250,000 scale digital bedrock data of the BC Geological Survey and the Geological Survey of Canada. This reconnaissance-level karst mapping is known to have significant limitations. Continual updating was considered essential to successful use of these maps when they were released in 1999. Continual updating and refinement have not happened anywhere in the province.

<u>Note that the proportion of the higher potential CWH karst modified by logging, *and not in protected areas*, has increased since 1999</u>. Up-to-date data have not been acquired at the scale of the whole Coast.

More recently, finer scale estimates have been derived for four higher potential CWH karst areas on Vancouver Island. These estimates were derived using up-to-date satellite imagery combined with field knowledge of the actual karst unit boundaries. Rough estimates were also derived for what is left when the residual natural forests of the karst units are buffered inward for 80 m and in one case for 100 m.

The four karst units examined by these methods include: Memekay (Griffiths, in progress), Upper Tahsish (Griffiths, in progress), Kinman (Ramsey, 2016; Griffiths, in progress), and the Glory ‘ole Cave/Karst Management Area (GCMA) (Griffiths & Ramsey, 2019). Each of these karst units has karst resource values of undisputed regional, provincial and in some cases, national or international significance. Karst units such these are (or at least, were) considered to be globally significant because of their association with unlogged coastal temperate old-growth forests which are by themselves, rare, worldwide. The results for the individual karst units are provided below:

<u>Memekay karst unit (source: Griffiths, in progress)</u>:

- **81.1%** of this 18.73 km^2 karst unit has been logged.
- **5.3%** is left when the residual natural forest is buffered inward for 80 m (to account for edge effects).
- The buffering reduces the 20 isolated polygons of residual forests in the unit down to 9.

Upper Tahsish karst unit (source: Griffiths, in progress):

- **83.3%** of this 21.37 km^2 karst unit has been logged.
- **5.5%** is left when the residual natural forest is buffered inward for 80 m (to account for edge effects).
- The buffering reduces 21 polygons of residual forests in the unit down to 10.

Kinman karst unit (sources: Ramsey, 2016; Griffiths, in progress):

- **67.2%** of this 6.50 km^2 karst unit has been logged.
- **8.5%** is left when residual natural forest is buffered inward for 80 m (to account for edge effects.)
- The buffering reduces 20 isolated polygons of residual forests in the unit down to 11.

Glory ‘ole Cave/Karst Management (GCMA) unit (source: Griffiths & Ramsey, 2019):

- **92.4%** of this 4.32 km2 karst unit has been logged.
- **3.23%** is left when the residual fragmented forest is buffered inward for 100 m (to account for edge effects).
- The buffering reduces the 5 isolated polygons of residual forests in the unit down to 1.

These results are summarized in Table 1 below.

Table 1: Table showing the percent (%) areas logged and areas and numbers of residual natural forest (i.e., unlogged old growth) polygons remaining for four karst units on northern Vancouver Island. The table also provides the areas and numbers of polygons of residual natural forest (i.e., unlogged old growth) polygons remaining when 80-m buffers are applied to account for edge effects. Note that the selected buffer width is probably generous. Examples of edge effects have been observed, and a good number of them (e.g., harvest-related tree windthrow) extend into the residual forests for distances greater than 80 or 100 m.

Karst Unit name	Area of karst unit (km^2)	Karst unit area logged (%)	Number of polygons of natural residual forest	Natural residual forest when an 80 m buffer is applied to account for edge effects (%)	Number of polygons of residual natural forest when an 80 m buffer is applied to account for edge effects
Memekay	18.73	81.1	20	5.3	9
Upper Tahsish	21.37	83.3	21	5.5	10
Kinman	6.5	67.2	20	8.5	11
GCMA	4.32	92.4	5	3.23	1

Source(s): Memekay (Griffiths, in progress); Upper Tahsish (Griffiths, in progress); Kinman (Ramsey, 2016; Griffiths, in progress); Glory ‘ole Cave/Karst Management (GCMA) (Griffiths & Ramsey, 2019)

Conclusions:

The proportion of these individual karst units modified by logging ranges from **67.2 to 92.4%**. However, when the residual natural forests are buffered for edge effects, the unmodified proportion ranges from **3.23 to 8.5%**.

With respect to these four karst units, which contain karst resource values of undisputed regional, provincial and in some cases, national or international significance, one can conclude that: 1) only small percentages of unmodified old-growth forest remain; and 2) the remaining area of old-growth forest is fragmented due to roads and timber harvesting, the extent of artificial edge influences (e.g., windthrow), and person-caused fires.

The Karst in Provincial Protected Areas on the Coast

It is sometimes claimed that we should not be concerned about the amount of coastal temperate old-growth forest that has and *is* being logged on karst because representative samples are contained within protected areas.

GIS spatial analyses recently completed by Griffiths (in progress) derived provincial representation levels for higher potential KPAs in provincial parks and ecoreserves, and conservancies on the Coast. These analyses considered the representation levels for karst in the CWH ecological zone (a naturally forested zone making up the majority of the coastal rainforest biome). The higher potential KPAs were defined as those with a Karst Likelihood (KL) rating of Primary and a Karst Development Intensity (KDI) rating of High. Griffiths’ results showed that **50.2 km^2** of higher potential CWH karst lie inside provincial parks and ecoreserves, and **41.1 km^2** in conservancies. These amounts equal provincial representation levels of **4.53%** and **3.71%,** respectively, for this karst type in these protected area categories.

A substantial area of these karst types in the provincial protected areas and conservancies has been previously logged, so even the small percentages of higher potential CWH karst in these areas are not necessarily pristine. The conservancies can allow for certain types of lower impact development.

8. Why a pause in the logging of old-growth temperate rainforest karst in BC is recommended.

Around the world, karst ecosystems are recognized as one of the most sensitive ecosystems on the planet (see, for example, Parise, 2015; IUCN, 1997; and many others). Some karst scientists are fond of saying, "All the karst we have is all the karst we will *ever* have." As the IUCN Guidelines for Cave and Karst Protection (IUCN, 1997, p. 5, emphasis the author's) point out,

> *… safeguarding natural processes is fundamental to karst management. In turn, that implies the need for careful management of the vegetation and soils of entire water catchment areas … There are relatively few places where the opportunity exists to safeguard truly pristine karst.*

Although unlogged coastal temperate rainforest is exceedingly rare on a global scale, BC has been reluctant to support research or maintain up-to-date inventories with respect to these rare ecosystems. Logging old-growth karst sites has proceeded and even been encouraged without the benefit of baseline data, adequate oversight, effective enforcement, up-to-date inventories, and comprehensive monitoring. In short, the integrity of BC's sensitive karst resources and their associated values for future generations have not been protected by the *Forest and Range Practices Act* (FRPA). Ramsey & Griffiths (2018) provided a detailed examination of the significant shortcomings of the FRPA/Professional Reliance model with respect to karst. It is available at:
https://engage.gov.bc.ca/app/uploads/sites/272/2018/02/Paul-Griffiths-Carolyn-Ramsey.pdf.

Very little old-growth coastal temperate rainforest karst is left in BC. What does remain should be inventoried and protected as soon as possible. British Columbia has a rare opportunity to save what remains.

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