*L. obliterata* and the more adapted *L. schurmanni* in the rest of El Hierro. The most troglomorphic animal on the island is the thread-legged bug *Collartida anophthalma*, a relict belonging to a genus from Central and Eastern Africa with the only troglobites on the Canary Islands. The aquatic fauna is scarce and limited to brackish interstitial waters, where two amphipod crustaceans have been found: *Pseudoniphargus salinus* and *Ingolfiella canariensis*.

The caves on El Hierro are generally well preserved but on La Palma and Tenerife some caves have open, easy access and in these there has been damage to speleothems, graffitti on the walls, and accumulation of rubbish. But probably the worst problem is pollution due to domestic waters poured into some caves, in which the adapted fauna has disappeared and alien opportunistic species invade the subterranean environment.

The only inhabited lava tube on Fuerteventura endures continuous alterations and pressure from politicians to become a show cave, which would be the epitaph for the unique *Maiorerus randoi*. An EU Legal Instrument For the Environment (LIFE) project on conservation of the cave habitat was carried out from 1999–2001, but it only concerned the caves located in public protected areas of three islands (Fuerteventura excluded). A study on the current hypogean fauna compared to that recorded 20 years ago, an inventory of the bat species and populations and their underground roosts, and an accurate analysis of the increasing factors of environmental damage were performed for 50 caves in Tenerife, La Palma, and El Hierro. The final report also included a proposal for a sewage network for the area of Cueva del Viento, as well as every necessary action for better conservation of other deteriorated caves. In spite of the initial interest by the Canary Government on this subject, no signs of continuity are evident and none of the recommended actions have been completed; in the meanwhile, this unique fauna remains threatened.

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*See also* **Hawaiian Islands: Biospeleology**

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# CAPE RANGE, AUSTRALIA: BIOSPELEOLOGY

Cape Range is the only Tertiary orogenic karst in Australia and supports one of the world's richer subterranean faunas. The fauna occurs in three parts, separate terrestrial faunas in Cape Range proper, on its coastal plain, and a relict fauna, largely of Tethyan origin, occurring in the anchialine groundwater of the coastal plain (see map in Australia entry).

Cape Range is an anticline of Eocene/Miocene marine limestones and forms a peninsula projecting northward into the Indian Ocean on the mid-west coast of Australia. To the west the peninsula is the closest point in Australia to the continental shelf, while to the east it abuts the vast North West Shelf. The peninsula is fringed by a coastal plain and exhibits a series of raised wave-cut terraces to the west. The range rises to an altitude of 330 m and is dissected by gorges which cut through the highly karstic Tulki Limestone into the underlying and marly Mandu Limestone. The gorges thus form a discontinuity in the karst which serve as a barrier to dispersal of the subterranean fauna. In addition the marl retains a groundwater layer at which the caves develop laterally. More than 600 caves are known, mostly vertical solution pipes, with or without collapse, to 100 m depth and similar lateral extent. Five caves within the range reach water and one has extensive development (> 6 km) near the water table.

Cape Range lies just within the tropics and experiences an arid climate (mean annual rainfall 284 mm, pan evaporation 3219 mm) in which the episodic rainfall is largely torrential. Consequently, caves may dry continuously for 1–2 years before being rewetted. The vegetation is largely tussock grass (*Triodia*) with areas of *Acacia, Eucalyptus*, and *Banksia*.

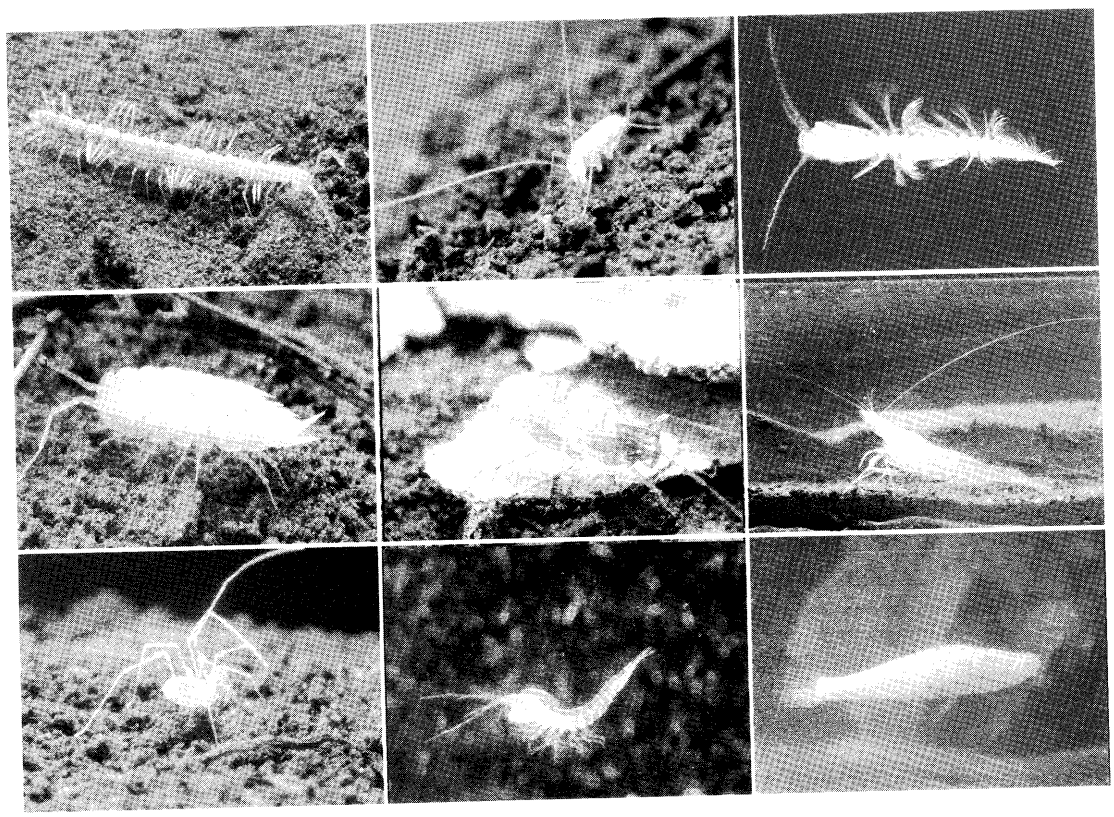
Although Cape Range is now an arid area, far removed from rainforest, the area has a relict rainforest fauna with both temperate and tropical elements. The diverse subterranean fauna encompasses both terrestrial and aquatic ecosystems and is entirely endemic to the range. It includes at least 30 highly troglomorphic species, among them the most troglomorphic cockroach in the world (*Nocticola flabella*) in which only the mouthparts and genitalia are heavily sclerotized. Characteristic taxa include myriapods (centipedes, millipedes), arachnids (micro-whipscorpions, pseudoscorpions, scorpions, spiders, mites), insects (beetles, cockroaches, crickets, planthoppers, japygids), and crustaceans

(slaters). A subfamily of pseudoscorpions (Indohyinae) confined to the circum-Indian Ocean region is represented in the cave fauna (*Hyella*), and there are at least six endemic genera, the micro-whipscorpion *Draculoides*, nemobiine cricket *Ngamarlanguia*, pseudoscorpion *Hyella*, paradoxosomatid millipede *Stygiochiropus*, a japygid dipluran, and a ctenid spider. The only aquatic taxon known from the range is an endemic genus of melitid amphipod (*Norcapensis*).

Allozyme analysis has shown that the southern two-thirds of the range contains three distinct genetic provinces, which are largely separated by areas of deep gorges. Even within these provinces *Stygiochiropus* millipedes mostly do not interbreed even between adjacent caves. Within the northern part of the range a suite of distinct species is recognized.

On the coastal plain and flanks of the range a related but quite distinct troglobitic fauna is present. Access is very limited due to sparse surface openings and much information has been derived from bores drilled for limestone resource assessment. A notable attribute of this fauna is the presence of six troglobitic species in three genera of micro-whipscorpions (Schizomida), a seventh, *Draculoides vinei*, being confined to the caves in range proper.

The coastal plain is fringed with the only continental anchialine system known in the southern hemisphere. These near coastal groundwaters, affected by marine tides, typically exhibit highly stratified physicochemical properties (see Anchialine Habitats entry). The characteristic fauna occurs below a thermohalocline and hydrogen sulfide layers, in conditions low in oxygen and supporting chemoautotrophic energy fixation. It is mostly accessed through traditional and later pastoral wells and recent bores, although several caves access this habitat including Bundera Sinkhole, a site globally notable for its fauna (Humphreys, 1999). The anchialine ecosystem contains the only blind cave fish in Australia, a gudgeon (*Milyeringa*), and a swamp eel (*Ophisternon*). Most of the remaining taxa are crustaceans and include halocyprid ostracods, harpacticoid, cyclopoid, calanoid, and misophrioid copepods, atyid shrimps (two species of *Stygiocaris*, sympatric in places), cirolanid isopods, remipeds, thermosbaenaceans, melitid, bogidiellid, and hadziid amphipods, and bathynellid syncarids. A number of other higher taxa are represented including turbellaria and polychaetes (Humphreys, 2000a,b).



**Cape Range, Australia: Biospeleology:** Some subterranean animals from Cape Range. *In rows from top left:* 1. The millipede, *Stygiochiropus communis*; 2. *Nocticola flabella*, the world's most cave-adapted cockroach; 3. *Lasionectes exleyi*, the only member of the Class Remipedia known from the southern hemisphere; 4. Unnamed blind philosciid isopodp; 5. *Bamazomus vespertinus*, one of seven species of micro-whipscorpions known from Cape Range; 6. *Stygiocaris stylifera*, an atyid shrimp inhabiting groundwater of the coastal plain; 7. *Glennhuntia glennhunti*, a harvestmen endemic to the coastal plain; 8. *Halosbaena tulki*, the only member of the Order Thermosbaenacea known from the southern hemisphere; 9. *Milyeringa veritas* (Eleotridae), one of two cave fishes sympatric on Cape Range. (Photos by Douglas Elford)

This fauna is notable because its affinities principally lie with the fauna from anchialine caves on either side of the North Atlantic. This relationship is supported by numerous congeneric (*Halosbaena, Haptolana, Lasionectes, Danielopolina, Liagoceradocus, Stygocyclopia, Speleophria*) or closely related species (endemic genus *Bunderia*). These lineages occur on the full "Tethyan track" (Stock, 1993), that is, they occupy that part of the ocean that contained congruent epicontinental seas in the Mesozoic (between 200 and 60 million years ago). These "Tethyan" lineages probably have a long stygal history, i.e. restricted to subterranean realms, following vicariant events resulting from the movement of the tectonic plates during the Mesozoic. This fauna includes the only southern hemisphere representatives of the Class Remipedia, the Orders Thermosbaenacea and Misophrioida, and the genera *Danielopolina* and *Haptolana* (Humphreys, 2000b).

About a quarter of the Cape Range karst province lies within Cape Range National Park. However, many of the most significant sites lie in areas of active resource exploitation or with resource potential under active pursuit. Water is abstracted from karst aquifers to supply Exmouth town and military facilities (airforce and naval communications bases) and the rapid growth of tourism attracted largely by the long Ningaloo fringing reef on the west coast. Nearly 100 $km^2$ are under limestone mining or exploration tenements and there is active petroleum exploration. A number of the terrestrial (e.g. *Hyella* sp., *Stygiochiropus* spp.) and aquatic subterranean species (e.g. *Milyeringa veritas, Ophisternon candidum, Lasionectes exleyi*) are listed under threatened species legislation or are recognized as belonging to endangered communities. Amongst the latter are Camerons Cave, within the Exmouth townsite, and Bundera Sinkhole which lies in a bombing range reserve. The World Heritage potential of Cape Range has been noted independently for its karst features and its subterranean fauna.

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# CARBON DIOXIDE-ENRICHED CAVE AIR

Carbon dioxide ($CO_2$) is a colourless, odourless gas, which tastes acidic. Most caves have air enriched with carbon dioxide, although in the majority of cases this is only slightly above the average surface atmospheric concentration of 0.04 volume/volume (v/v)%. Carbon dioxide in aqueous solution is a critical component in both the solution and precipitation of speleothems and the solution of limestone. In addition, an elevated level of $CO_2$ in cave air can be an indicator of pollution in the cave or in its catchment. Thus, it is important to understand how this gas is generated and distributed in caves.

To elucidate the sources of $CO_2$ and its distribution and movement, both spatially and temporally, within caves, it is necessary to conduct experimental studies. Identification of the $CO_2$ sources requires measurement of both $CO_2$ and oxygen ($O_2$) levels, together with measurement of humidity, temperature, and pressure. Analysis of trace gases, for example hydrogen sulfide and methane, can give additional information as to a $CO_2$ source. Early methods for the analysis of cave air are reviewed in James (1977). For $CO_2$ studies in wild caves, Dräger or Gastec gas analysers are recommended, as these instruments are portable, robust, and versatile, enabling $O_2$ and other gases to be measured in addition to $CO_2$. Modern methods of measuring air quality are described in the entry on Tourist Caves: Air Quality. Smith (1996) lists the simple $CO_2$ tests available to the exploration caver.

There are three distinct types of $CO_2$ enrichment in cave air (James, 1977):

### Type I: The addition of $CO_2$ to cave air with dilution of other air components

This type of $CO_2$ enrichment of cave air is common, particularly in caves containing active speleothems. As cave waters precipitate calcite, $CO_2$ is liberated and can degas from solution into the cave atmosphere. In general, the elevated level of carbon dioxide produced in this manner is low and the associated oxygen depletion is modest. Hence, the atmosphere in well-decorated areas is not hazardous. For example, in Tommy Grahams Cave, Nullarbor Plain, Australia, a chamber between two siphons has a measured $CO_2$ level of 4.0 v/v%. The $CO_2$ source is degassing of carbonate water, hence the depletion of $O_2$ (0.8 v/v%) is barely discernible. In contrast, Hanimec Cave, Slovakia, sometimes has a $CO_2$ level of 36 v/v%, mainly due to volcanic emis-