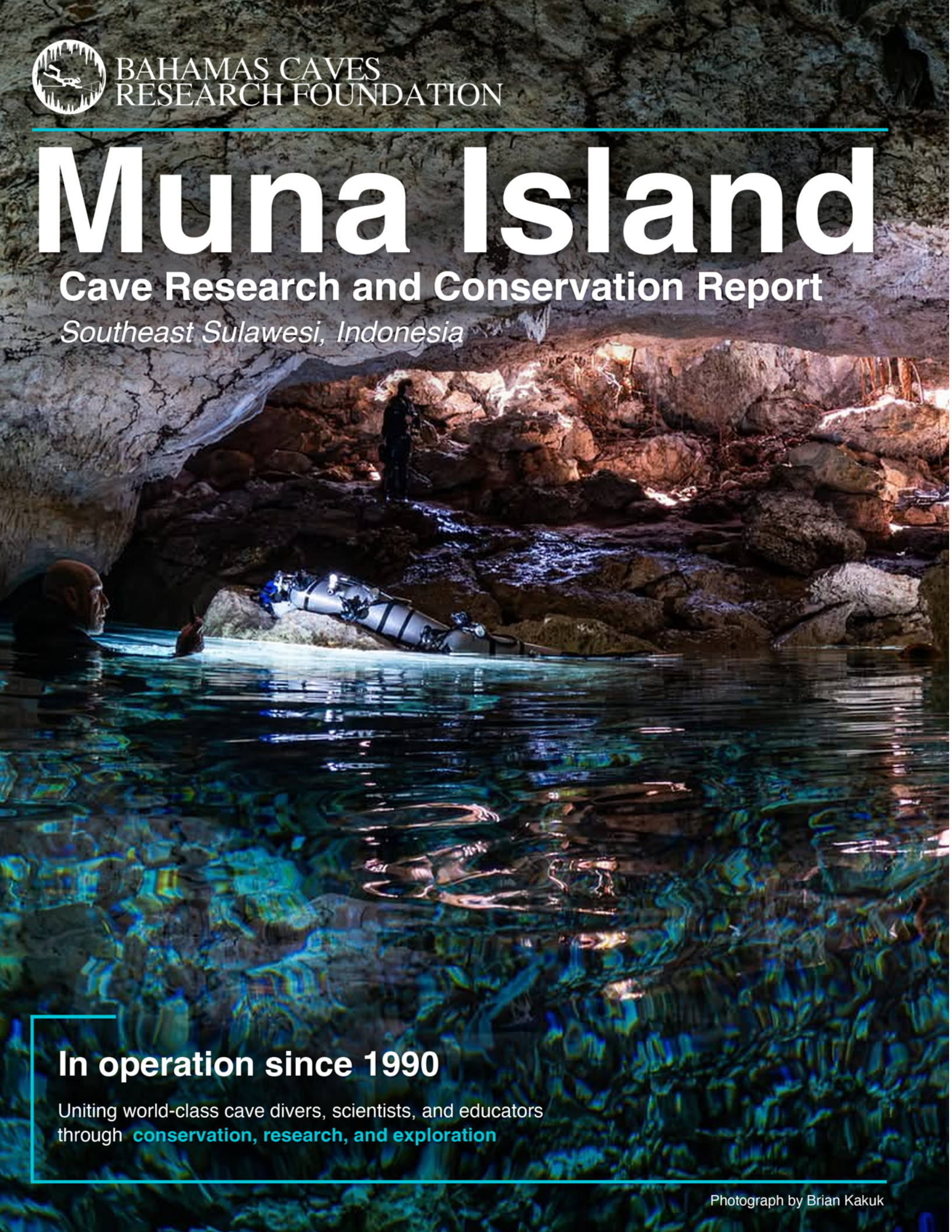
BAHAMAS CAVES
RESEARCH FOUNDATION

Muna Island

Cave Research and Conservation Report

Southeast Sulawesi, Indonesia



In operation since 1990

Uniting world-class cave divers, scientists, and educators through **conservation, research, and exploration**

Photograph by Brian Kakuk

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Photograph by M. Braun

2026 Muna Expedition

At a glance

August 16 – September 2, 2026

In total, over 14 field days, we explored 11 cave and karst sites

Our expedition:
- Identified freshwater sources and documented water-infrastructure risk at multiple sites
- Deployed 8 monitoring instruments across 6 sites to establish a baseline for future water and habitat research
- Provided equipment, training, and a preliminary research framework to launch R. Cuesta's doctoral research project
- Documented previously unreported geological, ecological, and cultural/anthropological materials across the survey areas
- Established a new BCRF project collaboration in Indonesia for a multi-year research and conservation partnership with local communities and guides

The diving team

Brian Kakuk, Founder, Bahamas Caves Research Foundation (BCRF)

Kenneth Broad, PhD, Chief Scientist, BCRF, Director of Abess Center for Ecosystem Science and Policy, Professor at Rosenstiel School of Marine and Atmospheric Science, University of Miami

Scarlette Hsia, PhD, Geologist, BCRF

Robin Cuesta, Doctoral researcher, Environmental Science, Gadjah Mada University, Sulawesi Dive Trek

Ken Smith, Radiolocation electronics specialist

Participation varied by date across the 14-day campaign. Additional field support was provided by Max Braun (filmography), Kharisma Yuda (MAHIPAL ropes specialist), and the staff of Sulawesi Dive Trek and Kadena Dive Resort.



Why this matters



Cave water on Muna Island is a drinking-water supply for villages like Watorumbe Bata, and a resource shared for laundry, recreation, and tourism. This expedition laid the groundwork for understanding where that water comes from, how it moves through the island's karst, and what threatens it. These efforts directly serve local water security and fuel doctoral student, R. Cuesta, in his research journey.

The caves themselves hold scientific and cultural value that has never been systematically documented: fossil reef deposits, an active bat colony supporting the underground food web, and cultural materials including pottery, graves, and gravemarkers. In addition to data collection, BCRF equipped R. Cuesta with the instruments and framework support to build his independent research career.

Photograph by S. Hsia

BAHAMAS CAVES
RESEARCH FOUNDATION

Field report for BCRF board and partners

August 16 to September 2, 2026

Executive summary

The 2026 Muna Indonesia expedition sought to gather baseline information relevant to scientific research, cave conservation, and local water security. Primary objectives included documenting cave passages and water-use infrastructure, identifying sensitive geological and biological features, photographing evidence of human-impacts, and establishing monitoring locations to support subsequent research. The expedition also contributed to a longer-term goal: helping local explorers and research partners develop the skills, equipment access, and continuity needed to sustain independent investigation and conservation efforts. Equipment support and preliminary research-framework development for R. Cuesta's doctoral project were a focal point of this expedition. Bahamas Caves Research Foundation (BCRF) provided resources and guidance to promote lasting value through accessible records, continued monitoring, and findings that can inform natural-resource management and benefit Muna's local communities.

The 2026 field campaign documented caves and associated water sources across 14 days at 11 named locations. A database of site coordinates, cave dive or dry-cave exploration details, observations of water conditions, geological features, fauna, cultural materials, and evidence of local water use was established. Mapping activities included MNemo, Caveway X1, and Pinger 2.0 equipment and were geospatially rectified through elevation data processed in QGIS and ArcGIS. HOBO temperature loggers were deployed at selected sites to support continuous observations and subsequent analysis. Additionally, access to a pneumatic drill and operational instructions were also provided to R. Cuesta for the duration of his fieldwork.

Campaign measure	Recorded coverage
Field records	14 records across 14 calendar days
Named locations	11; Lapahia visited 3 times and Laulawi 2 times
Field activity	11 cave dives and 3 dry-cave exploration log entries
Monitoring coverage	HOBO deployment marked at 7 sites; 8 serial entries
PhD advisory	Formulation and preliminary research framework development with R. Cuesta

Table 1. Summary table of data measured or developed during this expedition.

The campaign established a reconnaissance and practical starting point for the equipment-supported doctoral research project under R. Cuesta through support from the sponsoring NGO, BCRF. This report documents sensor placements, mapping-tool use and candidate research locations. It does not yet demonstrate improved water quality, completed cave maps, establish connections between cave systems, species population trends, or a dated geological history. Those outcomes depend on follow-up measurements and review which are at the discretion of R. Cuesta. Survey files, instrument metadata, and specialized assessments are anticipated independent outputs by R. Cuesta following preliminary interpretations made and equipment provided through this initial expedition.

Directorship discussions identified continuity between visits as a central challenge: short-term training and equipment provision need sustained opportunities for application. Future support should therefore connect technical diving, exploration, and scientific training to defined research tasks, local responsibilities, and follow-up milestones. Proposed criteria for future projects include a refined research framework, a data-management and archiving plan, a sustainability plan, and identifiable benefits for local communities. Progress should be documented through annual reporting, retained government documentation where applicable, and educational materials developed with local partners. These measures would help preserve the expedition's records and strengthen the foundation for the next generation of cave researchers and conservation partners.

Prepared by and signed,

Bahamas Caves Research Foundation

Brian Kakuk, Founder

_____

Kenneth Broad, PhD, Chief Scientist

_____

Scarlette Hsia, PhD, Geologist

_____

2026 Cave Exploration Areas on Muna Island

Southeast Sulawesi, Indonesia



Exploration team: Bahamas Caves Research Foundation and Sulawesi Dive Trek
Cartography: Scarlette Hsia
Fieldwork: August, 2026

Elevation: DEMNAS, Badan Informasi Geospasial (BIG)
Elevation reference: EGM2008
Site coordinates: reference BCRF field database
Coordinate reference system: WGS 84 / UTM zone 51S

Figure 1. Approximate expedition survey areas on Muna Island. Field team: Brian Kakuk, Kenny Broad, Robin Cuesta, Scarlette Hsia and Ken Smith. Participation varied by date. Map prepared for BCRF by S. Hsia. Requests to access to private data can be made on a case-by-case basis by contacting BCRF.

Water security and site priorities

Cave conservation is directly relevant to local water use. Piping and access to well water are instrumental tools that local villages rely on for daily use. A deep fracture cave near Watorumbe Bata was identified as a drinking-water source for Ayo Vuou village. Similarly, piping and access works at Laulawi, and a substantial pipe at Labungkari, indicate water infrastructure coordination between users and village leaders. Laundry, swimming and tourism are also primary examples of sinkhole use on Muna. These observations raise management questions surrounding prevention or reduction of contamination and lead to safer drinking-water practices [1].

Published research elsewhere on Muna confirms the importance of cave water to households. Mando et al. (2024) surveyed 32 of 105 households in Walengkabola and estimated annual domestic water use of 35,317.8 m^3 [2]. This village-specific estimate supports documenting users and demand alongside cave surveys; it does not establish water availability or drinking-water safety at the 2026 campaign sites.

Conduit flow transmitted rapidly through enlarged fractures and underground passages, make karst aquifers particularly vulnerable to contamination from human pollution. This means that protecting a cave-water source also requires understanding the land and drainage routes that supply it. Appreciable water flow detected during dives in La Ode Panu and Moko Morete indicate water transport mechanisms yet to be fully documented or understood and are candidates for future flow studies. Other cave systems such as Laulawi, Anoa, and Labungkari (which did not have noticeable water flow), could be compared and further mapped to determine whether the groundwater systems are truly isolated or modulated by other processes.

For Muna, a useful next step would be to document potential recharge areas and nearby land uses alongside the existing water-access inventory. These observations could guide subsequent investigations into where protective measures would be most effective [3].

Site	Number of Site Visits	Principal follow-up priority
Goa Lapahia	3	Freshwater interface; litter and pottery; survey and core-test records
Goa Lahumbe	1	Laundry use, pipes, sediment and logger at halocline
Goa La Ode Panu / Oe Kawawe	1	Observed siphon flow; fossil reef, remains and pottery
Goa Oe Mamba Kecil	1	Laundry and recreation; stratified water and two loggers, depth exploration
Danau Moko Morete	1	Swimming use; siphon flow, reef fossils and two loggers
Goa Laulawi	2	Water-use infrastructure; fragile deposits and coral-core candidates
Goa Labungkari	1	Swimming and probable abstraction; incomplete logger metadata
Dry cave near Watorumbe Bata	1	Village drinking source; fracture geometry and cultural materials
Dry Cave Exploration	1	Two neighboring dolines; graves and unstable host rock
Liang Kalolai	1	Bat colony, perched pool, pottery and large cave deposits
Goa Anoa	1	Logger and proposed sonde study; further bone documentation

Table 2. Summary table of sites visited during this expedition and priorities.



Figure 2. Documented water used and local practices on Muna. A) laundry and social-media content creation by a local at Goa Lahumbe, B) water piping extending into freshwater at the end of the cave line at Goa Lahumbe, C) recreational and social gatherings for young children at Goa Oe Mamba, D) water consumption piping from the entrance of Goa Laulawi down to the water table, E) K. Broad examines a water pump within Goa Labungkari, F) recreational gathering and swimming of locals and their families in Goa Labungkari, G) K. Broad circumnavigating water piping over 100 m down the entrance of the Watorumbe Bata fracture cave and H) local water pump repair by villagers at the entrance of the Watorumbe Bata fracture cave following exploration.

MAPALA & INDONESIA'S OUTDOOR CULTURE

Skills That Stay



Image 1. Dive gear racks at Kadena Dive Resort on Muna. Photograph by S. Hsia.

Knowledge passed on. Responsibility carried forward.

MAPALA, Mahasiswa Pencinta Alam, translates to "student nature lovers" and is part of Indonesia's university outdoor culture, connecting exploration with environmental stewardship and care for nature.

Alongside the dive gear, that tradition offers a reminder, lasting fieldwork depends on people sharing skills, building trust, and taking responsibility for the places they explore. Our equipment supports the journey, and the knowledge passed between generations give it purpose.

Geological interests

Deposits found in Muna's cave systems preserve environmental information through organic and inorganic calcium carbonate precipitation. As stalagmites and flowstones accumulate, their mineral layers can retain chemical signals influenced by rainfall, temperature and the water moving through the overlying rock. In addition to speleogenesis, it is also important to examine the underlying host rock, composition, and fossil assemblages. The formations documented during this expedition therefore provide potential targets for specialist assessment, with their scientific value depending on both preservation and careful sampling design [4]. When supported by reliable geochemical dating and an understanding of local conditions, these records can help reconstruct past environmental systems or parse out more information about cave formation.



Image 2. Extensive speleothem growth in Goa Anoa.

Okto et al. (2023) documented limestone lithologies, caves, coastal notches, natural arches and saline lakes on Muna. Their field inventory places the campaign's observations within a broader karst landscape and identifies limestone extraction as a conservation concern [5]. Their study does not provide dates for the caves surveyed here and these systems open up new opportunities to understand more about the timing and formation of different cave systems on Muna Island.



Image 3. Colossal stalagmite columns reach for the ceiling at Liang Kalolai. A 2 meter staff shows that larger scale speleogenesis is present in some of the larger cave systems in northern Muna.

Photo by S. Hsia

Natural wonders like helictites are visible in caves like Goa Lapahia. Intricate speleothem formations barely submerged by the freshwater table imply an interaction at the water/air interface that may modulate feature development and precipitation patterns.

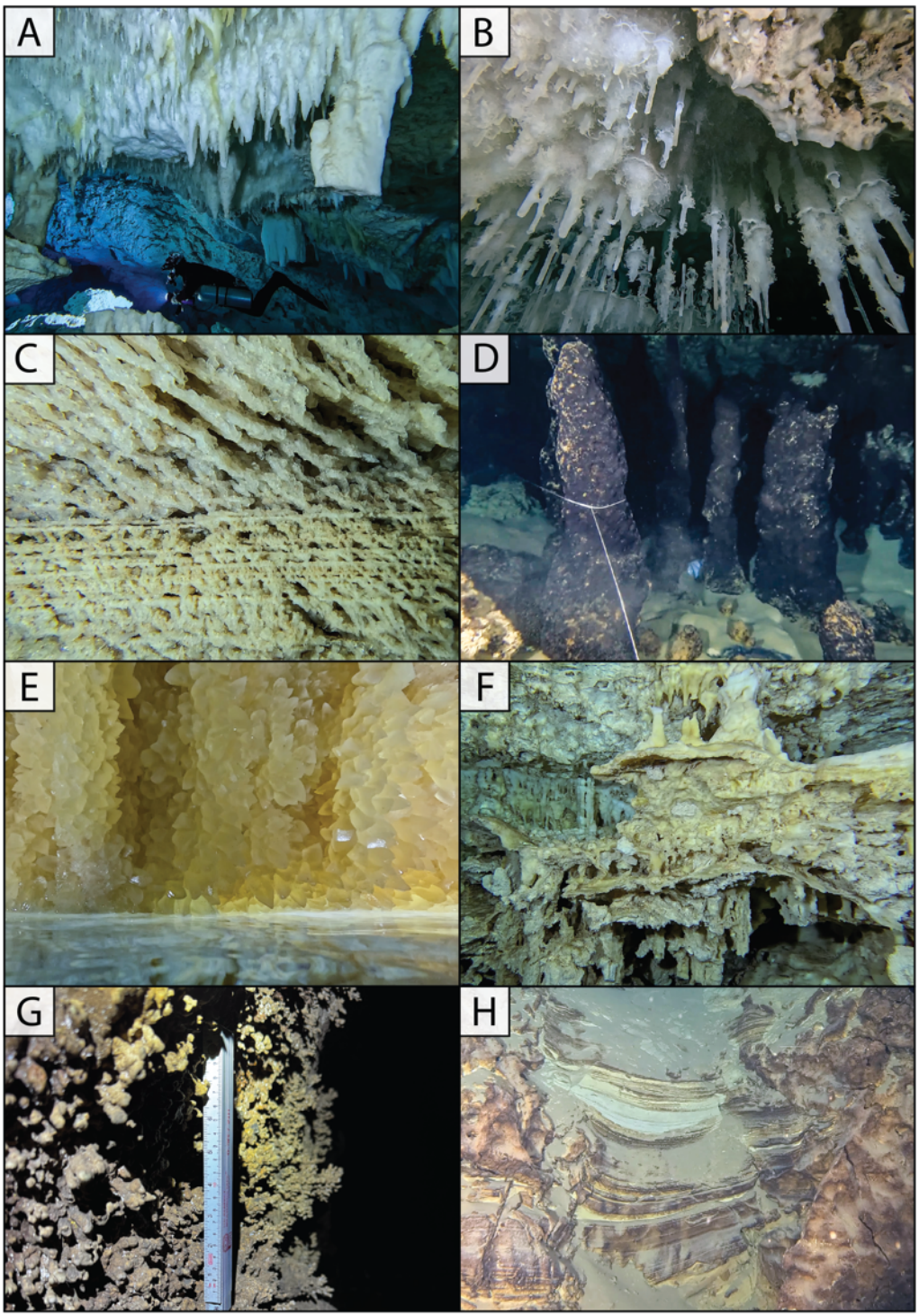


Figure 3. A) K. Broad for scale under a stalactite ceiling at Goa Lapahia, B) Helictites in Lapahia, C) Calcite growth structures in Lapahia, D) Organics encrusted speleothems in Lahumbe, E) Calcite crystal growth below, at, and above the water surface in Laulawi, F) Multiple stages of speleothem growth in Laulawi, G) Popcorn calcite with microbial/algal influence near the cave entrance of Liang Kalolai, H) Silt and fine grained chalk micrite interbedded strata in the deeper section of Labungkari.

The fracture cave near Watorumbe Bata offers a contrasting structural setting, with a deep vertical opening, large draperies and water at its base. Liang Kalolai contains large flowstones, multiple levels of dissolution and a perched pool. These observations support the opportunity for mapping comparisons and carefully designed dating studies. Cave size, ornamentation, and elevation alone do not establish relative or numerical age but when tied to geochemical constraints, are useful tools for understanding the timing and extent of cave formation.

Fossil corals, mollusks, and other reef material were recorded in several submerged caves, particularly La Ode Panu, Moko Morete, Laulawi and Labungkari. Bedding changes at Laulawi and Labungkari, together with calcite deposits formed within the caves, provide targets for studying how host rock and later dissolution shaped the passages. Fossil identifications in the field log remain provisional and should be reviewed before species-level publication [1].

For regional comparisons, Pedoja et al. (2018) combined landform mapping with uranium–thorium and radiocarbon dating of reef terraces on Buton, Wangi-Wangi and nearby islands [6]. Their approach informs future sampling design, but their terrace ages and uplift rates cannot be assigned directly to Muna's cave levels or DEM elevation bands without further investigation.



Image 4. S. Hsia next to an intact giant clam shell *Tridacna* spp. embedded in the reef wall in Moko Morete. *Tridacna* spp. distributions are sensitive to temperature and sedimentation changes and are important thermometers for the Indo-Pacific region [7,8]. Photograph by B. Kakuk.

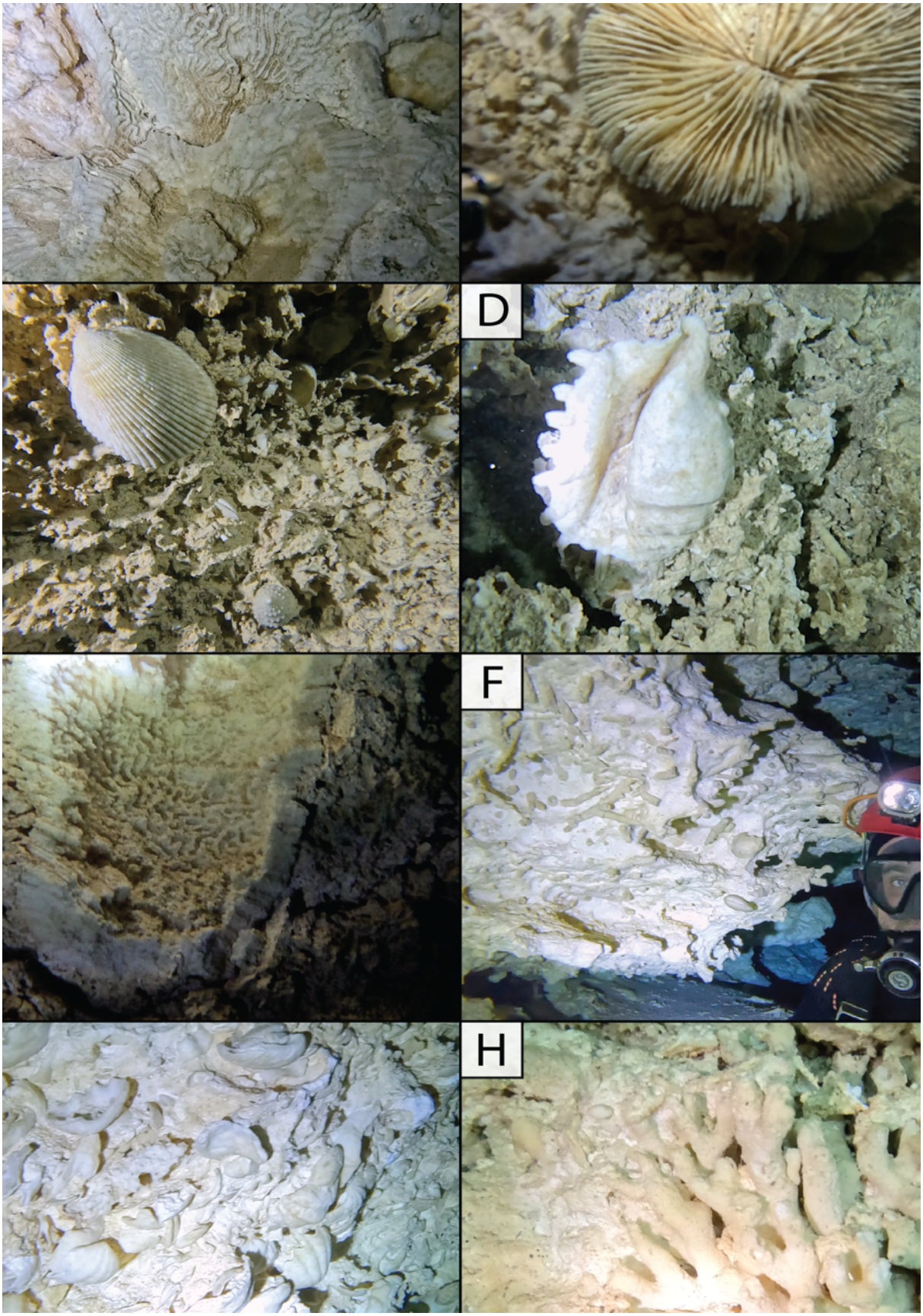


Figure 4. A) Coral head from La Ode Panu B) Coral in La Ode Panu C) Shell-dominated bioherm in Moko Morete D) Articulated Conch shell in Moko Morete E) Coral head in Moko Morete F) R. Cuesta near > 4m tall *Acropora cervicornis* colony in Goa Laulawi G) Shell death assemblage in Laulawi H) Branching coral near the cavern water entrance of Laulawi.

Ecological and biological interests

Coastal groundwater habitats can vary over short distances. Anchialine pools, which connect the underground to the sea, may have brackish surface water, increasing salinity at depth and water levels influenced by tides. Such habitats can support distinctive ecological communities. This information provides a useful framework for investigating Muna's stratified cave waters. Future biological observations could be paired with depth-specific salinity and dissolved-oxygen measurements to examine habitat differences, while testing (rather than assuming) connections to the sea [9].

Faunal observations include several taxa represented in Figure 5. Indonesian freshwater ichthyofauna include pipefish (Figure 5A) and demersal fish (Figure 5D) which were recorded in the light-limited freshwater zones of Oe Mamba and Moko Morete respectively and reinforce the idea that stratified habitats may be linked to water-chemistry, proximity to light, and depth. Other taxa, however, such as *Diancistrus typhlops* (Figure 5C), appear to have adapted to multiple environments, having been cited migrating between deeper freshwater in the caves to their feeding grounds within the cavern zone at night [10]. While shrimp, remipedes, and copepods were observed in several caves, macro-photo documentation proved to be a challenge (Figure 5B and 5E). Future efforts may call for specialized macrophotography equipment and dedicated sampling with Falcon tubes. Copepod documentation was previously conducted for three species on Muna (Boxshall and Jaume, 2012) although their relational behaviors with the rest of the food web, such as our observations that they carry off bat guano, are opportunities for further study [11].

Liang Kalolai, the massive sinkhole site containing cave crickets (Figure 5G) as well as a noticeable fecal stench from a sizeable (>150) fruit bat colony also warrants attention as a possible link between surface and underground ecology. Bat guano supplies nutrients to organisms living in caves, giving roosts ecological importance beyond the bats themselves. Follow-up work could document roost locations, evidence of seasonal occupation and associated invertebrates using methods that minimize disturbance. This would help determine how the colony contributes to the cave ecosystem and inform decisions about visitor routes and research access [12].

Anoa remains were recorded at La Ode Panu and Goa Anoa. These records justify specialist surveys, but neither species richness nor population condition was systematically measured at this time. A red-tinted layer at Oe Mamba Kecil was described as hydrogen sulfide in the log; that interpretation requires chemical confirmation and likely also interfaces with the local taxa, such as the various species of shrimp observed at this site.

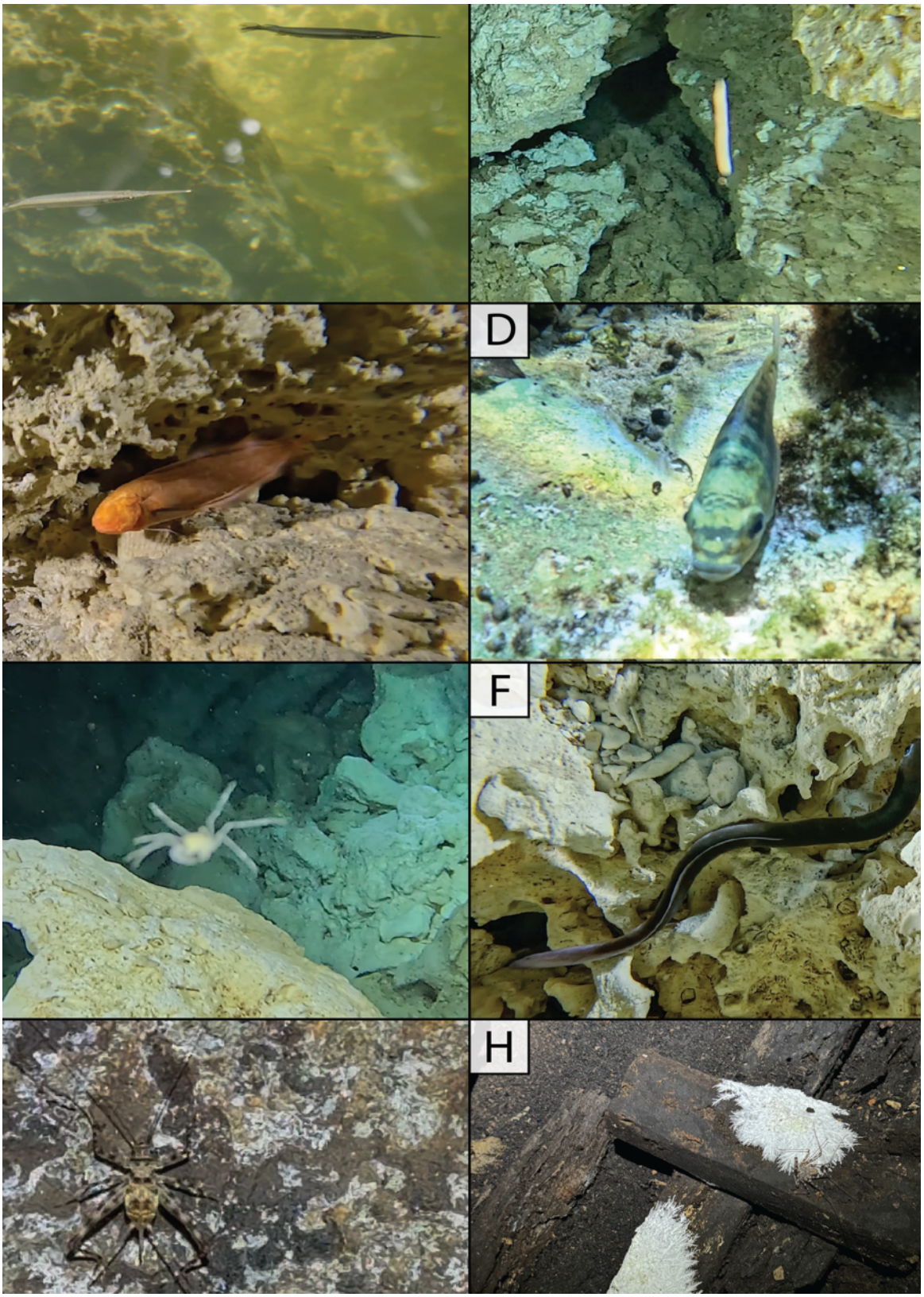


Figure 5. A) Pipefish (possibly *Microphis* spp. or *Doryichthys* spp.) sighting at Oe Mamba B) Unidentified *Remipedia* class or similar organism at La Ode Panu C) *Diancistrus typhlops* individuals spotted in Moko Morete D) Unidentified freshwater fish species spotted in the light-limited cavern area of Moko Morete E) An unidentified small translucent eight-legged crustacean-like organism about 3 cm in diameter F) A freshwater short-finned eel with large black eyes, small bilateral fins, and about 1.5 ft in length. G) A cave cricket spotted at Liang Kalolai within the cavern zone H) White fungal growth on organics and a tail whip scorpion perched nearby in the fracture cave.

Anthropological interests

During our excursions we found evidence of pottery, charcoal, graves, and grave markers (*referred to as nisan in Indonesian*). These observations, documented here and in our database [1], were purposely left undisturbed at each locality for future investigation.



Figure 6. A) B. Kakuk documenting pottery in La Ode Panu, B) pottery shards found in Watorumbe Bata fracture cave, C) Grave sites in dry dolines, D) Detailed carvings on a wooden grave marker resembling a house in the grave, E) Shards of pottery observed at the cave entrance of Liang Kalolai about 30m into the sinkhole, F) Assorted speleothems used as gravestones in Northern Muna.



Image 5. Trash observed at Goa La Humbe.

Trash, unfortunately, was also part of anthropogenic evidence left behind in the caves, especially in Goa Lahumbe. Single-use materials such as plastic bottles, empty plastic cartridges, broken glass, and plastic ties were among some of the items observed near both the site entrance, and at the open sinkhole at the end of the cave line. Scattered debris were also observed at Goa Lapahia and lesser amounts at La Ode Panu.

Future initiatives for R. Cuesta and BCRF could involve a coordinated cleanup, planned and carried out with cooperation from the local households who use Goa Lahumbe daily and would align directly with strengthening community relationships and conservation practices.

Equipment and research support

The deployment register provides a foundation for continued monitoring. In total, 14 HOBO loggers (10 MX2201 and 4 MX2203) were provided to R.Cuesta by BCRF. Eight serial-number entries are recorded across six sites. The six identified-site records list collection as “Uncollected,” which describes the log’s status rather than a verified present-day inventory. R. Cuesta will need to retrieve and reconcile the records before reporting data from a functioning monitoring network [1,13].

Site and deployment date	Serial number as logged	Model as logged
Lahumbe · 20 Aug	22386883	MX2201
La Ode Panu · 21 Aug	22386886	MX2201
Oe Mamba Kecil · 22 Aug	22386887; 22438023	MX2201; MX2203
Moko Morete · 23 Aug	22386884; 22386885	MX2201; MX2201
Laulawi · 24 Aug	22386881	MX2201
Labungkari · 25 Aug	Not recorded	Not recorded
Anoa · 31 Aug	22386892	MX 2201

Table 3. HOBO Logger data for study sites and deployed logger information

Several research discussions were led by K. Broad, B. Kakuk, and S. Hsia on the research potential and overarching themes that R. Cuesta could undertake during his dissertation. Ultimately, BCRF recommends that R. Cuesta focus on a case study, likely Laulawi, for his dissertation research, and that he prioritizes a research methodology that incorporates his technical diving background rather than a pure geological, hydrogeological, or geochemical focus.



Image 6. Research planning and discussions at Kadena Dive Resort.

The dive-equipment inventory transferred to R. Cuesta (Image 7, left) by B. Kakuk covers the full requested set needed to supplement technical dives, and hands-on refractometer instruction (Image 7, right) extended R. Cuesta's training into water-chemistry sampling. While HOBO loggers are able to record temperature and depth, BCRF recommends incorporation of more robust water quality parameter measurements such as conductivity, dissolved oxygen, pH, and isotope tracing.



Image 7. (left) Inventory of additional dive equipment provided to to R. Cuesta. (right) B. Kakuk instructing R. Cuesta on use of the refractometer for salinity readings of water sampled in the caves.

Deployment notes locate instruments at haloclines, passage landmarks and the Anoa room, but fixed depth, logging interval and calibration records should be added. The listed MX2201 and MX2203 models are temperature loggers; placing them at a halocline does not itself measure salinity or discharge [2]. A lasting research record requires enough documentation for another investigator to understand how each measurement was obtained. The FAIR principles—Findable, Accessible, Interoperable and Reusable—provide a useful framework for organizing scientific information. Applied to this project, a consistent site identifier could link logger files, survey stations, photographs and field notes, while accompanying records explain units, methods and processing decisions. Access arrangements should also be documented so that research partners can use the records appropriately while sensitive site information remains protected [13].

Pinger 2.0 training followed the same hands-on model. After a briefing from K. Smith, R. Cuesta installed several transmitters at the ceiling of Goa Lapahia (Image 8) and K. Smith demonstrated the directional null readings used to triangulate the transmitter's position from the surface. This technique allows future surface teams to confirm underwater survey points without a diver in the water and rectify cave line maps to a larger geospatial context.

Pneumatic drill coring techniques were taught by S. Hsia who supervised R. Cuesta through safe drilling operations. A pilot hole was tested in Goa Lapahia's cavern section, and inspection of the recovered core (Image 9) showed reasonable percent recovery which can be repeated by R. Cuesta independently.




Image 8. (left) R. Cuesta installing the pinger transmitter at the ceiling of Goa Lapahia. In its upright vertical form, the pinger actively transmits sound. (right) K. Smith showing R. Cuesta a null pinger reading when the receiver is held horizontally in the dipole field.





Image 9. Additional tungsten carbide pneumatic drill provided by S. Hsia was procured on loan to R. Cuesta for the duration of his first field season. (left) S. Hsia instructing R. Cuesta on protocols for safe drill operation. (center) R. Cuesta drilling a pilot hole in Goa Lapahia's cavern section with S. Hsia to test feasibility. (right) B. Kakuk examining the recovered core sample.

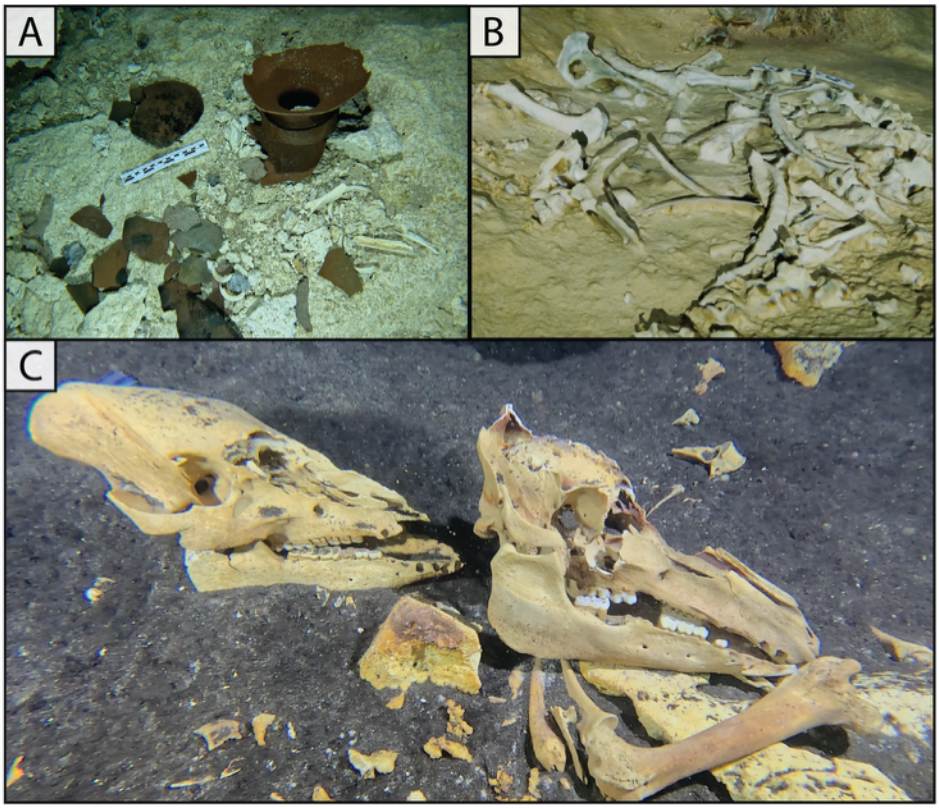


Figure 7. Video-to-3D model reconstructions by B. Kakuk and S. Kister from A) GoPro footage of broken pottery taken at La Ode Panu which were used to create a 3D model of the pottery and B) Anoa bones shown in 3D-generated model from GoPro video taken by B. Kakuk at Goa Anoa. C) Skeletons overlain on organic debris in Goa Labungkari at the base of a cave opening.

For sensitive material, the team implemented non-invasive documentation methods. GoPro footage of pottery and Anoa remains were processed into 3D reconstructions by B. Kakuk and S. Kister (Figure 7). Preservation of the spatial context for fragile anthropological and faunal material without physical disturbance or removal is a low-impact approach worth expanding upon, especially given the amount of material found during this expedition (see Anthropological interests).

Underwater HOBO logger installation occurred throughout the expedition (Figure 8). MNemo operation, GoPro videography, and dive-slate note taking together made up the primary methods for real-time data capture during cave dives.

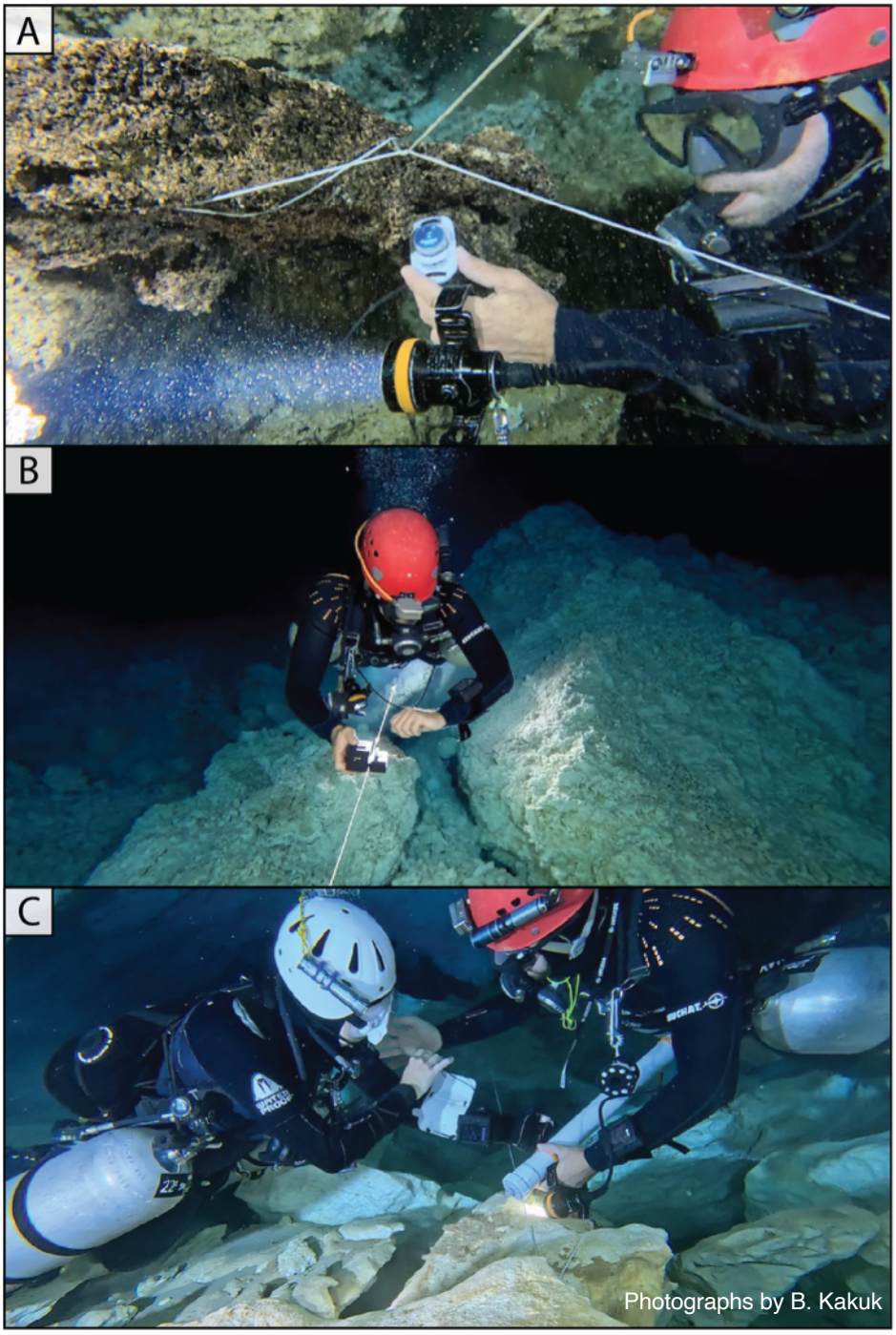


Figure 8. A) HOBO loggers were installed near or on the cave line, example shown from Goa La Humbe. B) MNemo devices were operated by R. Cuesta. C**)** Underwater data communication and documentation was done primarily through slate writing and video recording by B. Kakuk and S. Hsia.



Image 10. Shallow passages of Laulawi sometimes require maneuvering to get through limited spaces between collapsed reef structures

Photograph by S. Hsia

Mapping and technical contributions

Field conditions shaped what mapping was possible at each site. Laulawi's shallow passages, for example, required divers to maneuver through shallow sections from collapsed reef structures (Image 10). These physical constraints were factored into both the dive planning, but also the level of accessibility and equipment use during the dive. MNemo use is marked at four sites, Caveway X1 mapping on the three dry-exploration records, and Pinger 2.0 use on two Lapahia visits. Lapahia notes document relining, a pneumatic-drill core test and a subsequently reported 70 m extension of the cave line by R. Cuesta and R. Idhin. These are recorded activities linked to Appendix A - they should be linked to archived survey files, sample records and dated photographs by R. Cuesta for future research products.

Focus on Laulawi

In addition to field surveying, S. Hsia provided research guidance to R. Cuesta on remote sensing digital elevation model visualization through publicly available satellite data (https://tanahair.indonesia.go.id/portal-web/unduh/demnas) which was the highest resolution national DEM available at the time of the expedition. This dataset contains spatial resolution of 0.27 arcseconds and utilizes the EGM2008 vertical datum and EPSG:32751 - WGS 84 / UTM zone 51S coordinate reference system (Figure 9). This data was mosaiced, processed through a colormap and hillshade, and then shared with R. Cuesta as useful basemap to plot the extent of his cave mapping, and validate MNemo line measurements and Pinger data corroborated with GPS coordinates.

Overlaying MNemo survey points on the DEMNAS elevation model shows most recorded points clustering within roughly 10 m of present water depth, with a smaller cluster at greater depth, suggesting a second, or possibly tertiary, water horizon. These deeper points are promising candidates for target investigations by R. Cuesta through follow-up dives.

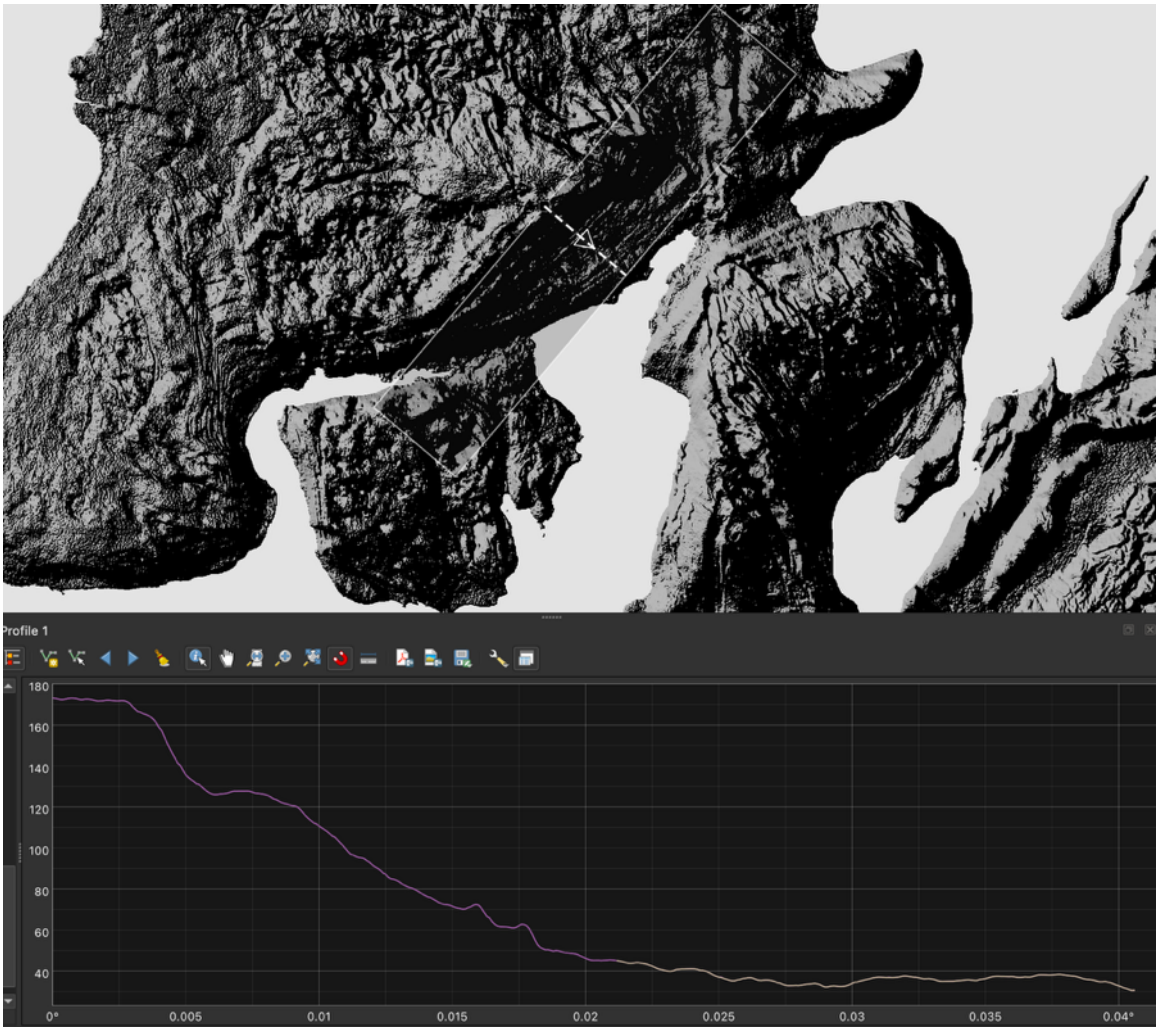


Figure 9. Example of elevation profile cutting across Laulawi's cave system. This profile moves across several relict reef terrace systems that may assist R. Cuesta in answering research questions on cave passage formation and water security. S. Hsia and R. Cuesta used the relative tectonic uplift rates reported in recent regional studies to back-calculate the terrace elevation for the MIS 5e highstand as a starting point for future exposed reef exploration.

The passage morphologies documented through GoPro recordings, and on R. Cuesta's line maps show a variety in cave morphologies. Goa Laulawi follows the orientation of marine terraces overlying the area. However, the direction of the cave passageways does diverge in the southeastern end indicating potentially other drivers of cave formation (Figure 10).

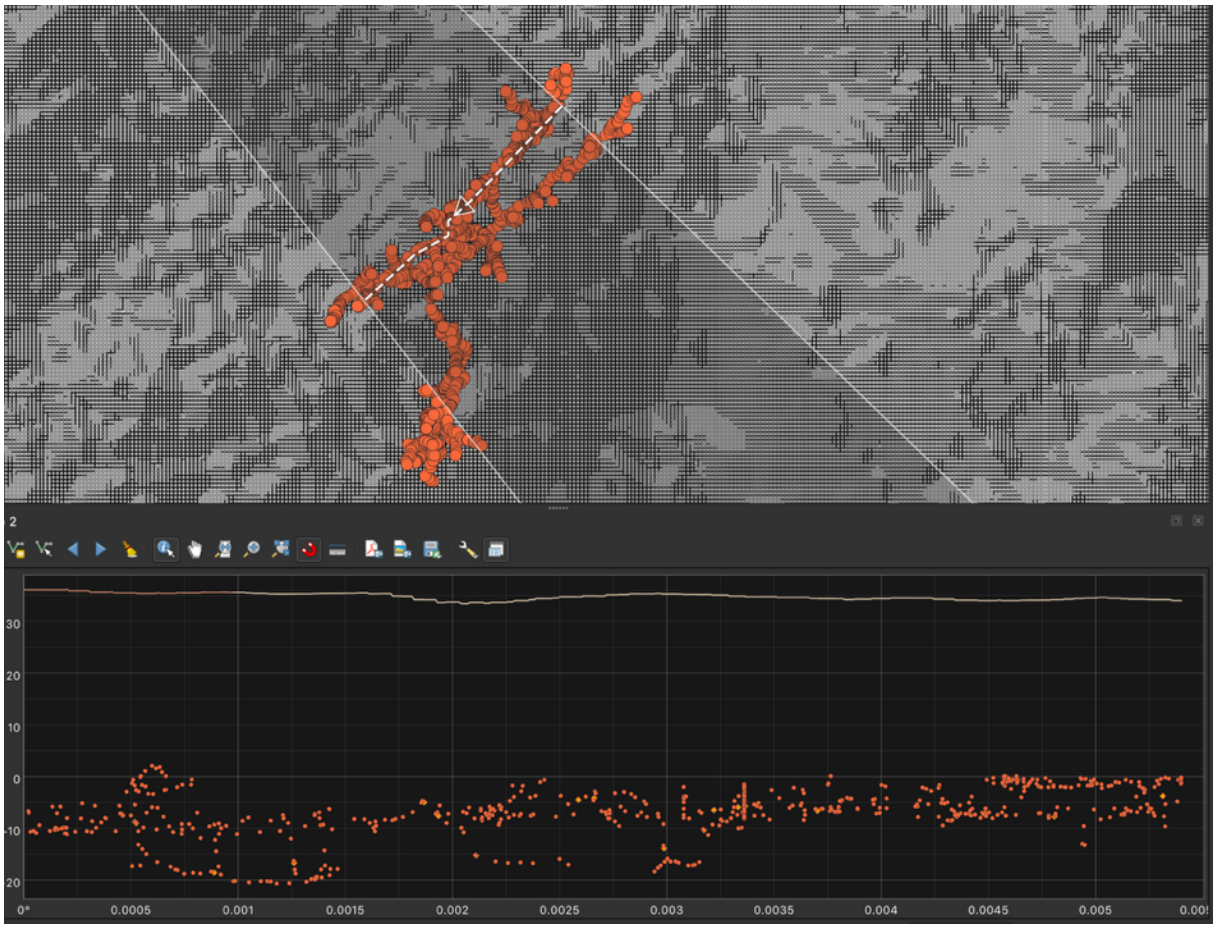


Figure 10. An elevation profile with underlying MNemo survey point data (orange points) overlain on merged DEMNAS data above. Much of the MNemo survey data falling within 10m water depth at Laulawi. However, a secondary or even tertiary water horizon are observed at deeper spots that could be candidates for further cave passage investigations.

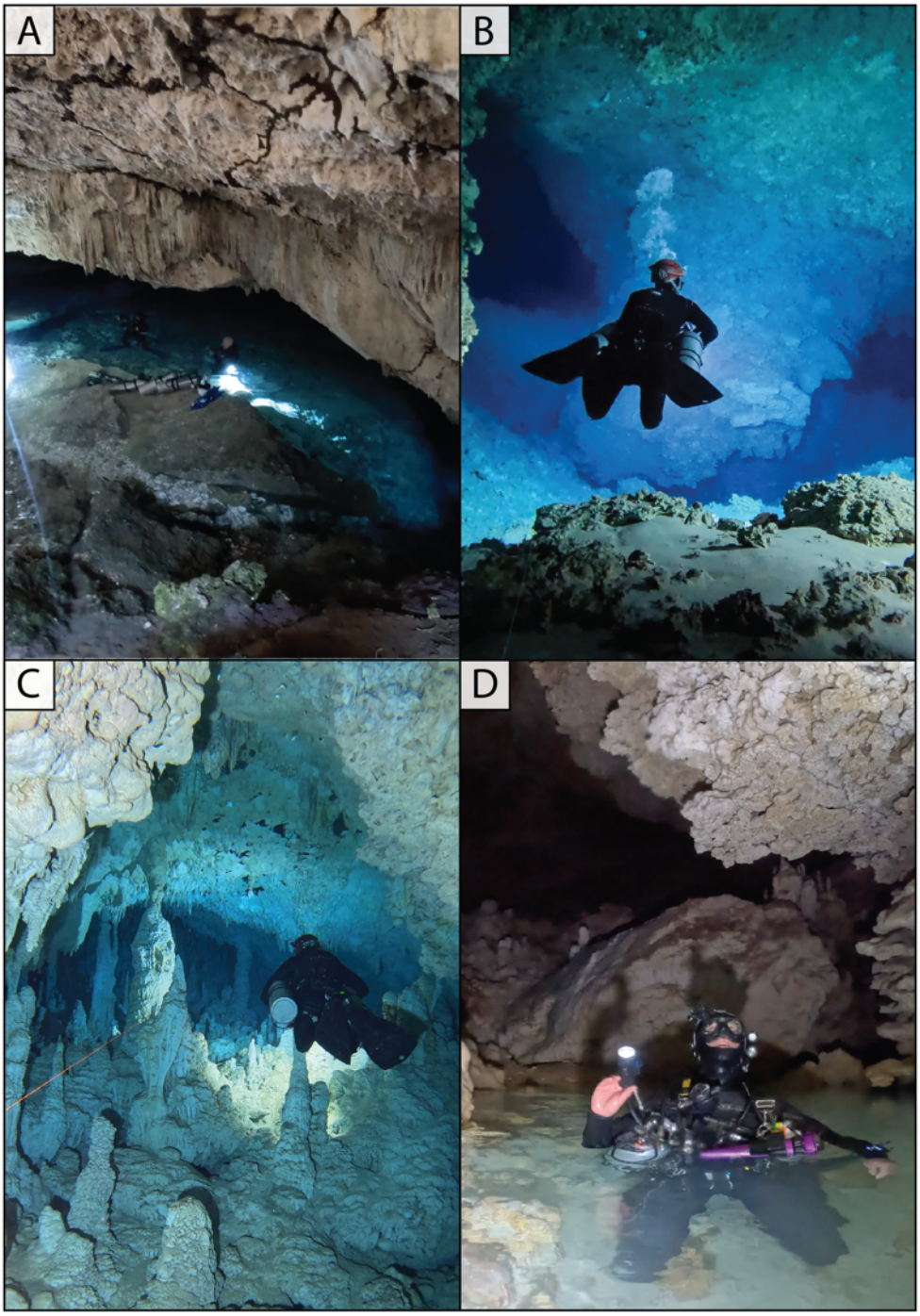


Figure 11. A variety of cave passage morphologies present a unique opportunity for further investigation into drivers of passage formation, their shape, size, composition, and degree of dissolution. A) Entrance to La Ode Panu with a sloping crescent opening down into the water where infilled cracks in the ceiling are visibly cemented with a dark brown paleosol and rooting. B) R. Cuesta facing a bifurcating passage within extensive reef facies within Moko Morete C) Speleogenesis shown in Goa Anoa indicating calcite precipitation over extensive timeframes D) K. Broad looking up while kneeling in the shallow section of Labungkari following a restriction. Dry passages are opportunities for Caveway 1 mapping to be linked to underwater MNemo data.

Spotlight: Launching a doctoral research career

Robin Cuesta, Doctoral student of Environmental Science, Gadjah Mada University Indonesia

Supervisors: Dr. Eko Haryono, Professor of Geography, Gadjah Mada University, Indonesia
Dr. Kevin Pedoja, Researcher, University of Caen Normandy, France
Dr. Tjahyo Nugroho Adji, Karst Research Group, Gadjah Mada University, Indonesia

A central goal of this expedition was equipping R. Cuesta's doctoral research with support, tools, and groundwork to succeed independently. BCRF provided:

- Dive and mapping equipment, including water quality loggers, a pinger transmitter system and a tungsten carbide pneumatic drill (on loan for the field season)
- Hands-on training, including instruction in refractometer use for salinity readings
- Site selection, instrument placement, and sampling reconnaissance across 11 locations
- Preliminary development of a research framework by scientists to guide the doctoral project's next phase



Image 11. Image of R. Cuesta next to his research framework during the expedition

After workshopping research ideas with R. Cuesta over the course of two weeks in the field and two weeks directly following the expedition, R. Cuesta has narrowed in on the following scientific research questions to guide his dissertation:

R1 What are the three-dimensional characteristics of selected submerged karst groundwater systems within the uplifted carbonate island of Muna, and how do they represent contrasting hydrogeological settings?

R2 How do groundwater level, temperature and conductivity responses to tidal and recharge forcing vary spatially and temporally among these contrasting settings?

R3 What do these differences in groundwater response imply for freshwater stability and sensitivity to salinization?

With this foundation in place, the next field season can transition from training and equipment deployment to sustained, independent data collection and data analysis. BCRF's equipment financing can sustain repeat measurements and a traceable field-to-analysis workflow. The log supports describing practical contributions to site selection, instrument placement, mapping and sampling reconnaissance. Advisory hours, formal supervision levels, equipment responsibilities are not yet quantified. These contributions will be reported through a separate signed support register in conjunction with annual research progress reported by R. Cuesta.

Conservation and awareness priorities

The next phase should pair research with practical stewardship. Water users, local guides and site custodians should help define priorities, access arrangements and how results are shared. Observed laundry and recreation are starting points for discussion, not grounds for attributing pollution without measurements [1].

Proposed action	Evidence of progress
Recover and audit monitoring sites	Device identity, retrieval status, backed-up files and usable record duration
Verify maps and sensitive locations	Entrance checks, survey validation with DEM and ground control
Develop water and habitat baselines	Repeat observations with methods, dates and instrument metadata
Agree site stewardship with users	Documented local priorities, access arrangements and maintenance roles
Share accessible research results	Community materials reviewed locally and feedback recorded

Table 4. Table of action and follow-up work towards cave conservation and water security on Muna.

Public awareness materials can be generated using the site map, cave schematics and photographs to explain the relationship between surface activities and underground water. Emphasis that caves contain living habitats, geological archives and cultural evidence would improve community understanding. Distinguishing observed features from hypotheses and agreements on how sensitive locations and images will be shared should be discussed before distributing a public map.

Conservation guidance is more likely to be practical when the people who use and care for a site participate in its development. International cave-management guidelines emphasize involving local communities and other stakeholders in planning and review. For Muna, this could include discussing proposed access routes, water-source protection and visitor information with village representatives and guides before materials are finalized. Locally reviewed explanations would help connect scientific findings to everyday concerns and identify responsibilities that can be maintained between research visits [15]

Muna's archaeological importance is demonstrated by Oktaviana et al. (2026), who dated calcite over a hand stencil at Liang Metanduno and established a minimum age of 67,800 years for the motif [16]. Although Liang Metanduno is outside this campaign's site inventory, their finding strengthens the case for careful documentation and specialist review of cultural materials, before dating the pottery or remains observed during this expedition.



Image 12. Photo from Liang Metanduno featuring ancient cave paintings. B. Kakuk is pointing to the hand stencil dated to 67,800 years located directly above R. Cuesta (red helmet).

Near-term success should be judged by recoverable data, reliable maps and agreed conservation actions. The campaign has identified where further work is justified. Converting that reconnaissance into defensible evidence will make the NGO's investment more useful to researchers and to the communities using these cave systems.

WATER SECURITY STARTS WITH A CONVERSATION

Engaging the Community

While R. Cuesta seeks out the local village elder, explorers K. Broad, B. Kakuk, M. Braun, and S. Hsia seek out interactions with the local school children. Here, K. Broad and the children of Watarumbe Bata exchange local greetings in English and Indonesian.



Image 13: Greetings at the school near Watorumbe Bata

Photograph by M. Braun

Access to Muna's caves is never assumed. At every village bordering a survey site, the team's first stop was not the cave entrance but a conversation with the village elder, a landowner, or local guides who rely on the water source. These conversations, and permission to enter the cave, shaped where the team could go, what could be documented, and how the findings would be shared with the local community.



Figure 12. Meeting with various village elders for permission to explore caves near villages.

ASKING FIRST

Seeking an Elder's Permission

Permission-seeking took different forms depending on the village. Conversations occurred seated, over coffee, in the village leader's home, or a common area and were settings that put weight on the relationship over formal paperwork. At times, these meetings occurred in the presence of onlookers, policemen, and family members. Oftentimes, village leaders sent their sons to accompany us into the sinkholes.

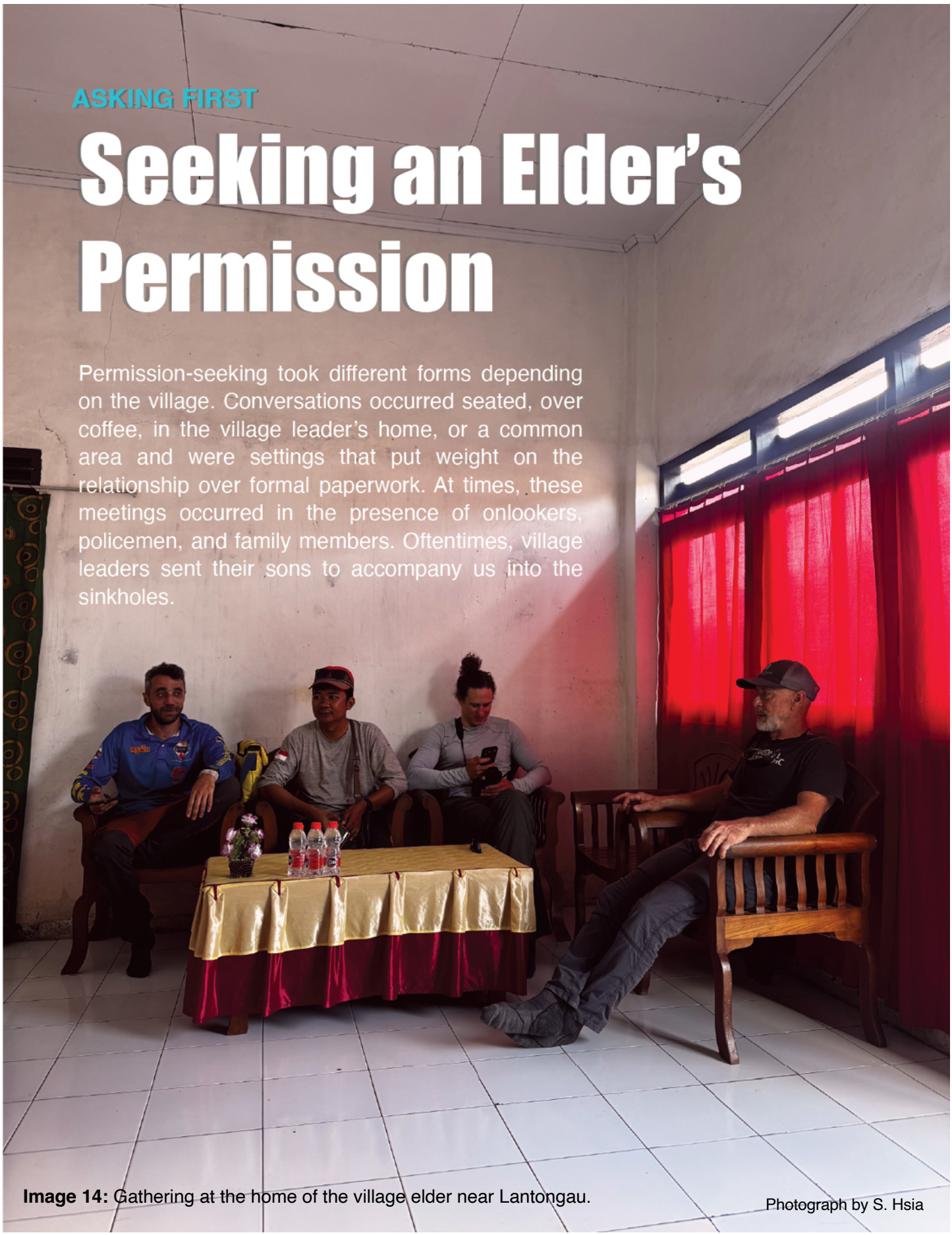


Image 14: Gathering at the home of the village elder near Lantongau.

Photograph by S. Hsia



Image 15. Following a local prayer by the village elder before descending into Liang Kalolai, the team engages with curious locals including children

Entry into Liang Kalolai followed a local prayer led by the village elder, who himself changed into field attire and accompanied us to the sinkhole. These places hold clear community significance to the local villages. Outside the caves, the BCRF's team presence drew curiosity, especially from children. While these encounters were not data-driven priorities, they presented natural opportunities to engage locally with young villagers and establish a positive rapport for future interactions.

Much of this season's vertical caving work, such as the descents required to reach several of the dry-cave sites discussed above, depended on rope and rigging expertise the research team did not carry on its own. That expertise came through a local partnership: Kharisma Yuda, a rappelling and ropes specialist affiliated with MAHIPAL, joined the expedition through Sulawesi Dive Trek and oversaw rigging and safe vertical access at sites the team judged unsuitable for freeclimbing. His involvement reflects a deliberate choice rather than a convenience: that the safest and most locally appropriate way to reach these sites is through people who already know them.

MAHIPAL is a local chapter of MAPALA at Universitas PGRI Ronggolawe (UNIROW) in Tuban, East Java. Founded in 1996, this chapter trains students in mountaineering, caving, and wilderness rescue while cultivating a long-standing culture of conservation volunteerism. In many regions, MAPALA-trained members are the only people nearby with practiced vertical rope skills, and they are frequently the first responders to local cave incidents. Drawing on this network connected the expedition to a body of institutional knowledge about these landscapes that predates, and will outlast, any single research season.



Image 16: R. Cuesta rappels down Liang Kalolai while K. Yuda oversees the ropes operation. Photograph by S. Hsia

Future involvement

A natural next step consistent with the stewardship priorities of BCRF would be to formalize a working relationship with a MAPALA chapter active near Muna's main cave clusters: offering invitations to visit during research expeditions and assisting in facilitating basic survey methods, in return for the rope access, safety oversight, and site continuity these groups are already positioned to provide. Of all the partnerships this project could build, one with local student cavers may do the most to solidify a legacy of continued monitoring and conservation efforts.

Instrument recovery and an assessment of data quality will also be a priority during the follow-up visits. Repeat visits could then target contrasting hydrological conditions before the team evaluates whether additional monitoring locations are needed. This staged approach follows the principle that monitoring should establish a reference condition and provide comparable observations through time. The duration of BCRF involvement should be reviewed against these research milestones, with field dates agreed according to local access, partner availability and the questions being investigated [14].

The next funding cycle should include a workflow and timeline required to turn field measurements into reusable

research outputs. Alongside equipment and field logistics, the budget could support data checking, specialist interpretation, archiving and preparation of materials for local partners or publication. Each priority should contain a reviewable deliverable, such as a documented temperature dataset or a verified survey package by the recipient, R. Cuesta. This proposed emphasis on usable outputs is consistent with the FAIR principles, which recognize documentation and data stewardship as essential to the continuing value of scientific research [14].



Image 17. Divers from left to right: S. Hsia, R. Cuesta, K. Broad in Goa Laulawi.

Notes from the team



Brian Kakuk, Founder
"I'm very impressed with [Robin's] work thus far and am sure [it] will be of great value to the local and governmental groups as well as to the cave community at large. We are looking forward to seeing [Robin's] dream come to fruition and hope to be back to assist in the not-too-distant future."



Kenny Broad, PhD, Chief Scientist
"It's rare to see a foreigner who has embraced the local community and environment, and this dedication seems to be well accepted and respected by the locals. It's impressive how much geology [Robin] has picked up on [his] own. I'm very much looking forward to seeing how [his] thesis ideas progress and helping in any way I can."

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Scarlette Hsia, PhD, Geologist
"This has been one of the most rewarding experiences with BCRF so far. The cave systems of Muna are geologically unique due to their shallow nature and uplift that has exposed carbonates from previous sea-level highs. This setting allows for the opportunity to answer many research questions! Robin has his hands full and I'm looking forward to supporting his mission and future collaborations with him."



Robin Cuesta, Sulawesi Dive Trek, Owner, PhD Student
"I want to thank you all for coming to my place and providing your invaluable insights and sharing your experience. It has been a true honor to have you all around…Thank you guys for believing in me, I [will] do my best to make you proud, looking forward to [seeing] you soon and can't wait to see where all of this is going."

Acknowledgments

This work is made possible through donations to the Bahamas Caves Research Foundation. In addition to the survey and scientific members, we thank Max Braun for his filmography, Kharisma Yuda (MAHIPAL rappelling and ropes specialist), the staff at Sulawesi Dive Trek, including Rasid Idhin ‘Chaca’, Syakira Dewa (Sulawesi Dive Trek intern), and Kadena Dive Resort in Muna.



Image 18. (top) The team pictured with guests and staff at Kadena Dive Resort, (bottom) Explorers and locals at the Watorumbe Bata fracture cave.

Sources

[1] Muna Cave Data Log 26 field log shown in Appendix. All site observations derive from these records. Equipment financing and doctoral-project context were supported by BCRF.

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Literature scope. References [2], [5], [10], and [15] concern Muna directly; [6] and [7] provides a regional comparison. Web resources [3], [4], [7], [9], and [11] provide supporting context and methodological framing rather than Muna-specific findings. Published findings are distinguished from the expedition observations in [1]. References checked 15 September 2026. English translations of Indonesian titles are provided in brackets.

Appendix

Source: Data tables are not reproduced here. Requests for access to survey data are considered by BCRF on a case-by-case basis under a data-sharing agreement.


DAIHATSU
Gran Max
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