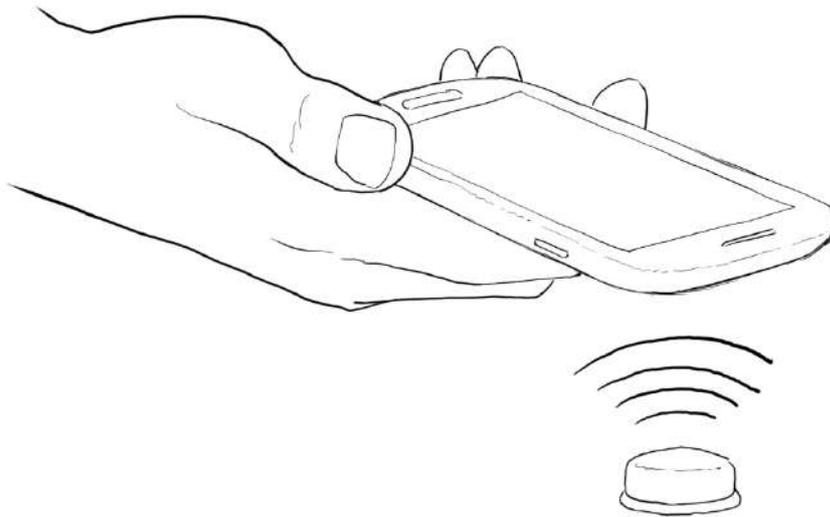


EnvLogger System

**A rugged and autonomous temperature logging system
with contactless communication**



User manual rev. 24 January 2020

Overview

The EnvLogger system is composed of two symbiotic parts, the hardware (i.e., a miniaturized and rugged temperature logger), and the software (a smartphone app).

The logger communicates with a smartphone using Near Field Communication technology (NFC). There are no cables or plugs to be connected when programming loggers or retrieving data. It is only necessary to “tap” the loggers with the smartphone (Fig. 1). EnvLoggers can be embedded in hard acrylic “pills”, making them completely watertight, and placed in humid, dusty or even moderately corrosive environments. They can also be left exposed to UV light or deployed underwater. They are quite resistant to mechanical stress, and because communication is touchless, they can then be permanently attached to or placed inside hard materials such as rocks or concrete, or made into robo-animals (such as robomussels¹, robolimpets² or robobarnacles³). With the dedicated smartphone app, logger servicing in the field or in the lab is extremely quick and easy.

The EnvLogger system has a vast number of applications in the fields of environmental and climate monitoring, thermal stress, ecology, cold chain monitoring, animal welfare, and pharmaceutical and medical industries.



Figure 1. Temperature data being retrieved from an EnvLogger in the field. This particular EnvLogger was previously encapsulated in a limpet shell and permanently

attached to the rock surface with Z-Spar A-788 epoxy compound.

Hardware

EnvLoggers are available in three main formats (see Figure 2): A – naked electronics in a disposable 3D capsule; B, C, E, F, G, H – encapsulated in hard acrylic; D – as biomimicking loggers, encapsulated in real shells.



Figure 2. A-H Variety of EnvLogger packages. All but A are highly resistant to dust, water and UV, and can be safely deployed in the intertidal zone, a hazardous environment for electronics featuring significant wave forces, sharp thermal transitions and salt water corrosion (I). A rugged smartphone is all that is needed to communicate with the EnvLoggers in adverse environmental conditions (J).

Format A has exposed electronics and thus should not be deployed directly as is. It is provided in a naked format so that advanced users can imbed it on their specific applications. Otherwise, loggers can be encapsulated in real shells such as the robolimpet in Fig. 2 D, or in waterproof, hard acrylic enclosures (Fig. 2 B-H). Both are highly resistant to environmental hazards such as UV, dirt, moisture, water and shock. They can even be deployed in areas submerged by seawater and pounded by waves (Fig. 2 J). For those encapsulated in acrylic, it is possible to use a wide variety of UV-

resistant pigments. Fig. 2B shows a 2:1 black:white gray logger and Fig. 2C shows a 1:3 black:white gray logger. Sizes are also customizable. Logger in Fig. 2 E has 19 mm in diameter, loggers in Fig. 2 B and F have 21.5 mm in diameter and loggers in Fig. 2 C and G have 27 mm in diameter. See the last page of this manual for more details on logger sizes.

Software

The software, *EnvLogger Viewer*, is an app that runs on Android smartphones (v 4.4 or higher) with Near Field Communication (NFC) capabilities or on iPhone 7 and higher. Examples of Android phones are CAT S41 or higher, Ulefone Armor 2, and most Samsung, Huawei, LGE and HTC models. *EnvLogger Viewer* is freely available from Android's Google Play or iOS's App Store (see the QR codes below).

Drawing from several years of field experience, the app has been specifically designed with clarity and reliability in mind. Graphics have high contrast to improving readability in adverse lighting conditions, and menus are designed to minimize any possibility of accidental data loss (in other words, it is a "fool-proof" design as far as it goes). For example, as soon as the user accesses the data of a given logger, they are automatically downloaded and saved in the background, ensuring that even in the event of a mishap, data will not be lost.

Data can be easily managed and instantly shared using a dedicated data manager included in the app.

Main features of the EnvLogger system

- Ability to work in tough environments, including resistance to UV, dirt, moisture, water and shock.
- Quick deployment and servicing. Programming individual loggers takes a few seconds, and because last mission's settings remain in memory, it is possible to

"tap" and program a large number of loggers in sequence in just a couple of minutes. Downloading data takes approximately 60 seconds for a full-memory logger. The ability to quickly service loggers is highly valuable in hazardous environments such as the surf zone.

- As soon as the app plots the data, they are automatically saved the smartphone's memory.
- "Automatic mode" to aid working in conditions where touching the screen is not easy (e.g., places hard to reach or underwater).
- Data are saved as CSV files, which are human-readable and easily imported into Excel, R, MatLab, or similar.
- Memory is non-volatile, meaning that data can still be accessed after battery depletion.
- Mission can be started immediately or at a later date. There is a "pretty dates" option allowing the user to choose a friendly and "rounded" date and hour.
- Full Time Zone support.
- Competitive price. Refer to www.electricblue.eu for more information including up-to-date pricing.

Step-by-step operation

Obtaining the app

On your smartphone, go to the Android or to the iOS App Store and download the app **EnvLogger Viewer**. You can also use the QR codes provided below. If your smartphone is not compatible, the app will not show up on the store. Regularly check the app store to keep the app updated with new features.

iCloud integration (iPhone users only)

For those using an iPhone, there is the option to store the logs locally or to save them to the iCloud. Using iCloud adds a significant layer of safety to data. It ensures that data is instantly backed up as they are download in the field, it prevents data losses associated with app uninstall and update, and makes data available across multiple devices. We strongly encourage users to enable iCloud

integration. If iCloud has previously been turned on, data will be saved there automatically upon choosing that option. If, however, iCloud has never been enabled, that need to be done first. To do that, go to Settings and sign in to your device with your Apple ID. When you sign in, iCloud is turned on automatically. Then, return to Settings, tap your name, then select iCloud. Scroll to apps and turn on iCloud on the EnvLogger Viewer app.

Connecting to a logger

You can either click the icon to open the app (Android and iOS) or just tap an EnvLogger and the app will open automatically (Android only). You must give permission to the app to access the smartphone's storage, otherwise the app will not be able to save data and consequently will not work. You should also turn on the GPS (Fig. 3). This will allow the app to get the GPS position and append the coordinates to the log file. This can be extremely useful to sort out large numbers of log files after they have been collected.



Due to logger size constraints, the size of the antenna is only optimized in the 27mm diameter loggers (Fig. 2 C, G). In smaller loggers (19 mm and 21.5 mm) the NFC antenna is not optimized and so the communication range is very short (it also depends on the smartphone specifications, but it is typically < 10 mm). Thus, the smartphone should be placed as close as possible to the logger (touching it) and because in most devices the NFC antenna is centered, the logger should be also centered with the smartphone (see fig. 4). In some cases, the antenna is in another location and thus a different alignment should be tried (e.g., some Samsung, Motorola or iPhone devices have the antennae at the very top). Check the smartphone documentation if necessary.



Figure 3. Warning asking for GPS to be turned on.

The situation where the antenna is mounted on top (e.g., iPhone) is quite handy when trying to reach loggers that are inside concavities or crevices – have that in mind when buying the smartphone.



Figure 4. Keeping the smartphone centered with the logger and touching will dramatically improve communications in most models. Note that on some models (e.g., iPhones) the antennae is located on the top of the phone and so the logger should touch that area (near the rear camera).

The app was tuned to run even in the slowest and oldest smartphones, and so allow some time for communications to be finished before moving the smartphone away from the logger.

Starting a new mission

Connect to the logger and in the main screen you should see “NO MISSION” highlighted in yellow (see Fig. 5 left side). That means that the EnvLogger is idle, waiting for a mission to start. This is the mode that uses the less amount of power and should be used to store loggers.

In the initial screen you can see the logger's unique serial number and its current temperature. This

field is updated by pressing the button “GET CURRENT TEMPERATURE”. You can also tap the field “CUSTOM NAME” to assign a human-friendly name to your logger in addition to its unique serial number (something that will later help distinguishing log files from different loggers). Finally, you can tap the padlock icon at the top right corner to assign a custom 4-digit password to the logger. The default password is “0000”. In this way your logger will only be accessible and programmed by someone that knows its password. If you do not want to set up passwords, just ignore this feature and leave the default value of “0000” unchanged. The password input screen will automatically pop-up in case there is a mismatch between the password defined in the app and the password defined in logger (Fig. 5 right side).

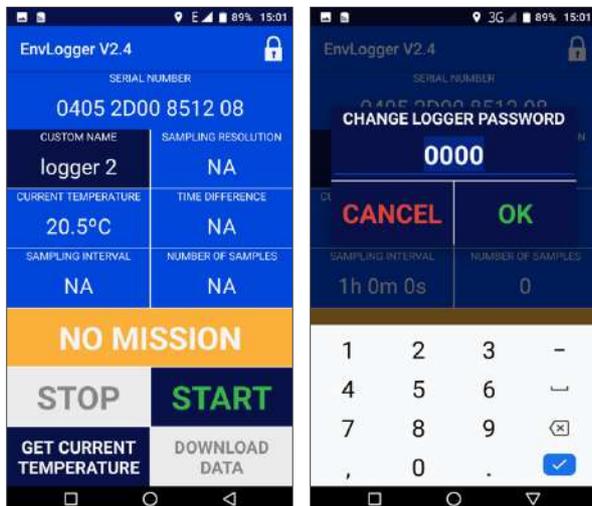


Figure 5. Initial screen and password setting screen.

To start a mission, press “START”. This will bring up a new screen (Fig. 6 left). From here you can choose a sampling resolution (0.1 °C or 0.5 °C), and the interval in hours (H), minutes (M) or seconds (S). The minimum value is 10 seconds.

The combination of sampling resolution and frequency will determine the minimum deployment duration, which is displayed on the screen to aid mission planning. As explained below (in the technical specifications section), the logger uses a data compression algorithm and thus the real deployment duration will always be longer than that minimum value.

Press “NOW” if you want the logger to start right away, or in alternative, choose any future date to start. The “PRETTY DATES” option rounds up the date so, for example, if the sampling interval is 1 hour, the logger will start working at the next round hour.

Press OK. A confirmation message will show up on the screen. If the logger was programmed to start later, you will see “WAITING TO START” highlighted in yellow in the main screen (Fig. 6, right). There is also an indication of when the first sample will be taken.



Figure 6. Start mission and waiting to start screens.

That’s it, your logger is ready to collect data! Before deploying the logger in the field, make sure you take note of the serial number (and the custom name) so you know which logger was deployed where.

Video on YouTube on how to start a mission:
<https://www.youtube.com/watch?v=qBGBRFtcN5s>

Downloading data from a mission

Connect to a logger. If a mission is running you should see “MISSION RUNNING” highlighted in green (see Fig. 7 left side). Mission-specific information is displayed in the screen, which can be used to quickly assess the logger status in the field. That includes the sampling resolution, the current clock drift (shown as “TIME DIFFERENCE”), the current sampling frequency and the current number of logged samples.

To stop the mission without visualizing or saving the data, press STOP. Be aware that data will be lost forever. A warning will pop-up and the only way to proceed is to accept it, so that you do not stop a mission by mistake.



Figure 7. Mission running screen (left), and download data screen (right).

To download data press “DOWNLOAD DATA” in the main screen. A progress bar will show up. Wait for the data to finish downloading (Fig. 7 right side). Once data has been fully downloaded it will show up as a graphic and a message will pop up indicating that data were saved to the smartphone’s memory in the folder “EnvLogger”. Each downloaded log will be placed inside a folder labeled with the current day. There’s no button to save data. Data are automatically saved to prevent accidental losses.

The download data screen also shows the minimum and maximum values ever registered in the current mission and their time stamp. Note that if there are multiple minima or maxima, only the first instance of that value will show up.

From the download data screen, there are four possible actions: (i) you can “STOP” the logger. You can do this safely because data was already automatically saved. Stopping the logger will set it in low-power mode. (ii) you can restart the logger, launching a new mission by pressing “START”. This will bring you back to the start mission screen (Fig. 6 left side). The logger can be re-started an indefinite number of times, providing that the

battery has power. (iii) You can “CANCEL” looking at the data. This will return you to the mission running screen (Fig. 7 left). You should use this option whenever you are just checking loggers and want to download and backup data but for some reason do not want to stop the current mission and start a new one. Note that pressing the back button on your smartphone will have the same result and will return the app to the main screen. (iv) Finally, you can also tap the button “SHARE”. This will open the system sharing options (see Fig. 12 below) and will allow you to send the data by email, for example, providing that the smartphone is connected to a data network or to Wi-Fi.

Video on YouTube on how to download data: <https://www.youtube.com/watch?v=IYZ0o4vYpSQ>

Automatic mode (Android users only)

Note: this mode will be released to iOS devices in a future update.

When servicing a long series of loggers at once, or dealing with those that are hard to reach or even underwater, it may be difficult or impossible to interact with the smartphone by tapping the screen. The automatic mode allows you to program the loggers without having to do so. To use this mode, first you have to open the app without connecting to any logger. From the main screen, touch the smartphone icon in the top right corner of the screen (Fig. 8 left).

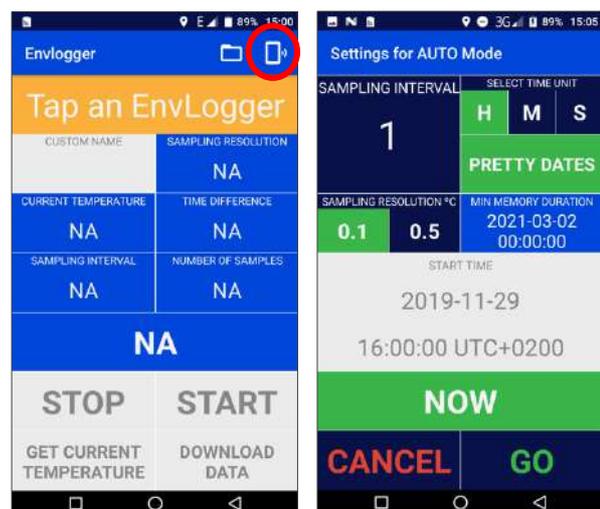


Figure 8. Enabling the automatic mode.

That will open a menu very similar to the “Start menu” screen (Fig. 6 left). Choose your options (sampling resolution, starting time and sampling frequency), and touch “GO”. The app will then show a different screen while it starts searching for EnvLoggers (Fig 9 left).

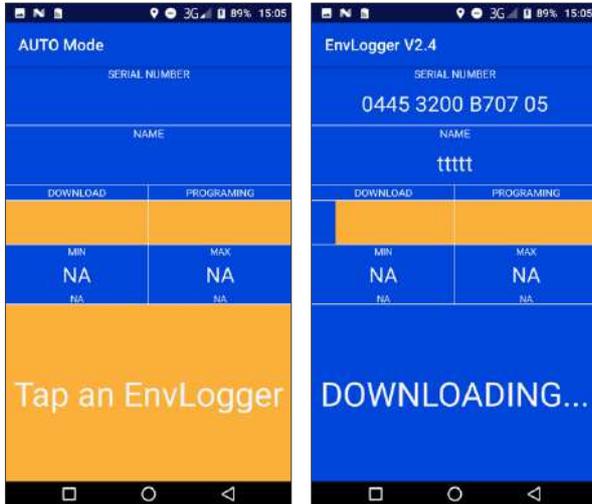


Figure 9. Automatic mode. The phone keeps searching for EnvLoggers, downloading data and starting new missions by itself. Press the “back” button 3 times in a row to leave this mode.

Once the smartphone is brought into contact with an EnvLogger, the app will automatically identify it, showing its serial number and name, and a progress bar will appear as it automatically proceeds to download the data (Fig 9 right). From here, two things can happen.



Figure 10. In the left, the automatic mode was able to download data and start a new mission. On the right, the download was interrupted and so it failed, as well as starting a new mission.

If everything goes as expected, the app will finish downloading the data and will immediately start a new mission. Both the “download” and “programming” sections of the screen will turn green and a large “SUCCESS” message in a green background will appear (Fig 10 left). If either the downloading or the programming fails, the message will say “FAIL”. This may happen because you moved the phone away, interrupting the download (see Fig. 10 right). In that case just bring the phone closer to the logger and the process should repeat automatically. Otherwise, it means that something is wrong with the logger and you should check it manually.

Leaving the automatic mode is hard by design. Otherwise an inadvertently (accidental) tap or touch on the screen would cause the automatic mode to stop, and by then the user could be in a situation where starting it again would be impossible (for example, while diving). So, to leave the automatic mode it is necessary to tap the “back” button three times in a row. That will bring the app to the regular, manual mode.

Stopping missions to save power

To store a logger more efficiently (i.e., using as little power as possible), missions should not be running. To stop a logger, either choose “STOP” from the main menu (Fig. 7 left, but be aware that this action will not save any data still in the logger) or choose “STOP” after downloading data from the data loading screen (safer, Fig. 7 right).

Dealing with full memory and with battery depletion

If battery runs out during a mission, the “DEPLETED BATTERY” warning will appear highlighted in red in the running mission (main) screen (Fig. 11 left). You can still retrieve whatever data is in the logger even without battery power. Just tap the button “DOWNLOAD DATA” and, as explained before, as soon as data is shown in the graph your data has been safely saved to the smartphone. Encapsulated loggers cannot have their batteries replaced. Battery life depends on various factors, such as sampling frequency (the more frequently data is sampled, the faster the battery is used) and environmental temperature

(extreme temperatures reduce battery life). For reference, sampling at every hour, the expected battery lives of 19 mm and 21.5 mm loggers is 2 years, and the battery life of the 27 mm logger is 5 years.



Figure 11. Depleted battery error (left) and memory full warning (right) on main screen.

If a logger runs out of memory, it will stop logging and will show the “MEMORY FULL” warning in the main screen (Fig. 11 right). You just have to download data by pressing the “DOWNLOAD DATA” button and then either stop the mission or start a new one. There is no limit on the number of times that the memory can be completely filled and re-used.

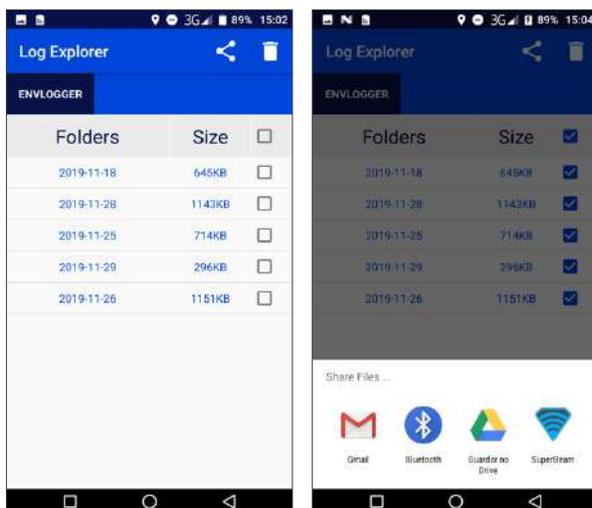


Figure 12. Log explorer (left) and share menu (right) screens.

Managing and sharing data (Android users only)

Note: this mode will be released to iOS devices in a future update.

The app allows you to manage the collected data after servicing EnvLoggers. To do that, open the app without connecting to any logger. From the main screen, touch the folder icon in the top right corner of the screen. That will open a data browser called “Log Explorer” (Fig. 12 left). There you will see the root folder called “ENVLOGGER”. Inside the log files will be organized in folders, grouped by day. You can select entire folders to delete or share or tap them to see the individual log files inside, which can also be deleted or shared using the system sharing options (Fig. 12 right).

Technical specifications

- Clock drift of 50 ppm at most.
- Measures temperature with a user-defined resolution of 0.1 °C or 0.5 °C.
- The user can choose the sampling frequency at equidistant intervals ranging from 10 seconds to 18 hours.
- Missions can be started immediately or at any given date up to 10 years in the future. This is useful whenever there is the need to synchronize readings among several loggers.
- The average temperature precision (average dispersion among multiple EnvLoggers at a given point) is less than 0.1 °C.
- The average temperature accuracy (average deviation of EnvLogger readings from a reference temperature) is less than 0.2 °C.
- Operational temperature ranges from -30 °C to +60 °C. Note that battery performance decreases dramatically at temperature extremes.
- The memory stores a minimum of 11,000 readings at 0.1 °C resolution or 15,000 at 0.5 °C resolution, but the actual value is typically higher. The EnvLogger uses a data compression algorithm and the amount of compression depends on the data structure. When readings are more

similar, more compression is achieved and more data are stored. If readings are very variable, then less compression is possible and less data can be stored. Typically, the minimum number of readings is about 15,000 for a resolution of 0.1 °C and 20,000 for 0.5 °C resolution.

- NFC range between 10mm and 20mm, depending on logger model (see more details at the end of this manual).
- Battery lifespan between 2 and 5 years, depending on logger model (see more details at the end of this manual).
- Reduced dimensions (see more details at the end of this manual).

Questions and answers

How are time zones managed by the app?

Time zone mishandling can lead to catastrophic effects. Thus, everything is done automatically. For user's convenience, the app will always show dates and times using the time zone that is defined in the phone's settings. In this way, the user can easily relate to the starting time and to the times that are shown in the log file. The system, however, works internally on standard UTC. Therefore, there is no problem if a logger is started using a specific time zone but later the data are downloaded using a different time zone. All dates are compatible because the logger is always working on UTC but showing whatever time zone the user chooses to see. Importantly, log file is also always in UTC. That information is explicit on the header of the log (UTC +000), and can be used for subsequent data ingestion or processing.

Are the iOS and Android app versions equivalent?

We typically roll out app updates first for Android, and only later for iOS. The user experience also differs. In Android devices, communication with the logger is permanent, thus the smartphone must be kept close to the logger at all times. This allows for quicker feedback but sometimes it is hard to keep the same position for a while. In the iOS app, connection is only needed to send commands or download data from loggers. Communication can be interrupted and resumed later because things are done in turns. When starting a new mission, for example, the user can choose the missions

parameters away from the logger, only briefly tapping the logger at the very end to commit changes.

I want to make a biomimetic robomussel or robolimpet or robosomething, which logger should I use?

It largely depends on the species you want to mimic. For larger body sizes use the 27 mm diameter logger as it has a larger battery and longer NFC range. For smaller mimics, use the 21.5 mm or the 19 mm loggers. For tiny animals you might even consider embedding the naked electronics (16.5 mm in diameter) in some waterproof compound that conforms to the organism you are trying to mimic. Contact us if you need assistance.

I don't want to log body temperatures, just environmental temperatures, which is the best logger for that?

The grey logger with 27 mm in diameter (Fig. 2 C). The grey colour was tuned to obtain roughly the same albedo as regular granite (0.3-0.4).

Does the NFC communication between the smartphone and the logger work underwater?

Yes. The smartphone must be touching the logger though, as the NFC range drops to a few mm. What does not work underwater is the touchscreen of the smartphone, but this can be fixed by using a waterproof flexible clear diving enclosure appropriate for the smartphone. The “**Automatic mode**” (see above) can be of great help underwater.

Why do you have transparent and opaque loggers?

Transparent loggers are more pleasant aesthetically, but otherwise have no advantage over opaque loggers. If the objective is to have the loggers exposed to solar radiation, then the transparent loggers should be avoided as they will heat up and cool down differently with the angle of the sun. Opaque loggers are much more homogeneous in the way they absorb and give away heat, and should be used whenever the logger is to be left (or can become) exposed to the sun.

Why do you have loggers with different shades of grey?

Because for specific applications it may be important to match the logger colour with the colour of the substrate (the rock, soil or even animal colour).

Is it possible to have loggers in [insert your favourite colour here]?

Yes, it is. Contact us for more information.

Is it possible to have loggers encapsulated in different resins/materials?

Sure, contact us to discuss the options on this regard.

Which is most appropriate logger for the MBON Pole to Pole network?

When the MBON Pole to Pole network started using loggers, the grey loggers with 27 mm in diameter (Fig. 2 C) had not yet been developed, so the network started with robolimpet loggers (Fig. 2 D), which, at the time, were the loggers that would capture a more generalist environmental temperature in the intertidal. Currently, the best loggers for this purpose are the grey loggers with 27 mm in diameter (Fig. 2 C).

Which is most appropriate logger for the WE-LOG network?

WE-LOG is the short name for the “collaborative global network of coastal temperature sensors”. Unveiled at ITRS 2019, it aims at collecting coastal temperatures at a global scale. Grey loggers with 27 mm in diameter (Fig. 2 C) were designed specifically for this task and thus should be used in this network.

My loggers keep being lost or stolen. What can I do?

The long-term deployment of eye-catching devices is problematic in some areas of the world. In locations heavily visited by recreative fisherman or tourists, it seems that regardless of how hidden the loggers are, people will always find them. In other cases, it's the wave action that either projects large quantities of coarse sand, or hauls small boulders or drifting wood, hitting the loggers and destroying them. For these situations, there is something that can help: embedding the loggers in the rock. That

will protect them from natural erosion and will hide them from people. It is possible to drill a hole with 30 – 35 mm in diameter into the rock and insert the logger, compacting it with Z-Spar⁴. The logger should also be covered with a thin layer of Z-Spar⁴ (Figs. 13 and 14). Because the NFC allows for communication at a range of a few cm, it is still possible to communicate with the logger, programming it and downloading data as necessary.

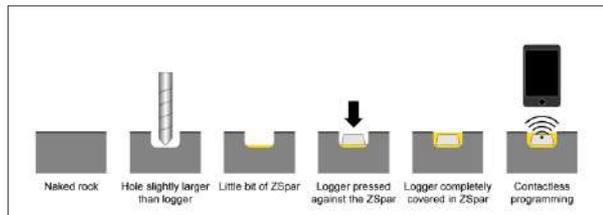


Figure 13. Instructions for embedding a logger in the rock.



Figure 14. Process of embedding loggers in the rock. From left to right: drilling, clean holes, pressing a logger against Z-Spar⁴, loggers covered in Z-Spar⁴.

References

1. Helmuth, B. S., & Hofmann, G. E. (2001). Microhabitats, thermal heterogeneity, and patterns of physiological stress in the rocky intertidal zone. *The Biological Bulletin*, 201(3), 374-384.
2. Lima, F. P., & Wetthey, D. S. (2009). Robolimpets: measuring intertidal body temperatures using biomimetic loggers. *Limnology and Oceanography: Methods*, 7(5), 347-353.
3. Chan, B. K., Lima, F. P., Williams, G. A., Seabra, R., & Wang, H. Y. (2016). A simplified biomimetic temperature logger for recording intertidal barnacle body temperatures. *Limnology and Oceanography: Methods*, 14(7), 448-455.
4. There are many types of glue or epoxy you can employ to deploy EnvLoggers. For harsh environments where adhesion is critical, we strongly recommend using “Z-Spar Splash Zone A-788 Underwater Two-Part Epoxy Putty”, available at www.go2marine.com.

EnvLogger comparison table

	Type of Envlogger				
	Naked	Robolimpet	Tiny	Small	Medium
Note that the three loggers on the right can be produced in any color					
Type of enclosure	Disposable 3D printed capsule	Elastic 3M 2131 polyurethane inside a real limpet or mussel shell	Hard and inert acrylic resin		
Maximum diameter at the base	16.5 mm	~ 35 mm	19 mm	21.5 mm	27 mm
Minimum diameter at the top	14 mm	-	17 mm	18 mm	24.5 mm
Height	7.5 mm	~ 15mm	8.5 mm	10 mm	11 mm
Minimum battery lifespan sampling at 1h frequency*	2 years				5 years
Maximum NFC range	10 mm				20 mm
Structural robustness	Weak	Good		Best	
Waterproofing	No	Tested in a pressurized water bath. Loggers withstood 56 bar + 100 cycles of pressurization between 0 and 20 bar (equivalent to a dive to 560m + 100 dives to 200m)**			
Maximum clock drift	≤ 50 ppm				
Temperature resolution	Programmable to 0.1 °C or 0.5 °C				
Average temperature precision and accuracy	≤ 0.1 °C and ≤ 0.2 °C				
Operational temperatures	- 30 °C to + 60 °C. Note that battery performance decreases dramatically at temperature extremes.				
Memory capacity	Minimum of 10k readings @ 0.1 °C resolution or 12k readings @ 0.5 °C resolution. Typically, 14k readings @ 0.1 °C resolution and 17k @ 0.5 °C resolution. For reference, 1 year of data at hourly resolution requires ~9K readings.				
Size on disk of a full log file	Approximately 1 Mb				

* an improved version of these loggers is being developed with a battery life approximately 30 times longer.

** see the graphs with the pressure test profiles in the next page.

Pressure test logs

All logger formats (with the exception of naked loggers) were successfully tested in a pressurized water bath where they were subjected to (i) increasing pressure culminating with 560 meters of water (left graph), and (ii) one hundred cycles of pressure variation between 0 and 200 meters (right graph).

