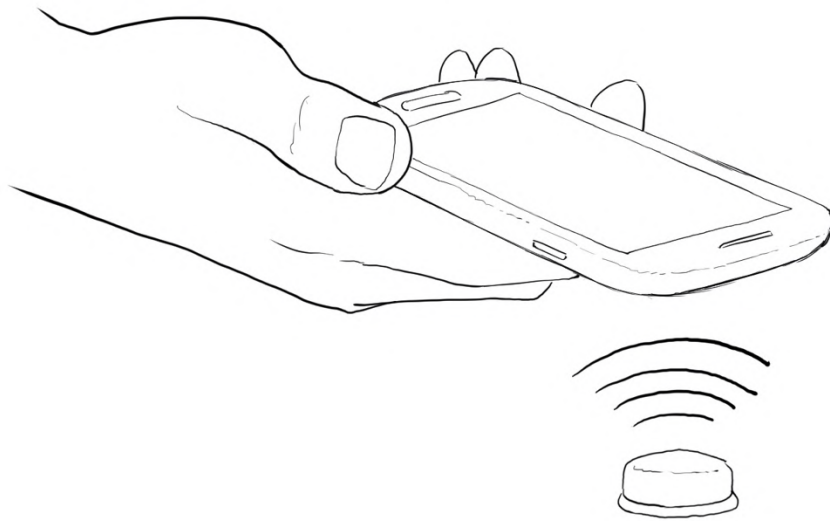# EnvLogger System

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

User's documentation package, rev. 12 January 2021

Overview

The EnvLogger system is composed by a miniaturized and rugged temperature logger and by a companion smartphone app. Both were designed with emphasis on reliability and ease of use in scientific applications.

The logger communicates with a smartphone using wireless Near Field Communication technology (NFC). It is only necessary to "tap" the loggers with the smartphone (Fig. 1). EnvLoggers can be acquired on a variety of formats, including as hard acrylic disks, which are completely watertight and can be deployed in dusty, subaquatic, UV-rich or even moderately corrosive environments. They are also quite resistant to mechanical stress, and because communication is touchless, they can be embedded in hard materials such as rocks or concrete, or made into robo-animals (such as robomussels[1], robolimpets[2] or robobarnacles[3]).

With the dedicated smartphone app, logger servicing is extremely quick and easy. This, in turn, facilitates the establishment and maintenance of large networks of loggers serviced by multiple scientists and/or citizens. 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 pharmaceutic 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 two hardware formats, v2.4 and v5.0. *Note: v5.0 is scheduled for release during the 2nd quarter of 2021.*

	Hardware version	
	v2.4	**v5.0**
Memory capacity at 0.5 ºC resolution	> 12k readings* (enough for 16.5 months at 1 sample/hour)	262k readings (enough for 30 years at 1 sample/hour)
Memory capacity at 0.1 ºC resolution	> 10k readings* (enough for 13.5 months at 1 sample/hour)	131k readings (enough for 15 years at 1 sample/hour)
Minimum battery lifespan at 20 ºC**	Approximately 5 years at 1 sample/hour	Approximately 20 years at 1 sample/hour
Temporal resolution	Programmable between 10 sec and 18 hours	Programmable between 2 min and 4 hours
Maximum start delay	10 years	255 minutes
Maximum clock drift	75 to 100 seconds/month	15 to 25 seconds/month
Size on disk of a full log file	Approximately 1 Mb	Approximately 5.4 Mb
Max download time of a full log	2 minutes (Android and iOS)	4 minutes (Android) or 6 minutes (iOS)
Maximum NFC range	10 mm	5 mm
Average temperature precision and accuracy	≤ 0.1 ºC precision and ≤ 0.2 ºC accuracy	
Operational temperatures	- 30 ºC to + 60 °C. Note that battery performance decreases dramatically at temperature extremes.	
Temperature resolution	Programmable to 0.1 ºC or 0.5 ºC	

*v2.4 uses data compression and typically can store more readings than these, which are the guaranteed minimum. **battery duration for a 27mm logger. The 21.5 mm logger only has 3 years of battery life. Actual battery life depends on the temperatures at which loggers are exposed to.

v5.0 is vastly superior to v2.4 in terms of memory, battery life and clock drift, but has a little less NFC range and the programable sampling frequency is slightly more limited.

Both v2.4 and v5.0 can be supplied in a virtually endless variety of shapes and colors. These can be grouped in three main categories (Fig. 2): A – naked electronics in a disposable 3D capsule; B – encapsulated in hard acrylic, and C – as biomimetic loggers (resembling real animals).
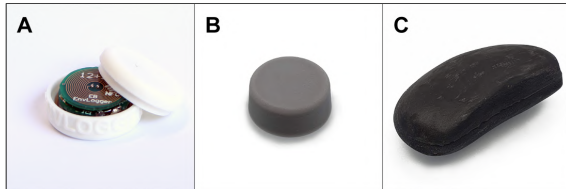

Figure 2. The three main EnvLogger categories (A – naked electronics, B – disk, and C – biomimetic).

The format shown in A has exposed electronics and thus should not be deployed directly as is. It is meant to be imbedded by advanced users in their specific applications. Otherwise, loggers can be encapsulated in hard acrylic such as in the disk shown in B or as biomimetic loggers (a *Mytilus californianus* is shown in C). B and C are highly resistant to environmental hazards such as UV, dirt, moisture, water and shock. They can be colored with a wide variety of UV-resistant pigments. Sizes and shapes are also customizable. See Fig. 3 for additional examples and the last pages of this manual for more details (including dimensions).

Software

The software, *EnvLogger Viewer*, is an app that runs on Android smartphones (v4.4 or higher) with Near Field Communication (NFC) 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 (just scan 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 improve 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 are not be lost.

The Android version of the app also includes a tool to automatically download data and reprogram loggers without having to use the touchscreen. This ability is particularly useful underwater.

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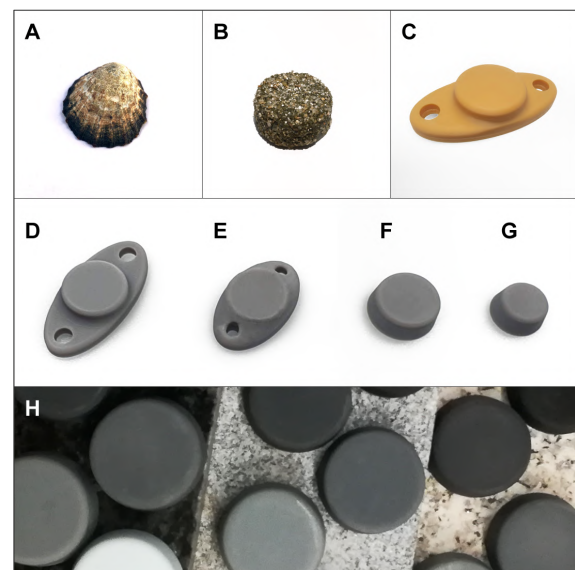

Figure 3. Some of the possible variations in shape, size and color. A – a robolimpet with a real shell from Patella vulgata. B – an EnvLogger coated in sand to deploy in Sabellaria alveolata reefs. C – a 27 mm diameter EnvLogger with mounting ears for M6 screws and in ochre to match the color of vermetid reefs. D – same as C but in gray. E – similar to D but with rounded corners to attach to macroalgae with zip cables. F – regular 27 mm EnvLogger. G – smaller 21.5 mm EnvLogger. H – 27 mm EnvLoggers in several shades of gray. Their color may be important if they are to be deployed exposed to the solar radiation.

Main advantages of the EnvLogger system

- Ability to work in tough environments, including resistance to UV, dirt, moisture, water and shock.
- Quick and intuitive 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. The ability to quickly service loggers is highly valuable in hazardous environments such as the surf zone.

- "Automatic mode" to aid working in conditions where touching the screen is not easy (e.g., places hard to reach or underwater).
- As soon as the app plots the data, they are automatically saved to the smartphone's memory.
- 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 even after battery depletion.
- Mission can be started immediately or at a later date, which can be used to synchronize readings among several loggers. There is a "pretty dates" option allowing the user to choose a friendly and "rounded" date and hour.
- Full Time Zone support.
- Automatic creation of a log file in the background registering all actions pretraining to EnvLoggers. This file can later be used to extract information on what was done and when, or to backtrace deployment issues.
- 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. Keep the app updated to benefit from 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. 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 needs 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.

Granting permissions
You must give permission for 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. This will allow the app to get a GPS fix and append the coordinates to the log file, which can be useful to sort out large numbers of log files after they have been collected.

Accessing this documentation from within the app
This documentation is now available from within the app. To open it, tap the ⓘ icon on the top right of the main screen, and then tap on the book icon.

Connecting to a logger
Due to size constrains, the antenna is only optimized in the 27 mm diameter loggers (Fig. 3 B-F, H). In smaller loggers (21.5 mm, Fig. 3 A,G) 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 < 5 mm). Thus, the smartphone

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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. 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, next to the camera). Check the smartphone documentation if necessary. 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 or deploying loggers in the field.

Thick smartphone cases should be avoided as they increase the distance between the phone and the EnvLogger and thus degrade communication efficiency. A better alternative is to use a rugged phone which does not need external protection.

The app was tuned down 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.
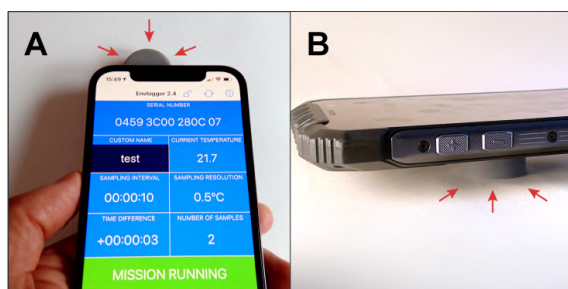

Figure 4. Correct positioning of smartphone and its stability greatly improves communication with EnvLoggers. A – on some models (e.g., iPhones) the NFC antenna is located on the top and that is the area that should touch the logger. B – on the majority of phones, however, the NFC antenna is in the middle, and thus the phone should be vertically and horizontally centered with 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 programmable 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).
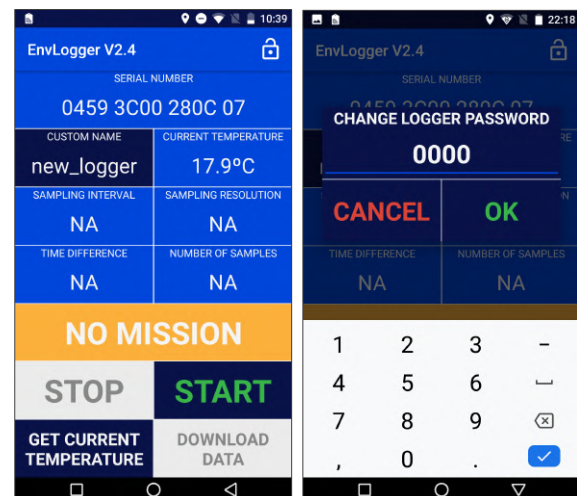

Figure 5. Initial screen and password setting screen.

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 ºC or 0.5 ºC), and the sampling interval in hours (H), minutes (M) or seconds (S). For EnvLoggers v2.4, the minimum value is 10 seconds. For v5.0, the minimum value is 2 minutes.

The combination of sampling resolution and frequency will determine the minimum deployment duration, which is displayed on the

screen to aid mission planning. Here lies another difference between v2.4 and v5.0: v2.4 uses a data compression algorithm and because of that the logger always manages to squeeze some more readings into the memory. Thus, the real deployment duration is always longer than what is shown on the app. V5.0, on the other hand, has much greater memory but no data compression and thus the predicted memory duration matches the actual duration.

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. This option is highly recommended when deploying several loggers as it will ensure they all collect readings in a synchronized manner.

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.
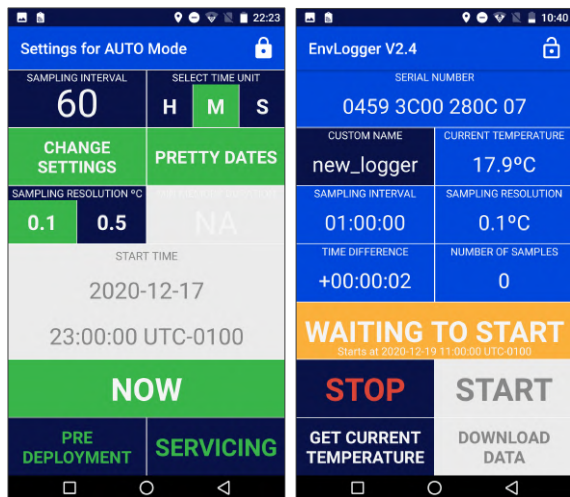

Figure 6. Start mission and waiting to start screens.

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. This information can also be found in the log file, so be sure to store it safely.

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 sampling frequency and the current number of logged samples. An indication of the remaining memory is also provided.

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. As soon as the downloading process is completed, data are automatically saved to prevent accidental losses.

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

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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: 1. you can "STOP" the logger. You can do this safely now because data has already been automatically saved. Stopping the logger will set it to low-power mode. 2. 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. 3. 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. Also note that if you do not restart the mission the memory will not be "cleaned", and thus you will not gain additional deployment time. 4. Finally, you can also tap the button "SHARE". This will open the system sharing options (see Fig. 14 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.
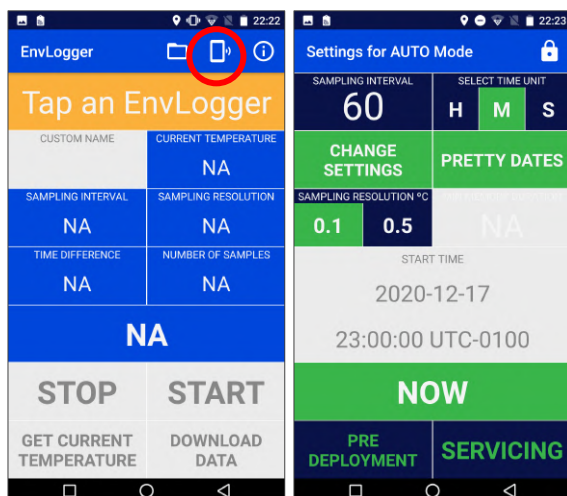

Figure 8. Enabling the automatic mode.

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.

The automatic mode allows the user to program or retrieve data from loggers without having to touch the screen. This is extremely handy in two situations: 1. to speed up the process of dealing with many loggers at once, and 2. to communicate with loggers that are hard to reach or underwater (i.e., when it is impossible to use the touchscreen).
To use the automatic 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). That will open the screen on Fig. 8 right. From there you can change the password (padlock on the top right corner). At the bottom of the screen there are two options:
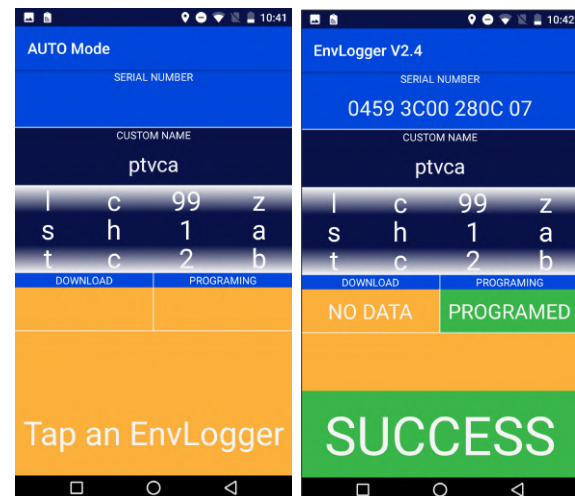

Figure 9. Automatic mode: "PRE DEPLOYMENT" screens.

1. The "PRE-DEPLOYMENT" mode allows the user to automatically set-up loggers before their first deployment, and includes a tool to assist in the process of naming them. It opens a screen where a fixed prefix can be defined in the field "CUSTOM NAME" (e.g., "ptvca" in Fig. 9).

Below that, there is a series of scrolling wheels that should be put in the desired position before programming each logger. By doing so, it is possible to quickly name loggers in a sequence,

for example "ptvcash1a", "ptvcash2a", "ptvcash3a", etc. This is a naming standard that makes sense for intertidal loggers, where the positions of the characters mean:
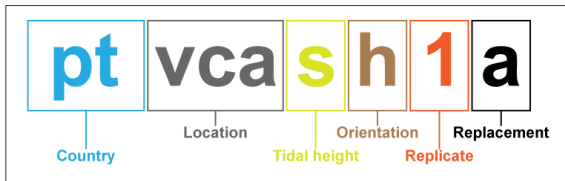
Note: This is the only naming standard available at the moment. In cases where this standard does not apply, the alternative is to program loggers manually (Fig. 5). Future updates will bring the option to customize these fields.

2. The "SERVICING" mode is meant to be used to automatically download data and reprogram missions in loggers already collecting data in the field. Since the smartphone screen does not work when wet, this is the only way to service loggers underwater (Fig. 10).

Figure 10. Servicing an EnvLogger underwater, with a waterproof (IP68) smartphone.

In the "SERVICING" mode it is possible to turn on or off the option "CHANGE SETTINGS" (Fig. 8 right side). When "CHANGE SETTINGS" is selected, then you will choose a new set of settings that will override those in the loggers you subsequently program in the automatic mode. However, if you deselect that option, "KEEP SETTINGS" will appear on the screen, meaning that the automatic mode will maintain the pre-existing parameters when servicing loggers. For example, if you have some loggers collecting temperatures at every hour and other

loggers at every half hour, each logger will retain its specific sampling rate after being serviced.

Tap "Servicing" and the app will then show a different screen while it starts searching for EnvLoggers (Fig 11 left). The user only needs to tap the loggers one after the other.
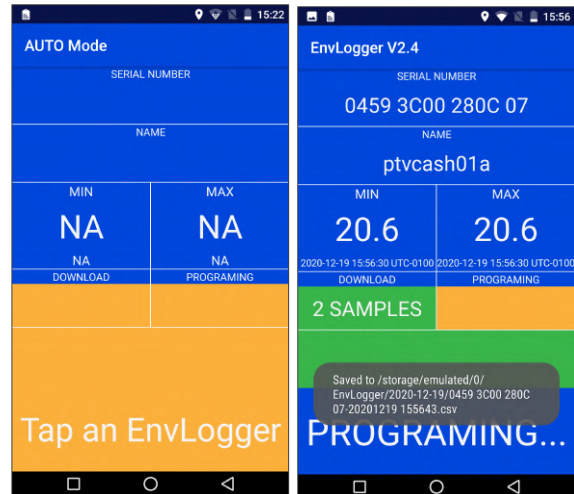

Figure 11. Automatic mode: "SERVICING" screens. The phone keeps searching for EnvLoggers, downloading data and starting new missions by itself. Press the "back" button 3 times in a row to leave this mode.

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:

1. 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 12 left).

2. If either the downloading or the programming fails, the message will say "FAIL". This may happen because you moved the phone way, interrupting the download (see Fig. 12 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.

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In this mode, because the user may not be able to look at the screen, the app gives feedback via vibrations and sound. 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 starting it again could be impossible (for example, underwater). 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.
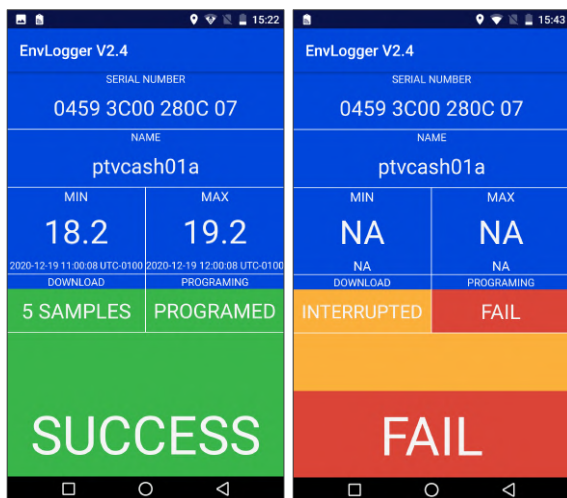

Figure 12. Automatic mode: "SERVICING" screens. In the left, the automatic mode was able to download data and start a new mission. On the right, the download was interrupted and so it failed, as well as starting a new mission.

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 (safe, 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. 13 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. Please note that in this case there will not be any information regarding the time difference between the loggers and 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). Check the table on Pag. 1 for the expected battery lives. If needed, loggers can be customized with larger batteries though.
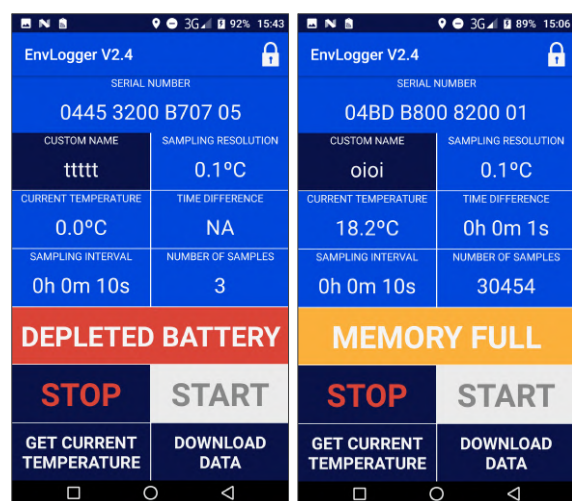

Figure 13. Depleted battery error (left) and memory full warning (right) on main screen.

If a logger runs out of memory, it will stop logging and will show the "MEMORY FULL" warning in the main screen (Fig. 13 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.

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. 14 left). There you will see the root folder called

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"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. 14 right).
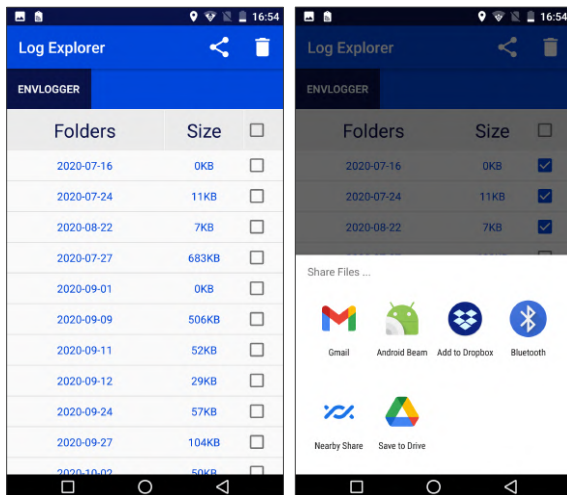

Figure 14. Log explorer (left) and share menu (right) screens.

App logfile

The app creates a daily log file in the background which registers all interactions with EnvLoggers. For example, every time the user connects to an EnvLogger, changes its settings, downloads data or starts a mission, a new line is created in the log file with the timestamp, serial number and description of the action. This information can be later incorporated into the workflow pipeline (to populate databases, for example) and can assist backtracing eventual deployment issues. These daily log files are stored together with the data logs downloaded from the EnvLoggers.

Application examples

Intertidal applications

At coastal locations, especially in regions with strong upwelling, water temperatures can differ markedly from what is measured using remote sensing techniques[5]. In addition, tidal height and exposure to solar radiation during low tide are the main drivers of temperature[6]. Thus, it is crucial carefully plan logger deployment. In the WE-LOG initiative (short name for the "collaborative global network of coastal temperature sensors"), the standard methodology is to deploy loggers in triplicate, six per location (3 facing the equator, and 3 facing the pole) in the mid-intertidal, approximately at mid sea level (Fig. 15).
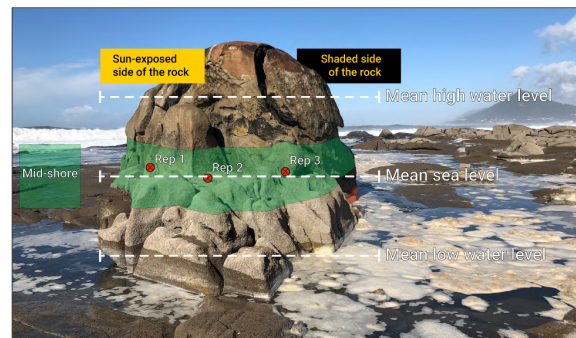

Figure 15. In the locations contributing to the WE-LOG global network, six loggers are deployed at mean sea level, three in hot microhabitats facing the equator, and three in the shade, facing the pole.

Grey loggers in Fig. 2 B were designed specifically for this task. If possible, they should be inserted in holes drilled into the rock (Fig. 16).

The deployment of loggers in holes into the rock helps solving two problems:
1. Human disturbance. In locations heavily visited by recreative fisherman or tourists, it is not uncommon to find loggers purposely destroyed in the intertidal.
2. Wave/ice action. In some locations, the sea hauls large quantities of coarse sand, drifting wood or even boulders to the shore, hitting the loggers and destroying them. Ice scouring may also be an issue on polar regions.

Thus, embedding the loggers in the rock protects them from natural erosion and hides them from people. It is possible to use a drill bit with ~30 mm in diameter (Fig 16 A), making a hole into the rock (Fig 16 B), and then compacting an EnvLogger inside the hole with Z-Spar[4] (Fig 16 C). The logger should also be covered with a thin layer of Z-Spar[4] (Fig. 16 D). Because the NFC allows for communication at a range of a few mm, it is still possible to communicate with the logger, programming it, or downloading data as

necessary. Caution must be taken not to put the logger too deep in the rock as it may prevent communication.

Figure 16. Process of embedding loggers in the rock. A – using a battery-powered driller with a 30 mm drill bit to make a hole on the rock. B – clear holes on the rock. C – pressing an EnvLogger against the rock with Z-Spar[4]. D – carefully covering a logger with a thin layer of Z-Spar[4].

For other applications, different formats may be more appropriated. The EnvLogger hardware can be encapsulated in many different packages. See Fig. 17 for some examples. In any case, whenever the logger is to be exposed to the sun, it is advisable to thoroughly test the shape, albedo, colour or even the attachment method to ensure that loggers are accurately measuring what they should. See for example the field test on Fig. 17 D which was used to validate the grey EnvLogger with 27mm (Fig. 2 B). We can provide technical assistance for this step.

Figure 17. A – a robolimpet with a real limpet shell glued to the rock. B – a robolimpet with a resin shell and another with a real shell deployed in Antarctica. C – 27 mm EnvLoggers (as those in Fig. 2 B) but with different shades of gray. D – range of colors and shapes being tested on the field.

Subtidal applications

The NFC communication does work underwater, although the smartphone must be touching the logger, as the NFC range drops to a few mm. At low depths (up to a couple of meters), it is enough to use a waterproof smartphone together with the app's automatic servicing mode (Fig. 18 A). At greater depths (i.e., at scuba diving depths) loggers can be deployed inside PVC pipes or 3D-printed structures that can be detached and brought to the surface to service them, being re-deployed on a subsequent dive (Fig 18 B).
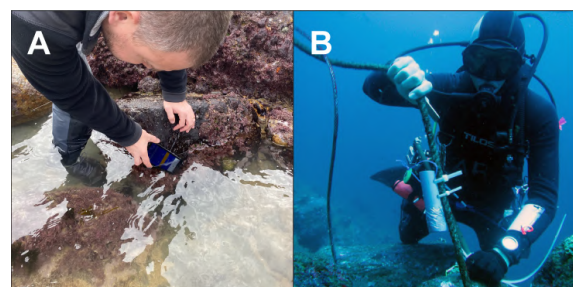

Figure 18. Working with loggers underwater. A – at low depths B – at scuba diving depths.

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 times shown in the app. 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 connection stable for longer periods and while using the touchscreen. 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. And while downloading data from a logger, the iPhone will pause at fixed intervals and resume automatically. These differences make both platforms preferable in some situations and not others, the ideal being for the user to have both at hand.

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. 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 B). The grey colour was tuned to obtain roughly the same albedo as regular granite (0.3-0.4). See one of the field tests on Fig 17 D.

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. See, for example, Fig. 3 C. 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?

Currently, the best loggers for this purpose are the grey loggers with 27 mm in diameter (Fig. 2 B).

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*, 201:374-384.

2.   Lima, F. P., & Wethey, D. S. (2009). Robolimpets: measuring intertidal body temperatures using biomimetic loggers. *Limnology and Oceanography: Methods*, 7:347-353.

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*, 14:448-455.

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*.

5.   Meneghesso, C., Seabra, R., Broitman, B. R., Wethey, D. S., Burrows, M. T., Chan, B. K. K., Guy-Haim, T., Ribeiro, P. A., Rilov, G., Santos, A. M., Sousa, L. L., & Lima, F. P. (2020). Remotely-sensed L4 SST underestimates the thermal fingerprint of coastal upwelling. Remote Sensing of Environment, 237: 111588.

6.   Seabra, R., Wethey, D. S., Santos, A. M., & Lima, F. P. (2011). Side matters: microhabitat influence on intertidal heat stress over a large geographical scale. Journal of Experimental Marine Biology and Ecology, 400:200-208.

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EnvLogger encapsulations: general comparison

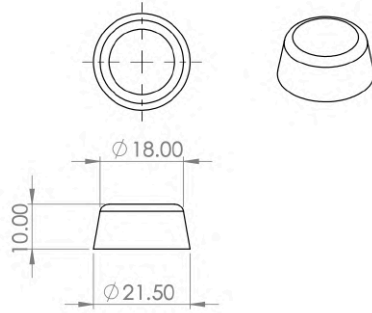# Note: both v2.4 and v5.0 can be encapsulated as any of the formats below

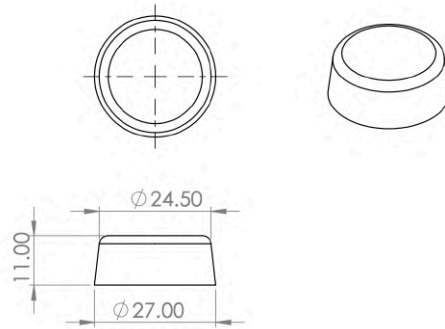|	Naked	Robolimpet	Robomussel	21.5 mm EnvLogger	27 mm EnvLogger	27 mm EnvLogger with zip-tie mounting holes	27 mm EnvLogger with M6 mounting holes
Note that the 5 formats on the right can be produced in any color							
Type of enclosure	Disposable 3D printed capsule	Elastic 3M 2131 polyurethane inside a real limpet or mussel shell	Hard and inert acrylic resin				
Weight	-	-	50 g	5 g	9.5 g	10 g	13 g
Diameter at the base	16.5 mm	~ 35 mm	-	21.5 mm	27 mm	[distance between holes: 33 mm]	[distance between holes: 43 mm]
Diameter at the top	14 mm	-	-	18 mm	24.5 mm	21 mm	24.9 mm
Height	7.5 mm	~ 15mm	-	10 mm	11 mm	11 mm	11 mm
Structural robustness	Weak	Good	Best				
Thermal inertia (time to reach 90% of a sudden change in temperature)	-	Not tested yet	Not tested yet	3 min and16 sec	4 min and 24 sec	5 min and 15 sec	Not tested yet
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)**				

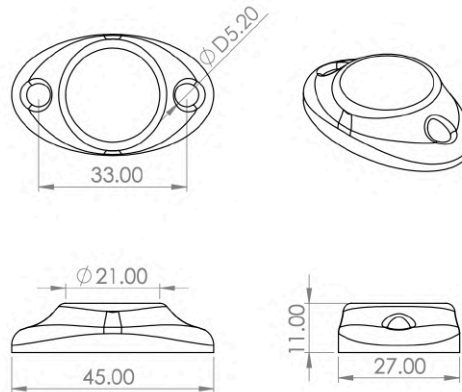** see the graphs with the pressure test profiles in the last page

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Technical drawings

21.5 mm EnvLogger:

Ø 18.00
10.00
Ø 21.50

27 mm EnvLogger:

Ø 24.50
11.00
Ø 27.00

27 mm EnvLogger with zip-tie mounting holes:

Ø D5.20
33.00
Ø 21.00
45.00
11.00
27.00

27 mm EnvLogger with M6 mounting holes:

Ø7.00

43.00

Ø24.90

5.00

57.00

11.00

27.00

Robomussel (*Mytilus californianus*):

43.00

73.00

25.00

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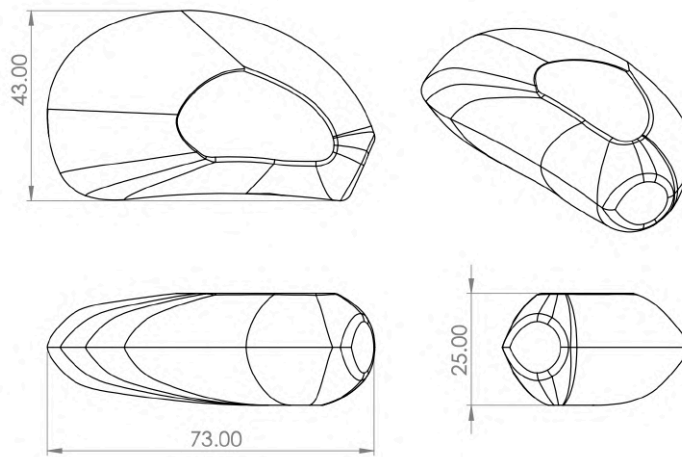
Pressure test logs

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).