The Mini Buoy Handbook

Assessing hydrodynamics in intertidal environments

Title:

The Mini Buoy Handbook: assessing hydrodynamics in intertidal environments

Authors:

Thorsten Balke
Cai Ladd
Alejandra Vovides
Marie-Christin Wimmler

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Contents

1 General Introduction

The Mini Buoy is a tool to measure inundation, current and wave orbital velocities from acceleration data. The equipment to assemble Mini Buoys is commercially available, offers an inexpensive alternative to conventional hydrodynamic sensors, and is supported with an online App and open-source code to analyse the data. This guide provides an overview of how to assemble, deploy, and analyse data from the Mini Buoy.

1.1 Mini Buoy designs

There are presently three Mini Buoy designs, each with their own strengths and limitations:

- **B4** (left) is the original Mini Buoy design featured in Balke et al. (2021) that contains an MSR145 B4 acceleration data logger inside a self-standing centrifuge tube attached to an anchor via a fishing swivel. The B4 measures inundation duration and current velocity only.
- **B4+** (middle) is a more durable version of the original Mini Buoy ideal for long term deployments[1]. The B4+ has a UV-resistant casing without the skirt and a metal eye bolt connected to a mooring by crimped fishing line rings. In addition to measuring inundation duration and current velocity, the B4+ has been calibrated to measure wave orbital velocities. Whilst the durability and functionality may be improved, the B4+ requires more effort to assemble.
- **Pendant** (right) is an integrated accelerometer data logger, float, and anchor point, attached to a pole by a fishing swivel. The Pendant is less expensive and easier to assemble than the B4 and B4+, however memory capacity and sampling rates are lower. Because of the low sampling rate, the Pendant measures inundation duration and current velocity only.

Further detail about each acceleration data logger can be found in the table below.

	B4	B4+	Pendant
Total weight (g)			

[1] After long term deployments, it was found that the fishing swivel of the original Mini Buoy design occasionally became jammed by fine sediment and would chafe and damage the centrifuge tube skirt to which it was attached, leading to possible failure of the tether. Moreover, the centrifuge tube became brittle over time and more vulnerable to cracking, likely due to UV exposure. The metal eye bolt, fishing line tether, and UV-resistant housing of the B4+ Mini Buoy increases durability.

Height above bed when fully submerged (cm)			
Axis used in analysis			
Deployment length (1 s)			
Deployment length (10 s)			
Inundation sensitivity (min)			
Current velocity detection range (m/s)			
Current velocity prediction interval (m/s)			
Wave orbital velocity prediction interval (m/s)			

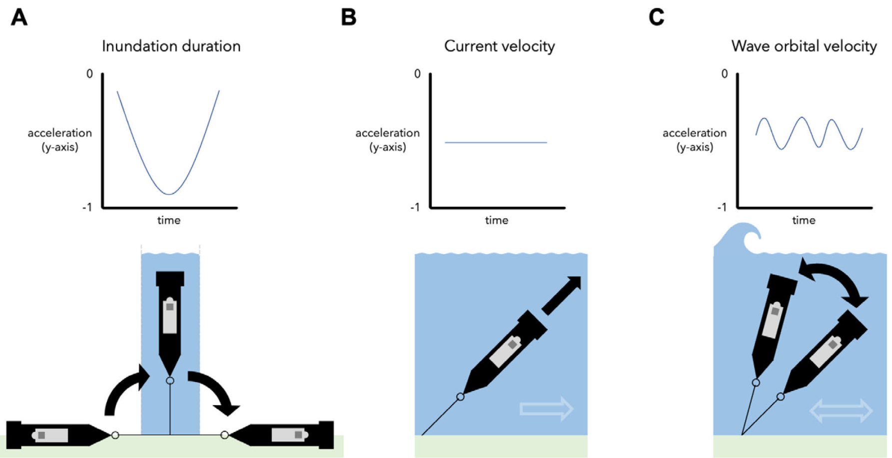
1.2 Operating principles

Inundation duration, current velocity and wave orbital velocity parameters can all be derived from acceleration data. A gradual change in the y-axis from 0 g towards -1 g (or 1 depending on orientation of the logger) reports a change from the horizontal to the vertical position, and hence the floating of the Mini Buoy as the tide comes in. The return of the acceleration to a horizontal position (reading towards 0 g) indicates the tide has retreated. The time when the Mini Buoy deviated from the horizonal position gives inundation duration (panel A below).

When the Mini Buoy is fully inundated, any dip (represented by acceleration values somewhere between 0 and -1 g) is caused by a current. The stronger the current, the closer the Mini Buoy is dipped towards a horizontal position (0 g). The median acceleration value over a set period is used to measure current velocity (panel B below).

Finally, waves passing over the Mini Buoy cause it to wobble side to side. This signal is recorded by the acceleration logger as a repeated wave between 0 and -1 g. Rolling standard deviation over a 20-minute window is used to measure wave orbital velocity. The greater the standard deviation, the greater the wave orbital velocity (panel C below).

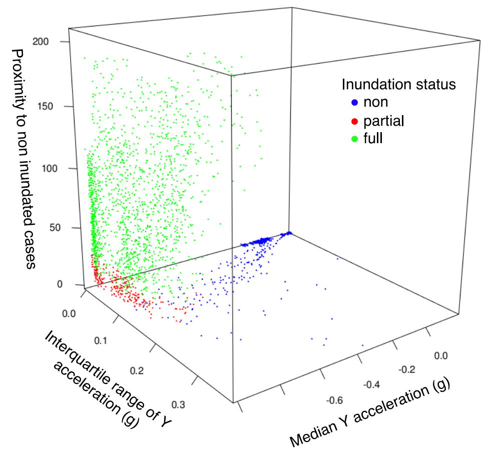
The steps described below to infer inundation duration, current and wave orbital velocity from acceleration data will be described fully in Ladd et al. (in prep).



1.2.1 Inundation duration

One problem with only using acceleration data to interpret hydrodynamics is that a reading of 0.3 g, for example, could be interpreted as both a strong current and that the logger is only partially inundated. Unless water level is measured alongside a deployment, one cannot immediately tell which case may be true.

Using a two-stage classification procedure can, however, distinguish between non, partial, and fully inundated status of a Mini Buoy based on the characteristics of a Mini Buoy's motion when the tide is in and out (see an example below). Essentially, a pair of classification algorithms were trained on acceleration data gathered for each Mini Buoy design in a study where water levels were known. The first algorithm classifies non-inundated and inundated cases based on median and interquartile range acceleration values over a set period[2]. A series of distinct inundation events can then be identified. The second algorithm then uses an additional parameter – an arbitrary count to the nearest non-inundation event – to identify partially inundated cases. Both algorithms are then automatically applied to new Mini Buoy data to accurately predict its inundation status.



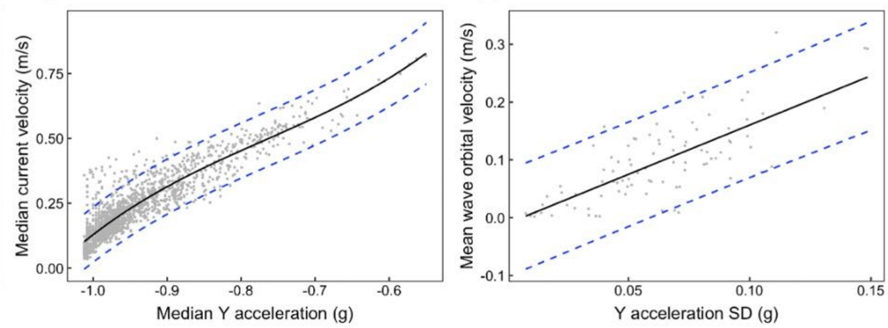
Once the inundation status is known, inundation duration can be calculated by summing the time the Mini Buoy was partially and fully inundated.

1.2.2 Current and wave orbital velocity

During a calibration study, each Mini Buoy design was deployed alongside an acoustic doppler profiler (which measure velocity directly). Simultaneous readings of acceleration and velocity were then used to construct the velocity calibration curves.

For all Mini Buoy designs, median Y acceleration was correlated against median velocity of the acoustic doppler profilers (see an example on the left panel below). For the B4+, wave orbital velocities were calculated from the acoustic doppler profiler (an Acoustic Doppler Velocimeter) and correlated against the standard deviation in Y acceleration (see right panel below).

[2] A non-inundated Mini Buoy will show median acceleration values near 0 (i.e., lying horizontal on the tidal flat) and minimal interquartile range (i.e., no bobbing), whilst an inundated Mini Buoy will show acceleration values near -1 (i.e., floating upright) and larger interquartile ranges (i.e., a greater amount of bobbing and swaying due to currents and waves).



The regression and prediction interval of each calibration are used to convert acceleration to velocity for any new Mini Buoy data when fully inundated.

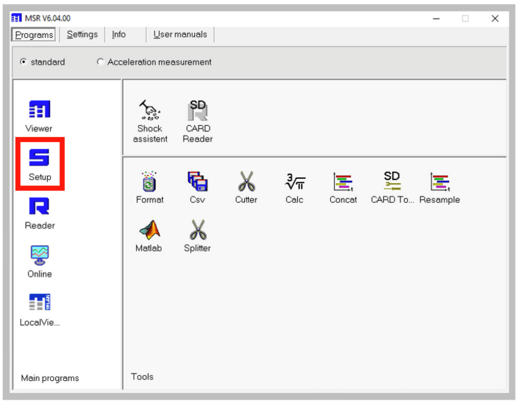
2 Configuring the data logger

Prior to each deployment of the Mini Buoy, the data logger will need to be fully charged, have a full memory, and be correctly configured according to the user's requirements. The following section describes how to configure the MSR145 B4 (used in both the B4 and B4+ Mini Buoy designs) and HOBO Pendant acceleration loggers.

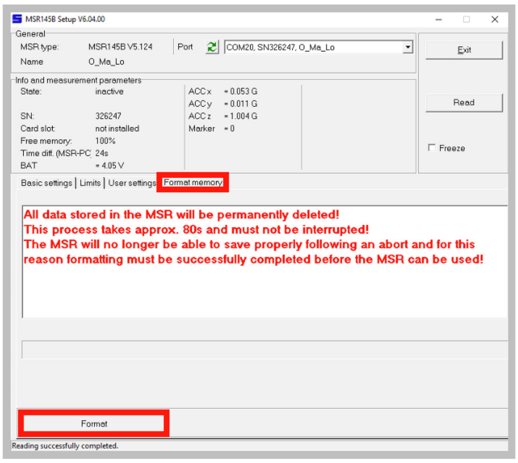
2.1 MSR145 B4

The MSR145 B4 acceleration data logger is compact, relatively inexpensive (~£300 when bought individually), and waterproof. Source the MSR145 B4 from a supplier operating in your country (https://www.msr.ch/en/product/msr145/). To configure the MSR145 B4:

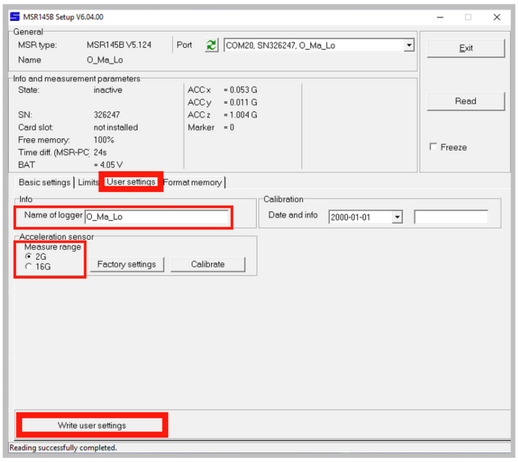
1. Download and install the MSR software to configure the data logger (https://www.msr.ch/en/support/pcsoftware/)
2. Connect a logger to a Windows PC. A yellow LED will light up on the logger, indicating the internal battery is being charged. The light will extinguish once the battery is fully charged
3. Open the MSR software
4. Double-click **Setup**



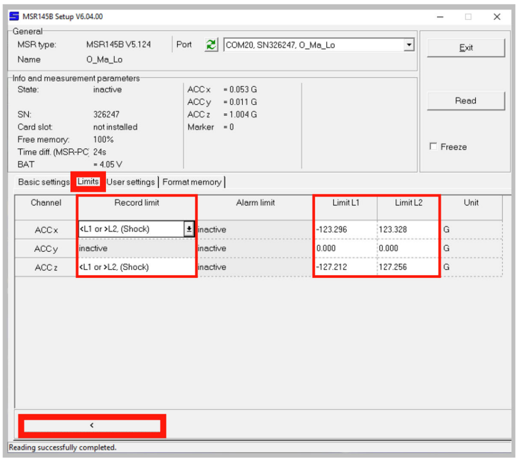
5. Select the **Format memory** tab
6. Click **Format**. This will delete any data stored on the logger



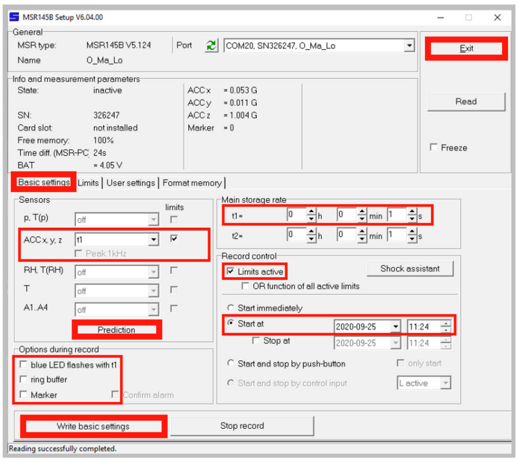
7. Select the **User settings** tab
8. Set the acceleration sensor measure range to **2G**
9. You can define a name for the logger under **Name of logger**
10. Click Write user settings



11. Select the **Limits** tab. We can use limits to effectively disable the X and Y sensors by setting unrealistically high acceleration limits. This will allow your logger to store more Y acceleration data. See section 1.1 for more information
12. For ACC x and ACC z channels, select **<L1 or >L2, (Shock)** from the record limit drop-down menu
13. Set the corresponding **Limit L1** to -999 and **Limit L2** to +999. The MSR software will default to the maximum possible range, here +/-123
14. Make sure there are no limits set on the ACC y channel by selecting **inactive** from the record limit drop-down menu
15. Click the **<** button



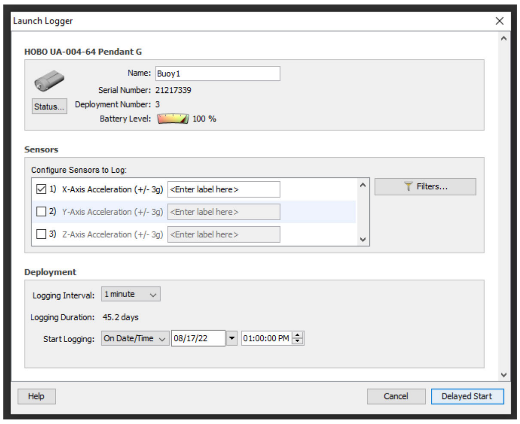
16. Select the **Basic settings** tab
17. Under **Sensors**, select **t1** from the ACC x, y, z drop-down menu
18. Check the **limits** box
19. Under **Main storage rate**, set ‘t1=’ to ‘1 s’
    - This will instruct the MRS logger to measure the acceleration every 1 second. Increasing the storage rate will increase the duration that the logger will record data, however this may decrease the accuracy of current velocity measurements in post-processing. We recommend a maximum of 10 seconds should be used as the storage rate to measure current velocities accurately. Click **Prediction** to see how changing the storage rate will affect the battery and memory capacity. The memory capacity will be underestimated, as it does not consider the limit settings
20. Under Record control, check the Limits active box
21. Check the **Start at** box, and set the date and time shortly after your planned deployment
    - Review your settings again to ensure the logger is configured correctly for the deployment
22. Under **Options during record**, uncheck all options. This will extend the battery life of the logger
23. Click **Write basic settings** to upload your settings to the logger
24. Click **Exit** and disconnect the MSR145 logger from the computer. A blue light will begin to flash, confirming the logger is primed and ready to begin logging when the start date and time is reached. If sampling at 1 s intervals, the deployment will last 25 days. If sampling at 10 s intervals, deployments will last at least 4 months.


MSR145B Setup V6.04.00
General
MSR type:
MSR145B V5.124
Port
COM20, SN326247, O_Ma_Lo
Exit
Name
O_Ma_Lo
Info and measurement parameters
State:
inactive
ACC x
= 0.053 G
ACC y
= 0.011 G
ACC z
= 1.004 G
Marker
= 0
SN:
326247
Card slot:
not installed
Free memory:
100%
Time diff. (MSR-PC
24s
BAT
= 4.05 V
Read
Freeze
Basic settings
Limits
User settings
Format memory
Sensors
limits
p, T(p)
off
ACC x, y, z
t1
Peak 1kHz
RH, T(RH)
off
T
off
A1..A4
off
Prediction
Main storage rate
t1=
0
h
0
min
1
s
t2=
0
h
0
min
1
s
Record control
Limits active
Shock assistant
OR function of all active limits
Start immediately
Start at
2020-09-25
11:24
Stop at
2020-09-25
11:24
Start and stop by push-button
only start
Start and stop by control input
L active
Options during record
blue LED flashes with t1
ring buffer
Marker
Confirm alarm
Write basic settings
Stop record
Reading successfully completed.

2.2 HOBO Pendant

The HOBO Pendant acceleration data logger is inexpensive (~£150 when bought individually), waterproof, and comes with an attachment to anchor a fishing swivel. Source the HOBO Pendant from a supplier operating in your country (https://www.onsetcomp.com/products/data-loggers/ua-004-64/). To configure the HOBO Pendant:

1. Download and install the HOBOware software to configure the data logger (https://www.onsetcomp.com/hoboware-free-download/)
2. Connect a logger to a computer
3. Open the HOBOware software
4. You can define a name for the logger under **Name**
5. In the **Sensors** tab and in the **Configure Sensors to Log** section, check the **X-Axis Acceleration (+/- 3g)** box
6. From the **Deployments** tab, set the **Logging Interval** to **1 minute** using the drop-down menu
7. In the **Deployments** tab, set the **Start Logging** date and time for shortly after your planned deployment
8. Click **Delayed Start** and disconnect the Pendant logger from the computer.



3 Assembling the Mini Buoy

Depending on their requirements, the user has a choice of three Mini Buoy designs for measuring hydrodynamics. In the following steps, we provide instructions for the assembly of each design.

3.1 B4

The B4 is a transparent and self-standing centrifuge tube with an MSR145 B4 acceleration logger sealed inside the tube and supported by floral foam, and tethered to an anchor using fishing swivels attached through two holes in the centrifuge tube skirt.

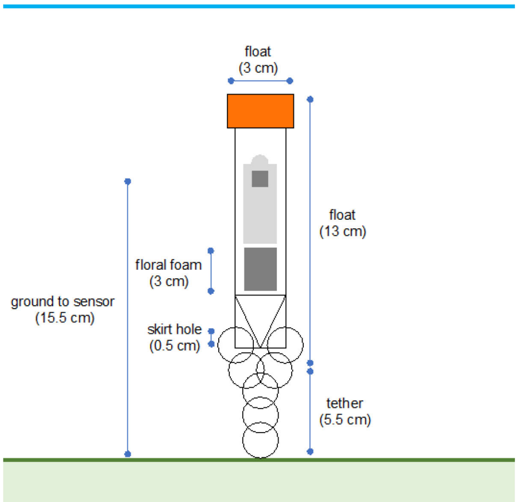
Gather the following equipment:

- 50 mL clear self-standing centrifuge tube
- Label
- Floral foam
- MSR145 B4 acceleration data logger
- Silicone sealant
- Drill with a 4 mm dowel bit
- 3 × 5 cm (1.1 g) fishing swivels

To assemble the B4 Mini Buoy:

1. Place a label inside the centrifuge tube, with the text legible through the plastic, indicating the owner, a “do not remove” notice, and contact details
2. Insert a 3 cm cylinder of floral foam into the centrifuge tube. This ensures the logger is positioned at the top of the tube
3. Roughly cut a 5 cm cylinder of floral foam with matching diameter of the centrifuge tube and cut down the middle
4. Place both halves around the configured MSR145 B4 acceleration data logger (see section 2), then gently push the logger into the centrifuge tube **with the PC connector facing outwards**. The floral foam will prevent the logger from moving inside the tube
5. Apply silicone sealant around the screw thread of the centrifuge tube and fasten the tube cap
6. Apply more sealant along the rim of the centrifuge cap
7. Drill two holes at opposite ends through the centrifuge tube skirt 5 mm from the bottom
8. Fix two fishing swivels through each hole, and connect both to another swivel

The B4 should appear as below once fully assembled.



3.2 B4+

The B4+ is a UV-resistant centrifuge tube with an MSR145 B4 acceleration logger sealed inside the tube and supported by floral foam, and tethered to an anchor using fishing line rings.

Gather the following equipment:

- 50 mL UV-blocking centrifuge tube
- Sand paper
- Drill with a 4 mm dowel bit
- M4 Eye bolt and nut
- M4 rubber washer
- M4 long socket
- Epoxy glue
- M32 O-rings
- 20 g lead shot weight
- Floral foam
- Waterproof label
- 250 lb / 113 kg nylon coated 1×7 steel strand fishing line
- Single barrel copper/nickel crimp sleeves (the sleeves should be rated to correctly fit the fishing line)
- Crimp tool with cutter (the tool should be rated to correctly crimp the sleeves)
- MSR145 B4 acceleration data logger
- Silicone sealant

To assemble the B4+ Mini Buoy:

1. Abrade the bottom of the centrifuge tube (this removes any lubricant on the tube and creates a better surface for the epoxy glue to bond with)
2. Drill a 4 mm hole in the bottom of the centrifuge tube
3. Thread the eye bolt through the hole

4. Place the rubber washer over the eye bolt thread from inside the tube
5. Dab some epoxy glue around the eye bolt (inside and out) to seal the hole
6. Secure the nut in place using the long socket

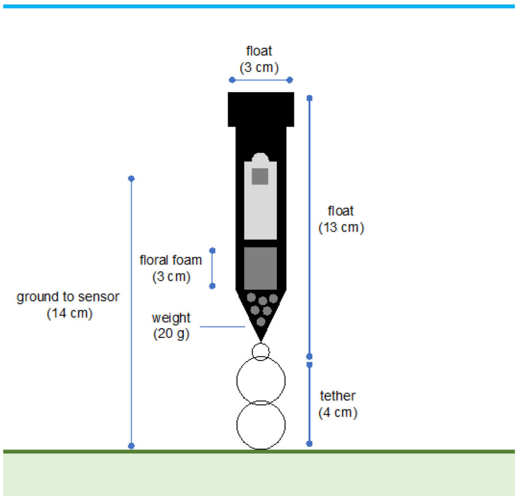
1. Install a rubber o-ring around the inside lip of the lid, to ensure the tube is watertight. Use tweezers to help install the o-ring

2. Pour 20 g of lead shot into the tube. The lead shot reduces the buoyancy of the Mini Buoy, making it less stable in the water column (this has been shown to improve the accelerometer sensitivity for wave orbital velocity analysis)
3. Cut a 3 cm length cylinder from the floral foam that will fit comfortably into the tube
4. Insert the floral foam cylinder into the tube (this hold the lead shot in place and ensures the logger is positioned at the top of the tube)

5. Stick a waterproof label onto the centrifuge tube indicating the owner, a “do not remove” notice, and contact details
6. Thread the fishing line through a crimp sleeve and loop the fishing line back on itself to form a ring of ~2 cm diameter
7. Crimp the sleeve so it fits tightly around the fishing line
8. Thread another fishing line through a new crimp sleeve, then through the eye bolt and first fishing line ring
9. Adjust the diameter of the ring so the total chain length is 4 cm, then crimp (the B4+ has been calibrated to measure hydrodynamics 4 cm above the tidal flat)

7. Roughly cut a 5 cm cylinder of floral foam with matching diameter of the centrifuge tube and cut down the middle
8. Place both halves around the configured MSR145 B4 acceleration data logger (see section 2), then gently push the logger into the centrifuge tube **with the PC connector facing upright**. The floral foam will prevent the logger from moving inside the tube
9. Apply silicone sealant around the screw thread of the centrifuge tube and fasten the tube cap
10. Apply more sealant along the rim of the centrifuge cap

The B4+ should appear as below once fully assembled.



3.3 Pendant

The Pendant can be directly tethered to a pole in the ground using fishing swivels as the logger itself is buoyant and waterproof.

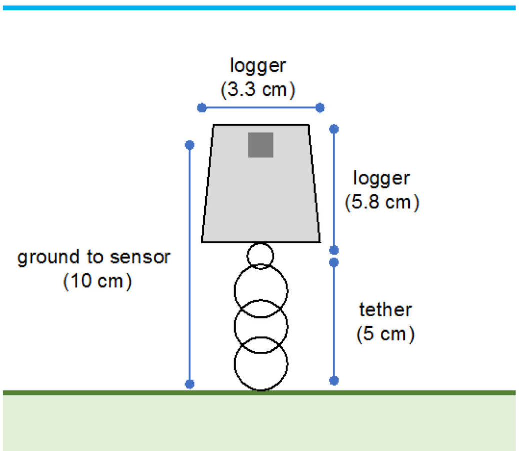
Gather the following equipment:

- HOBO Pendant acceleration data logger
- 5 cm (1.1 g) fishing swivel

To assemble the Pendant Mini Buoy:

1. Attach the fishing swivel to the anchor point on the Pendant logger

The Pendant should appear as below once fully assembled.



4 Deploying the Mini Buoy

Once the acceleration data logger has been configured and desired Mini Buoy design assembled, the Mini Buoy can be deployed at the survey location.

4.1 Installing the Mini Buoy

Mini Buoys can be used in single deployments to assess inundation characteristics at a given location or used in comparative deployments such as when comparing conditions between restoration and reference ‘natural’ sites.

Deployments should last **more than 15 days** to cover spring and neap tide variability. When deploying the Mini Buoy in the field, it is important to consider characteristics of the site and duration of the deployment. High-energy locations may be subject to excessive scouring that stress the Mini Buoy tether and may dislodge the anchor. At low-energy locations excessive sedimentation can bury the Mini Buoy. Using a cable tie to attach the Mini Buoy tether to an anchor buried > 0.5 m into the ground is recommended for a standard set-up.

Gather the following equipment:

- Large cable tie
- 0.7 m length of metal rod with perforations

To install the Mini Buoy:

1. Hammer the metal rod into the ground until 1 cm is protruding from the surface
2. Attach the end of the fishing line chain to the anchor using the cable tie
3. Move the Mini Buoy 360° around the anchor, and remove any obstructing objects

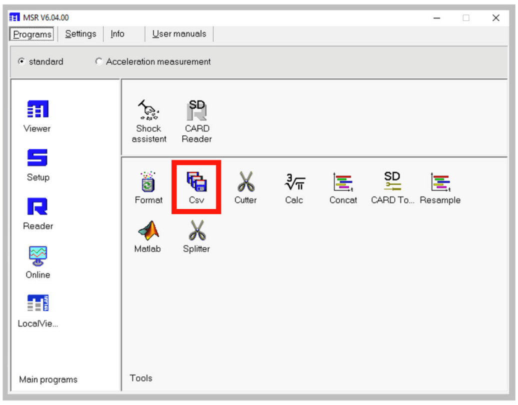
5 Exporting the logger data

After a deployment, the data can be retrieved from the logger and exported as a .csv data table using the MSR software. It is important to save your data in the data format that can be recognised by the Mini Buoy App (see section 6).

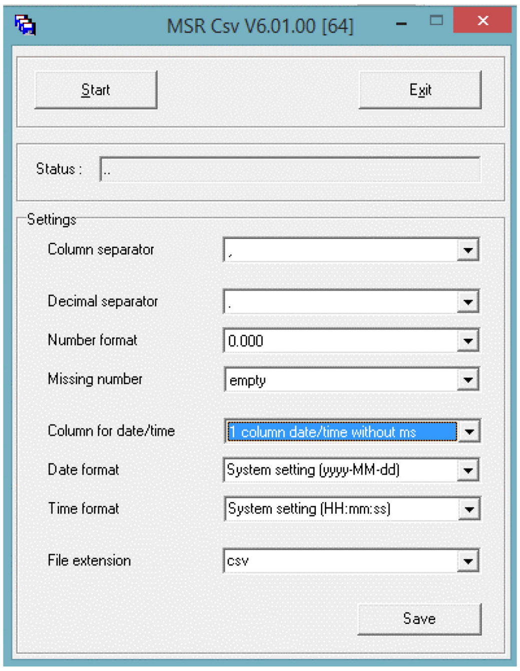
5.1 MSR145 B4

To export acceleration data from the MSR145 B4 logger:

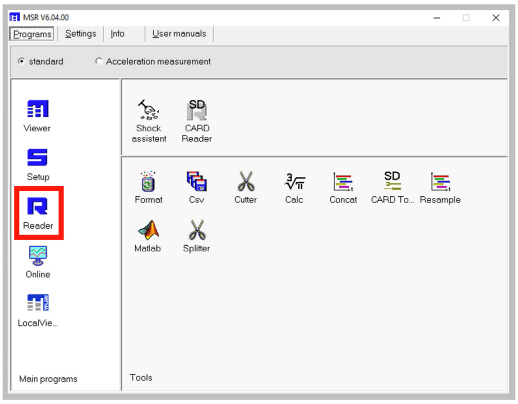
1. Open the MSR software and double-click **Csv**



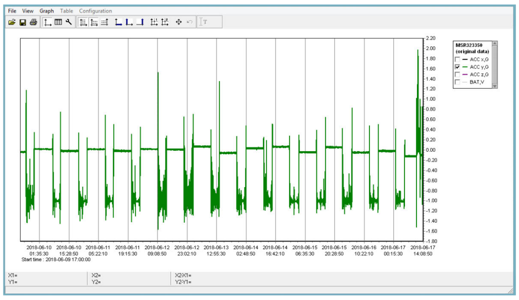
2. Choose the settings according to the template below and click **Save**



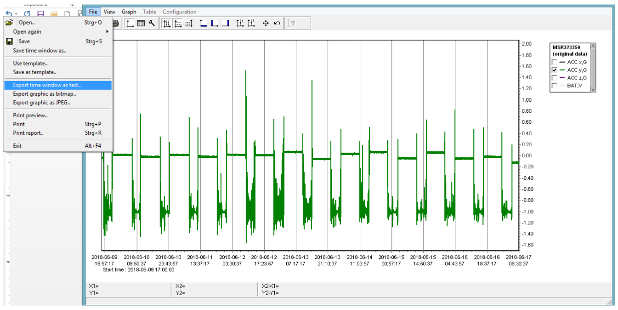
3. Connect your data logger with the USB cable
4. Open the MSR software and double-click **Reader**
   - The data will be saved onto the computer as a .msr file



5. The MSR software should automatically open the .msr file in order to view the data. If nothing happens, double-click **Viewer** and select **File**, **Open**, and select the .msr file
6. Your data should look similar to the graph below, with low tide recorded as 0 and high tide recorded around -1. Any data at the start and end of the deployment which is not part of the desired measurement period can be removed by using the cross arrows button and selecting the period of interest. The graph should always start and end with a period of low tide (i.e. 0 y acceleration)



7. Select **File**, **Export time window as text…**, and select an appropriate folder to save the data as a .csv file



Kommentiert [AV1]: In Export file instructions we need to add a section defining export settings. Is it possible on MSR to define one "datetime" column or two date & time columns? -> provide instructions to user.

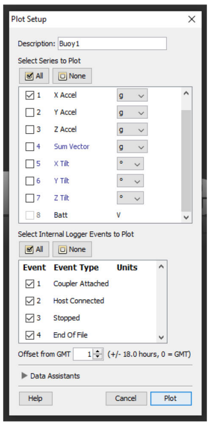
In Hobo it's possible by going to Preferences>General>Export settings: disable the *Date and time format: Separate into two columns*

5.2 HOBO Pendant

To export acceleration data from the MSR145 B4 logger:

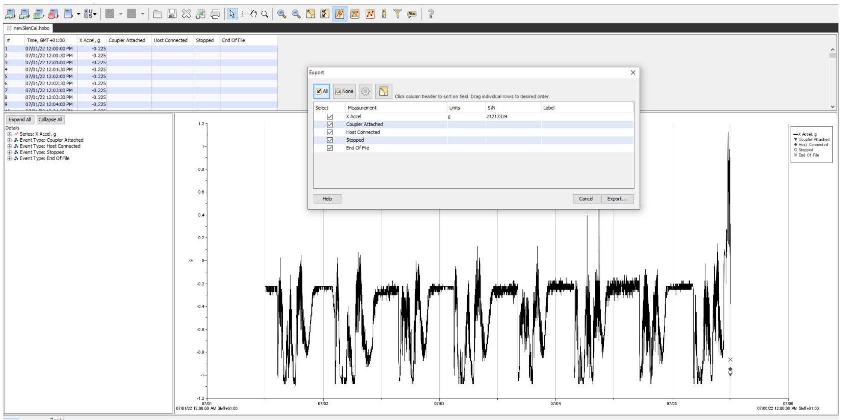
Kommentiert [AV2]: Hobo Pendant?

1. Open the HOBOware software
2. Select **Plot Setup**
3. Check the **X Accel** box



4. Select **Plot**

5. Select **Export**
6. Save the file as **.csv**



6 Analysing the data

Features the app should do before release on 20th Sept:

- Be accessible online
- Have an export feature to save the results
- Calibration for 1 or 10 second data

6.1 The Mini Buoy App

The Mini Buoy App is an online tool to analyse data gathered by any of the three Mini Buoy designs. The App is optimised for determining the suitability of a site for restoration, and so can accept two datasets at a time – a 'target' dataset (i.e., the location of interest where restoration is being considered) and a 'reference' dataset (i.e., a location near the target site with a natural habitat for providing reference conditions). The goal is to assess how similar the hydrological conditions from the target site is to the reference site. If similar, the presumption is the target site is suitable for restoration.

It is not a requirement that a reference dataset is uploaded, so the user can continue only with the target data if they wish.

6.1.1 About

Upon loading the App, the first page displays information about each Mini Buoy design. The menu on the left-hand side can be used to navigate between data upload

6.1.2 Project settings

If no reference site is supplied at the data upload stage, the analysis will work regardless, without displaying differences between target and reference sites.

6.1.3 Data

6.1.4 Hydrodynamics

As shown below, the App will present for the duration of the study:

- a summary table of key hydrodynamic parameters
- daily inundation duration in minutes
- current velocities
- wave orbital velocities (if data from B4+ is uploaded)

example output

6.1.5 Further development

The Mini Buoy App is still under development. We aim to implement the following features soon:

- A bulk upload feature to analyse multiple Mini Buoys at once.
- A metadata page to upload additional information about the Mini Buoy survey site. This will be uploaded to a server to provide context to Mini Buoy results .

The conversion of acceleration data into useful metrics like inundation frequency, current velocity, ebb-flood asymmetry, and Windows of Opportunity can be done online using the R shiny app at:

- https://mangroverestoration.shinyapps.io/Rshiny_restoration_app/

When using the Mini Buoy App, the site of interest time series plot and summary table will first appear (this may take a while, depending on the size of the file). Each inundation event is identified and separated into flood (blue) and ebb (green) tides. The current velocities are estimated for 15-minute periods. A grey colour indicates the lower detection limit of current velocities, which is around 0.1 m/s. The summary table provides statistics for the entire measurement period.

Warning text in red will appear if 1) the average high tide duration exceeds 24 h indicating the signal is likely not tidal. In this case, the current velocity predictions may be inaccurate; 2) the measurement duration is shorter than 15 days. A longer deployment time is required for the app to work 3); the 75th percentile velocity is the same as the median current velocity meaning that no velocity could be detected. This may be the case when velocities are <0.1 m/s.

The same plot will be created for the reference site, the example above is of a non-tidal inundation operated by a sluice in an enclosed pond. A difference table is created with the reference site conditions subtracted from the target site conditions.

6.2 Interpreting results

Inundation duration per tide and inundation per day over the measurement period are key parameters to assess suitability of a site for restoration. If inundation duration is longer at potential resotration sites than the reference site, mangrove seedlings are unlikely to survive. Where there is no reference site, the following classification can be used as a rule of thumb for South East Asia (Van Loon et al. 2007):

- 400-800 min/d: *Avicennia* spp., *Sonneratia* spp.
- 100-400 min/d: *Rhizophora* spp., *Ceriops* spp., *Brugueira* spp.
- 10-100 min/d: *Lumnitzera* spp. *Bruguiera* spp.
- <10 min/d: *Ceriops* spp.

Current velocities may vary in time, hence it is important to compare hydrodynamics between loggers in the same deployment period. The 75 percentile gives an estimate of how strong the currents are during flood and ebb tides. If the 75 percentile velocities of loggers deployed at the same time (i.e. during the same weather conditions allowing for a relative comparison) are higher at the restoration site compared to the reference site, hydrodynamic energy may be too severe to attempt mangrove restoration. Excessive current velocities preventing mangrove establishment is most likely for seafront planting.

Given that velocities are analysed over successive flood and ebb tides, tidal asymmetry can be detected, and indicate the potential net transport direction of sediments and propagules. Asymmetry can provide an indication as to the long-term erosion/progradation trends of mangrove forests

WoO (Windows of Opportunity) provide information about the length of consecutive inundation-free days between inundation events (see Balke et al. 2011). It has been shown that natural recruitment of mangrove pioneer species requires 1-5 days of inundation free periods. A maximum WoO value at the restoration site below 1 may indicate that elevation is not sufficient for natural recruitment to occur. Please note that WoO periods will depend on the duration of your measurement period and the season of the year. For a meaningful WoO analysis a deployment across seasons is recommended to cover weather and tide patterns.

6.3 Code download

Alternatively, the R.app file can be downloaded and run on your local PC from XXX. You will need you to install R, R-Studio and the rshiny package to run the app.

6.4 Sharing results

The Mini Buoy has been developed as part of a research project and we would like to continue to improve the Mini Buoy data analysis. If you would like to share your data with us for research purposes, please send an email to thorsten.balke@glasgow.ac.uk with the GPS location of your Mini Buoys and you will receive a link to upload your data.

7 References

Balke, T., Bouma, T., Horstman, E., Webb, E., Erftemeijer, P., & Herman, P. (2011). Windows of opportunity: thresholds to mangrove seedling establishment on tidal flats. Marine Ecology Progress Series, 440, 1–9. doi:10.3354/meps09364

van Loon, A. F., Dijksma, R., & van Mensvoort, M. E. F. (2007). Hydrological classification in mangrove areas: A case study in Can Gio, Vietnam. Aquatic Botany, 87(1), 80–82. doi:10.1016/j.aquabot.2007.02.001

7.1 Useful links

- The Cave Pearl Project (https://thecavepearlproject.org)