FORESTS IN CITIES

COOLING STUDY

Methods document for study question 2:

Within a natural land cover class, are healthy sites cooler than those that are degraded?

Natural Areas Conservancy

Concept: Clara Pregitzer & Crystal Crown
Design & Documentation: Crystal Crown
Review: Helen Forgione
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Table of Contents

Section 1: Overview 2

Section 2: Materials 3

Section 3: Methods 4

A. Sensor testing *4*

B. Site selection 4

Forest condition requirements 4

Sensor placement requirements 5

All sensors 5

Natural area sensors 6

Control sensors 6

C. Sensor deployment *6*

D. Optional tracking of extreme weather events 8

E. Data sync 8

F. Take sensors down 8

Appendix 1: Sensor Placement Summary Checklist 9

Appendix 2: Habitat types 10

Appendix 3: Condition rubric 11

Appendix 4: Data sheet & data dictionary 12

Appendix 5: ArcGIS Field Maps 14

Appendix 6: Sensor Testing 17

Section 1: Overview

Study Question: Within a natural land cover class, are healthy sites cooler than those that are degraded?

Study Design

Groups of three sensors will be placed in/around three sites, resulting in a total of nine sensors deployed in each participating city. At each site will be placed:

- 1 control sensor on a tree in a tree pit/built area (e.g. street tree, parking lot tree).
- 2 natural area sensors:
    - 1 in a degraded woodland or forest.
    - 1 in an intact/healthy woodland or forest.
    - Ecosystem condition should apply to at least the 30m radius around the sensor.
    - All sensors must be at least 60m apart from each other and no greater than 1 mile from each other.

Sensors Used

- ONSET MX2304 w/ radiation shields

Section 2: Materials

Required Equipment/Resources

- A mobile device (tablet or phone) with a data plan & the following apps installed:
    - ArcGIS Field Maps: User Guide - please review guide for details on log-in
    - HOBO Connect: User Guide - please review guide for details on log-in

HOBO Connect

ArcGIS Field Maps

- ArcGIS Online login with the appropriate permissions (the one you sent Crystal).
- NAC HOBO Connect login info
    - Username: NAC
    - Password: nac2021!
- Temperature sensors (3 per site)
- Data sheet & additional condition rubric printouts (Appendices 3 & 4)
- Pen or pencil
- DBH tape

Optional

- Plant ID guide to ID tree species.
- Step ladder for attaching temperature sensors at least 7 ft on tree

Section 3: Methods

A. Sensor testing

Before you head into the field take inventory and test your sensors by following the instructions in Appendix 6.

B. Site selection

Before proceeding, note these guidelines were developed for forest & woodland systems (see Appendix 2). If you do not have suitable forest or woodland sites in your city (e.g. grasslands), please reach out to Clara & Crystal who can assist further.

Before deploying sensors, each team should convene to review the site selection parameters below. Natural area locations are required to meet certain conditions, but within those guidelines teams are welcome to build in other dimensions that are meaningful to them. For example, teams may want to focus on sites where management work has occurred, or that are of a specific community type, and so on.

The site

The site/location is loosely defined as the area within which a group of three sensors - matching all of the requirements laid out below- is placed. **All sensors within one site should be no more than 1 mile from each other and no closer than 60m.** It does not need to be a named location (e.g. a park) or a discrete space. Each city should have three "sites." These should ideally be in different parts of the city, but we have not put hard constraints on distribution since all cities have different quantities and distribution of natural areas.

Forest condition requirements

The study design calls for three locations with three sensors deployed at each condition (9 sensors total):

- **Control**: Under a street tree/parking lot tree or tree in the right of way (not a natural area tree).
- **Healthy natural area**: Characterized by most or all of the following: high native richness and proportion, diverse forest structure and composition, high canopy cover, low mortality, high tree health.
- **Degraded natural area:** Characterized by most or all of the following: high invasive proportion, low woody regeneration, low native richness and proportion, large canopy gaps, low structural complexity, high tree mortality, poor tree condition.

To ensure uniformity across replicates we developed a system to rate site condition, located in Appendix 3. The system we're using is a *modified* form of a habitat condition rating system for forests & woodlands published by Natural England as part of their Biodiversity Metric 3.0.

For this study, as per the rating system, the area within a 30m radius of:

- The degraded sensors should have a points total of <14
- The healthy sensors should have a points total of >17

... However, if you are not able to find sites with these points ratings, please try to maximize for the healthy site, and find a degraded site with the lowest points score possible.

We recommend compiling a list of locations around your city that contain both Healthy & Degraded portions, with a few backups just in case your first choices don't meet the criteria. Most of the criteria are stark enough that you will probably have an idea of locations that qualify before doing a field visit, though please make the final call after running through the rubric on-site. This process may be iterative & require some scouting in the field, where you pick a location of interest & walk around, running through the rubric multiple times until you find a spot that falls into the 'goldilocks zone.'

Note the condition rating only applies to the 30m radius from the sensor location, so if you assess a spot & it doesn't qualify, you may be able to find another a short distance away.

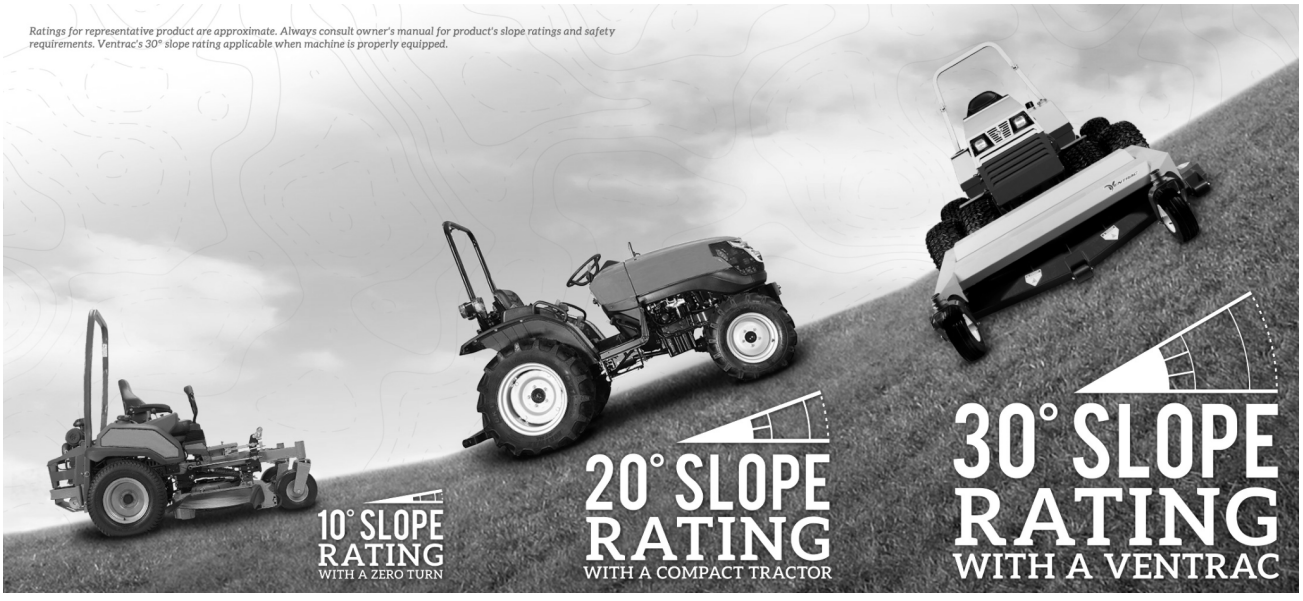
Sensor placement requirements

In addition to the condition criteria, there are additional location constraints for the sensors that are intended to control for variables that may influence air temperature.

All sensors

- *S*ecured on the **north** side of the tree/stem, 7 ± 1 foot from the ground
- Attached to a stem no larger than 20cm DBH.
- Attached in an **open-air** setting.
    - E.g. The sensor should be attached below where branching starts, not inside of tree cavities or canopy. The goal is to put the sensor in a location with air temperatures characteristic of the larger area.
- At locations with *similar (within 10 degrees)* slope, elevation (within 10 feet), & distance to water.
    - If locations are on a slope >10 degrees (see example image below), the slope should have the same aspect (e.g. north facing, east facing).
- Fall within sites digitized in part 1 of the cooling study *(you can digitize after placing the sensor)*.
- Within 1 mile of one another and at least 60m apart.

Our goal in setting these constraints is to increase likelihood that sensors in a group experience the same conditions.



Example of what different slopes look like on the ground, image from Ventrac site.

Natural area sensors

In addition to requirements for all sensors.

- >=30m from the forest/woodland edge, in the interior.
    - If this edge distance is not possible, sensors should be a similar distance from an edge with the same exposure (e.g. N, S, W, E).
- The same general habitat type for both Healthy and Degraded sensors.
    - See Appendix 2

Control sensors

In addition to requirements for all sensors.

- Attached to a tree that is in a tree pit or planting bed in a built area.
- >=60m from the natural area.

C. Sensor deployment

Gather all materials listed in Section 2, head to your site, & follow the instructions below.

Please deploy all sensors with the same suffix # (e.g. XXX_X_1) at the same site, and ensure that the site type (Control, Healthy, Degraded) matches the sensor type as indicated by the second part of the sensor name (C, H, and D, respectively). The site and sensor type should also be noted on the boxes they were packaged in when they arrived.

For all sensors, please adhere to the placement requirements specified in Part B of this section.

1. **Scout sensor locations.**
   This can happen in any order, though we recommend saving the Control sensor for last since that will probably be the easiest to find a place for.
    - For Healthy & Degraded Sensors: Scout the location for your sensor at your site.
        - Locate a suitable tree for attachment.
        - Measure 30m from the stem to get a visual of what 30m looks like. *This is the buffer that the condition rating should apply to*.
        - Run through the condition rubric (>21 points for healthy, <16 points for degraded)
            - Qualified? Mark the location in *Field Maps* (tutorial: Appendix 5)
            - Not Qualified? Adjust your location & rate again.
    - Control Sensor: Scout a location for the Control within 1 mile of both natural area sensors.
            - Locate a suitable tree for sensor attachment.
            - Mark the location in ArcGIS Field Maps (tutorial: Appendix 5).

2. **Review proposed locations**: Now that you have three locations marked on your Field Map take time to review & ensure the locations fit all the requirements (simplified checklist in Appendix 1, see how to measure distance between locations in Field Maps in Appendix 5).

3. **Deploy Sensors**: For each sensor- navigate back to the location using the field map & locate your tree.
    - Record the sensor name/ID on the datasheet.
    - Attach the sensor to the stem using the positioning guidelines in part B of this section. You may want to use a step ladder for easier access.

- Attach the sensor using the two holes on the radiation shield using zip-ties around the stem. Depending on the size of the stem & the size of the zipties you may have to get creative & string zip ties together.
- Coil the cord around the stem, then attach the white box to the coil using zip ties.
- The final attached sensor configuration should look something like this, with the solar radiation shield in an upright position:

- Complete datasheet in Appendix 4 for each sensor. Standalone PDF here.
- Final test: Check the connection to the sensor once again on your phone or tablet to be doubly sure it's working:
  - Open the HOBO Connect app & verify that you're logged in to the NAC HOBOlink account (click settings 

, then view the HOBOlink info).
  - Verify that the sensor shows up in the device list & that the status is "logging."

  - Connect to the sensor by selecting it from the list.
  - Do one last test download of data to HOBOlink (click  then 'OK').
- Scan the completed datasheet & save it in this Google Drive folder.
  - *Please name files with the sensor name.*
  - *You can scan using a mobile device (e.g. on iPhone documents can be scanned using the Notes app).*

    - Repeat the above for the other two sensors in the group.

4. **Take a photo of the site** from the north side of the site facing south, and upload it to this Google Drive folder.
    - *As with the datasheets, please name the photos with the sensor name as well.*
5. **Move on to your next site** & run through steps 1-4 until you've deployed sensors at all three sites.

D. Optional tracking of extreme weather events

- Teams may make note of the date, time, & duration of extreme weather events. This is so we can easily locate & analyze data for heat wave events. This is not mandatory. If your team would like to do this, find your city's tab on this spreadsheet and fill out the required fields.

E. Data sync

You can sync the data anytime you are within bluetooth distance from the sensors and as many times as you visit the sensor. However, we ask that all teams sync the data at least twice.

- Required syncs:
    - Mid season: Sometime in the second half of July.
        - This sync is to ensure that the sensors are all still present and functioning so the date isn't of the utmost importance.
    - End of season: After Friday September 30th.
        - We ask that you don't take them down early so we can have data for the full day of September 30th.
- To sync the data to HOBO, open the HOBO Connect app on your mobile device while in proximity to the sensor you are downloading data from.
- Select the sensor from the device list.
- Tap the readout icon  then click Ok in the prompt.
    - *This uploads the temperature data to the central HOBO account where we can access it.*

F. Take sensors down

This study will officially end on September 30th. After that date we ask that you undertake the final data sync, then take the sensors down and ship them back to us. However, if you would like to continue monitoring air temperature for your own records or continue the study within your own team let us know and we can help facilitate that any way we can!

Appendix 1: Sensor Placement Summary Checklist

Sensor Placement

Within a group of sensors...

All sensors

- Secured on the north side of the tree/stem
- 7 ± 1 foot from the ground
- Stem <=20cm DBH.
- Open-air setting.
- All locations with *similar (within 10 degrees)* slope, elevation (within 10 feet), & distance to water.
- Fall within sites digitized in Part 1 of the Cooling Study.
- Within 1 mile of one another, but no closer than 60m.

Natural area sensors

- >=30m from the forest/woodland edge, in the interior.
- Same general habitat type for both in a group. See Appendix 2
- Healthy sensor site has >17 points on the rating scale.
- Degraded sensor site has <14 points on the rating scale.

Control sensors

- Tree that is in a tree pit or planting bed in a built area (e.g. street tree, tree in parking lot).
- >=60m from the natural area.

Appendix 2: Habitat types

The condition rubric used to rate sensor locations is appropriate for forest & woodland sites:

- FOREST. formed by trees at least 5m tall with their crowns interlocking.
- WOODLAND. (Open stands of trees.) Formed by trees at least 5m tall, with most of their crowns not touching each other, grass cover is sometimes present.

The natural area sensors at a location should both fall within the same habitat type.

- Upland Forest or Woodland: Tree dominated communities on soils that are well-drained and never regularly flooded; or on soils that are usually well-drained and not hydric, and lack predominantly wetland vegetation. Site is usually not within or adjacent to a wetland. Contains structural understory layers that can include herbaceous and shrub species.
- Forested Wetland: A forested wetland (PFO) or swamp is a closed-canopy tree-dominated vegetation type adapted to tolerate flooded conditions, where the soil is saturated or flooded for some or all of the growing season.
- Mangrove Swamp: Brackish to saline coastal wetlands dominated by mangrove trees & other halophytic vegetation. Found in tropical & subtropical regions.

Appendix 3: Condition rubric

The rating rubric to be used to assess the 30m radius around temperature sensors. **The degraded area for sensor placement should have a points total of <14, & the healthy area should have a points total of >17, as per the rubric below.**

	Indicator	3 Points (Good)	2 Points (Moderate)	1 Point (Poor)		Points
1.	**Vertical Structure**	☐ All strata present throughout and complex as appropriate for community type.	☐ Strata present but impacted or limited.	☐ Missing or highly impacted vertical structure appropriate for community type.	→	
2.	**Invasive Groundcover** (circle range)	0% | 1 - 10%	11 - 25 %	26-50% | 51-75% | 76-100%	→	
3.	**Native woody species richness**	☐ >=5	☐ 3-4	☐ <3	→	
4.	**Native tree & shrub proportion**	☐ >80% native	☐ 50-80% native	☐ < 50% native	→	
5.	**Canopy gaps** (circle range)	0% | 1 - 10% | 11-25%	26-50%	51-75% | 76-100%	→	
6.	**Native Woody Regeneration**	☐ All classes present & distributed across the plot as appropriate for community type..	☐ 1-2 classes present & distributed across the plot as appropriate for community type.	☐ No or very limited regrowth present for all classes as appropriate for community type.	→	
7.	**Tree health**	☐ Mortality, pests/disease, & dieback <10% each.	☐ Max of 11-25% mortality, crown dieback, or pests/disease.	☐ >25% mortality, crown dieback, and/or pests/disease.	→	

↓

Final Rating	**Healthy** (> 17 points)	**Moderate** (14-17 points)	**Degraded** (<14 points)	←	**Total Points** (sum)
	☐	☐	☐		

Appendix 4: Data sheet & data dictionary

FORESTS IN CITIES **COOLING STUDY** | DATASHEET FOR CONDITION ASSESSMENT & TEMPERATURE SENSOR DEPLOYMENT

See data dictionary for term definitions.

Part A: To be filled out for all sensors	
City:	**Plant Community** (optional):
Sensor Name:	**Sensor Sun Exposure Estimate** (circle): Full Sun (6+ hrs) | Part Sun (4-6 hrs) | Shade (<4 hrs)
Deployment Date:	**Canopy Type of Attached Tree** (circle): Individual | Interlocking
Sensor Type (circle): Control | Healthy | Degraded	**DBH of Attached Tree (cm):**
Habitat type:	**Attachment Tree Species**:
Notes:	

Part B: Complete for natural area sensors only. Rating of 'Healthy' required for healthy sensor and rating of 'Degraded' required for degraded sensor.

Dumping (circle): 0% | 1-10% | 11-25% | 26-50% | 51-75% | 76-100% **Herbivore Damage** (circle): Present | Absent

	Indicator	3 Points (Good)	2 Points (Moderate)	1 Point (Poor)	Points
1.	**Vertical Structure**	☐ All strata present throughout and complex as appropriate for community type.	☐ Strata present but impacted or limited.	☐ Missing or highly impacted vertical structure appropriate for community type.	
2.	**Invasive Groundcover** (circle range)	0% | 1 - 10%	11 - 25 %	26-50% | 51-75% | 76-100%	
3.	**Native woody species richness**	☐ >=5	☐ 3-4	☐ <3	
4.	**Native tree & shrub proportion**	☐ >80% native	☐ 50-80% native	☐ < 50% native	
5.	**Canopy gaps** (circle range)	0% | 1 - 10% | 11-25%	26-50%	51-75% | 76-100%	
6.	**Native Woody Regeneration**	☐ All classes present & distributed across the plot as appropriate for community type..	☐ 1-2 classes present & distributed across the plot as appropriate for community type.	☐ No or very limited regrowth present for all classes as appropriate for community type.	
7.	**Tree health**	☐ Mortality, pests/disease, & dieback <10% each.	☐ Max of 11-25% mortality, crown dieback, or pests/disease.	☐ >25% mortality, crown dieback, and/or pests/disease.	

Final Rating	**Healthy** (> 17 points)	**Moderate** (14-17 points)	**Degraded** (<14 points)	**Total Points** (sum)
	☐	☐	☐	

Data Dictionary

Variable	Definition
	PART A OF DATASHEET
City	The name of the city the temperature sensor is being deployed in.
Sensor Name	The name assigned to the sensor. This is the name that is written on the sensor & that shows up in the HOBO Connect App on the devices. E.q. NYC_C_1, MIA_D_2.
Deployment Date	The date the sensor was attached to the stem.
Sensor Type	The sensor type within the study design. Control, Healthy, or Degraded. This should match the middle part of the sensor name.
Habitat Type	Description of the 30m radius area as per the definitions outlined in the protocol. Upland Forest or Woodland, Forested Wetland, Mangrove Swamp. Appendix 2 of protocol for definitions.
Plant Community	Optional field to list the specific plant community. If known, the CEGL code can be entered,
Sensor Sun Exposure Estimate	An estimate of how much direct sun the sensor will receive per day. If the sensors are attached on the N side of the stem as instructed, they should not receive full sun. If sensors will be deployed in a location where they will be in direct sun, additional shielding may be required.
Canopy Type of Attached Tree	Indicates whether the canopy of the tree the sensor is attached to is individual: not touching the canopies of other nearby trees OR interlocking: overlapping with the canopies of nearby/adjacent trees.
DBH of Attached Tree (cm)	The diameter at breast height (4.5"/1.37m from the ground) of the stem the temperature sensor is attached to in cm
Species of Attached Tree	The *scientific name* OR *USDA Code* of the tree species the temperature sensor is attached to.
	PART B OF DATASHEET
Dumping[1]	The percent of the 30m radius area covered by dumping, such as large surface piles of debris, large amounts of residential waste, discarded tires, litter at abnormally high levels, etc. Small pieces of garbage at a site (e.g. a few candy wrappers) would not count, the point of this variable is to note dumping that exceeds small debris.
Herbivore Damage	Present or absence of visible damage to vegetation by herbivores.
Vertical Structure	Forest and woodland vertical structure within the 30m radius area. We are aware the presentation of a healthy vertical structure will vary by location and plant community so the interpretation of this variable should be appropriate for your locality. A **good** rating for this variable would be structurally complex as per the plant community. This may include overstory- w/multiple/varied stories- midstory, shrub, and herb/groundcover layers present and in sufficient density/coverage throughout the site; a **moderate** rating may have all strata but one or more are sparse or missing in portion of area; and a **poor** rating be missing one or more forest layers or have otherwise highly impacted structural complexity, such as overstory being limited to a single age/size class.
Invasive Groundcover[1]	The percent of the 30m radius area covered by invasive groundcover species. Consider specimens with foliage at or below DBH (4.5"/ 1.37m from the ground). Invasiveness should be relevant to the geography.
Native woody species	The count of native tree and shrub species in the 30m radius.
Native tree & shrub %	The proportion of trees and shrubs in the 30m radius plot that are species native to the geography.
Canopy gaps	The percent of the 30m radius area that is not covered in tree canopy.
Native Woody Regeneration	Presence & distribution of native saplings (2-10cm), seedlings (1-2cm), & germinants <1cm) distributed within the 30m radius area.
Tree health	Refers to the proportion of stems that are dead, afflicted with pests, or are experiencing crown dieback within the 30m radius area. The proportion ranges for each rating are listed in the rubric above.

[1] For reference, 1% of a 30m radius circle is around 28m^2 - an area a little larger than a square with a 5m side.

Appendix 5: ArcGIS Field Maps

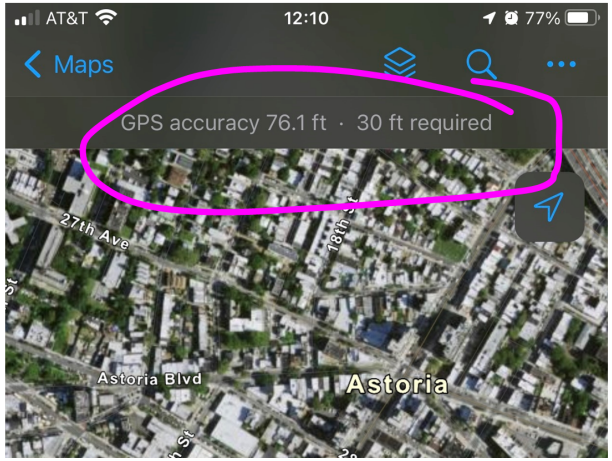
Recording Sensor Location

- Download ArcGIS Field Maps on your mobile device.

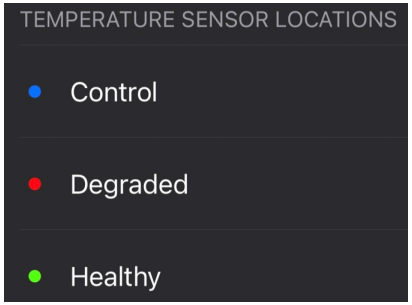
ArcGIS Field Maps

- Open app and login as an AGOL username that is part of the FiC Cooling Study AGOL Group (the one shared in the Google form).
- Navigate to the Cooling Study Field Map in the list and select it.

- Stand on the north side of the tree on which you are attaching the sensor, and wait for your location on the map to steady to a GPS accuracy of 10 feet or less. Accuracy is displayed on the top of the map (note - screenshot is showing very low accuracy!)

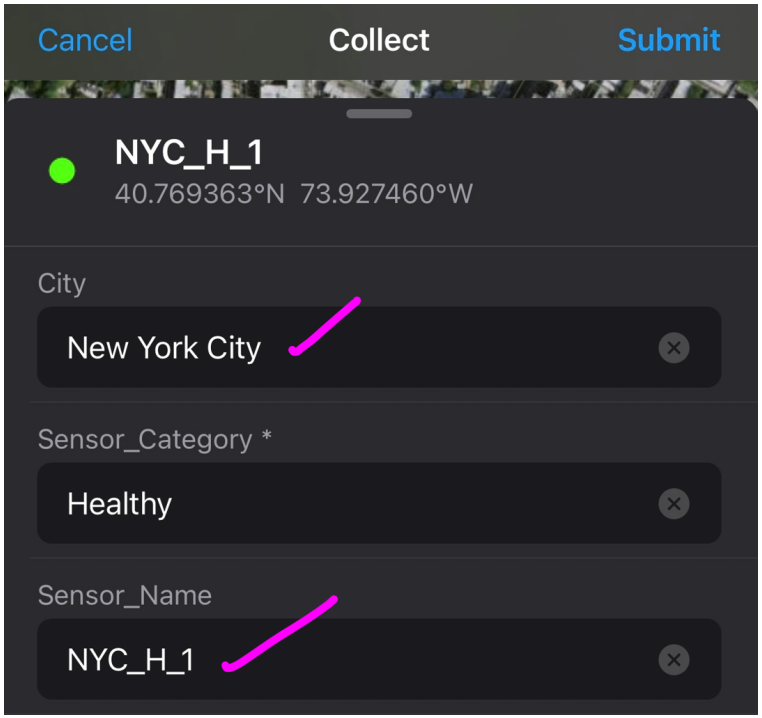


- Hit the  button and select the template for the type of sensor you're installing (Control, Degraded, Healthy) - you may need to scroll down to see the options

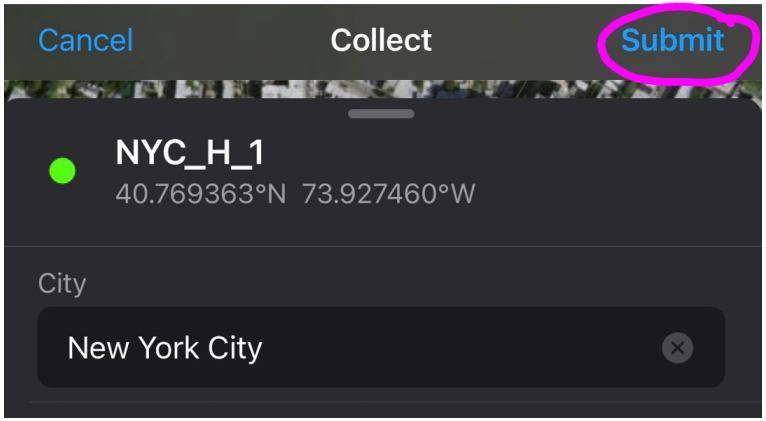


- Then tap ‘Add Point’ - this records the location

- Fill in the required fields (City & Sensor Name -- Sensor Category will already be populated based on the template you chose)



- Tap ‘Submit’ at the top right.



- That's it! The location is now saved -- view the map to verify that the point location was recorded.

Measuring Distance

- Tap the overflow menu (the three dots in the top right '...') and select 'Measure'
- Pan the screen so that the target is over the starting point and click 'Add Point'
- Pan the screen so that the target is over the end point and click 'Add Point'
- The distance will show up on the bottom
- Use this method to verify that:
    - All the sensors in a group are within one mile (5,280ft) of each other.
    - The control sensors is >= 60m (196.85ft) from a natural area
    - The natural area sensors are >=30m (98.43ft) from an edge.

Appendix 6: Sensor Testing

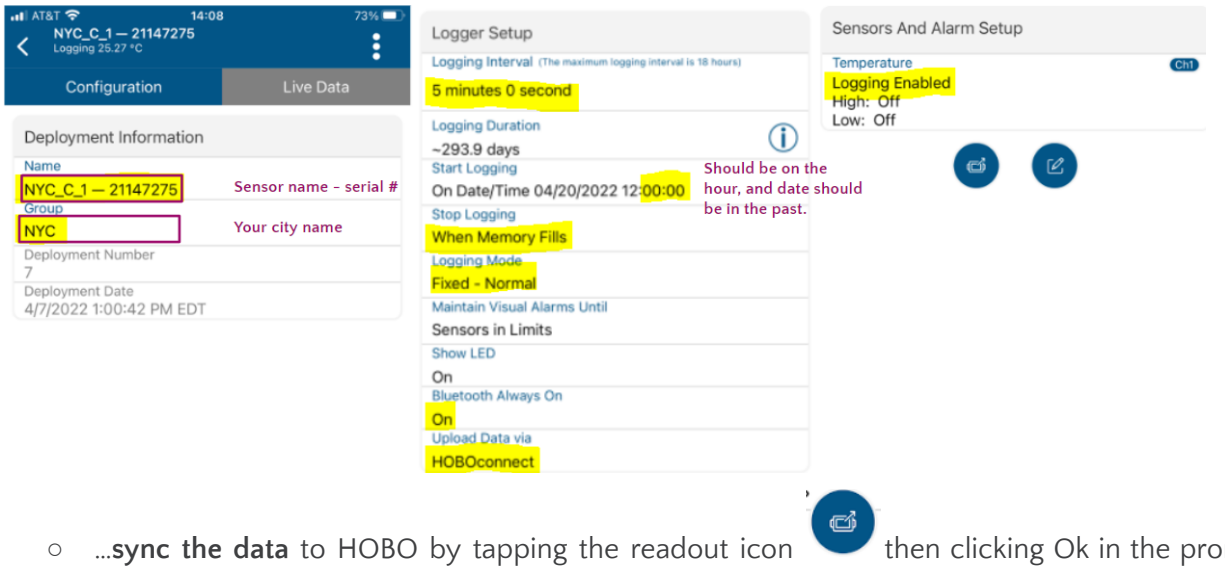
If you have already inventoried and tested your sensors, move on to Section C.

Before going out into the field, prepare & test the sensors to ensure they are functioning & programmed correctly.

1. Take inventory. Your team should have received nine pre-labeled sensors with the following naming structure/type assignment:

Type	Sensor Name
Control	XX_C_1
Healthy	XX_H_1
Degraded	XX_D_1
Control	XX_C_2
Healthy	XX_H_2
Degraded	XX_D_2
Control	XX_C_3
Healthy	XX_H_3
Degraded	XX_D_3

   In the table above, prefix 'XX' represents your city's initials, & the suffix should correspond to the site number when deployed (e.g. all #1 go to the same site, & so on). Verify that the number & naming structure of the sensors you received matches the above. If not, contact Clara & Crystal.
2. Next, cross check your sensors with the sensor names & serial numbers shared here. If they do not match, contact Clara & Crystal.
3. On your mobile device, ensure bluetooth is turned on, open the HOBO Connect App, & login:
   - Username: NAC
   - Password: nac2021!
4. Review the Devices page on the app, verify all nine sensors appear & their status is "Logging."
   - *Each sensor may appear as a serial number in the list the first time it's detected by a device, that will change to the sensor name followed by the serial number after the first time you connect.*
5. Connect to each of the nine sensors by selecting it from the device list and:
   - ...verify the sensor settings match the following:



- ...**sync the data** to HOBO by tapping the readout icon then clicking Ok in the prompt. This uploads the temperature data to the central HOBO account where we can access it. **This is also how you will sync data in the field.**
  - *This might take a few mins because the sensors were logging in the mail.*
- ...wait a few mins (for the data to upload) then login to HOBOlink.com with the same credentials & verify that the "last sensor reading" for your sensors reads the current date.

6. Now the sensors are ready to be deployed!