

A satellite view of Earth from space, showing the curvature of the planet, blue oceans, white clouds, and green and brown landmasses. The text is overlaid on a semi-transparent white rectangular background.

# Ecosystem Services, part 2: Carbon Storage and Sequestration

Prof. Justin Andrew Johnson

[jajohns@umn.edu](mailto:jajohns@umn.edu)

University of Minnesota, Department of Applied Economics

# Agenda

- Introduce the theory behind the carbon model
- Use the carbon model as an easy entry-point for running an InVEST model
- Hands-on exercises with the carbon model and QGIS for visualizing results.
  - Throughout, a bonus goal of this workshop is to give a crash-course in GIS and visualization of results.

# InVEST Carbon Storage and Sequestration model

**InVEST**

integrated valuation of  
ecosystem services  
and tradeoffs

**natural  
capital**

**PROJECT**

## Decision contexts

- How do changes in land use affect carbon storage and sequestration?
  - Carbon markets
  - NDCs (Paris Agreement)
  - Corporate metrics
- Target payments for conservation
- Look for overlaps with other ecosystem services (co-benefits)

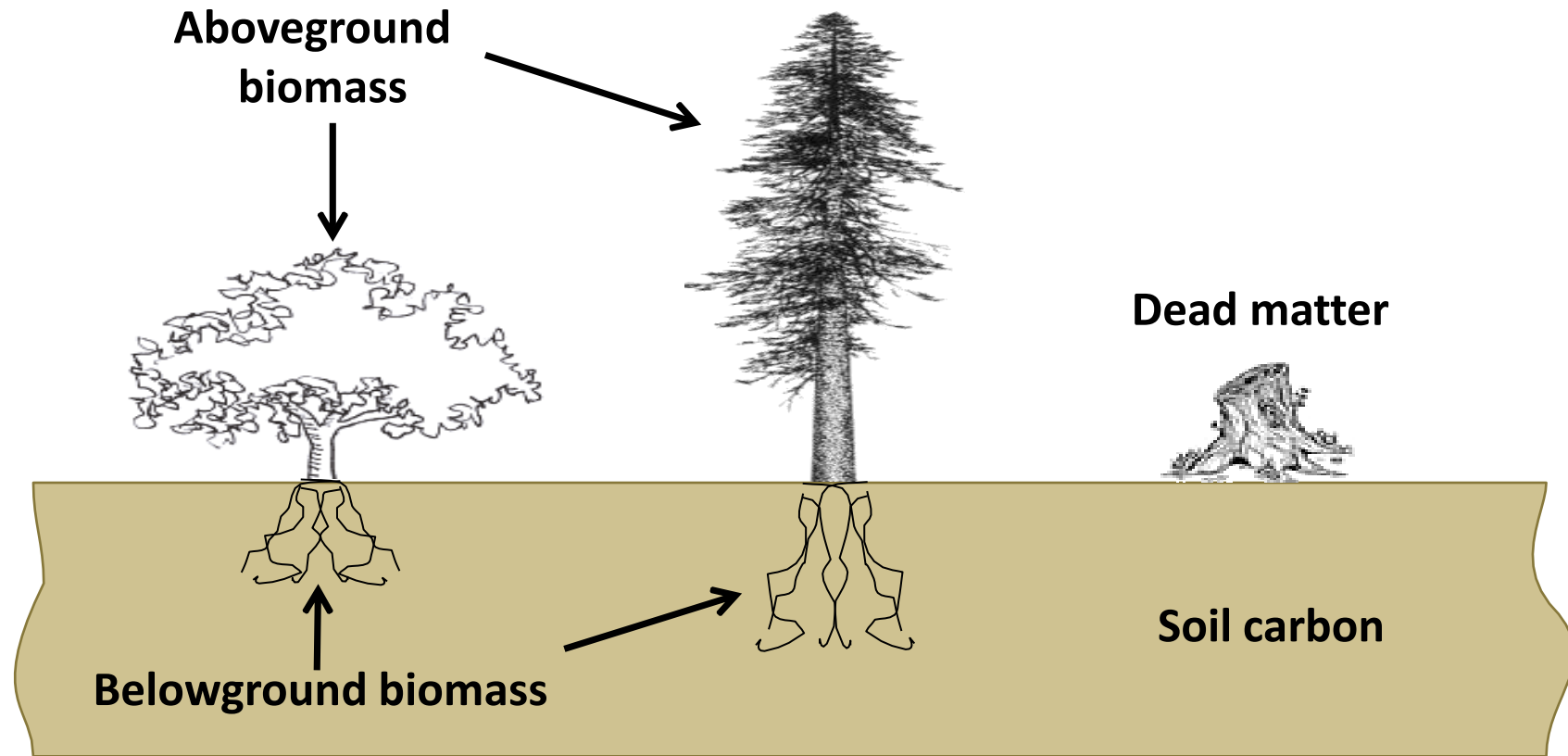


# InVEST Carbon Storage and Sequestration model

- Carbon stock estimated as a function of land use/land cover
- *Storage* indicates the mass of carbon in a landscape at any given point in time
- *Sequestration* indicates the change in carbon storage over time
  - Valuation is only applied to sequestration



# Carbon pools



**CARBON STORAGE** = Sum of all 4 pools

**SEQUESTRATION** =  $\text{storage}_{t+1} - \text{storage}_t$

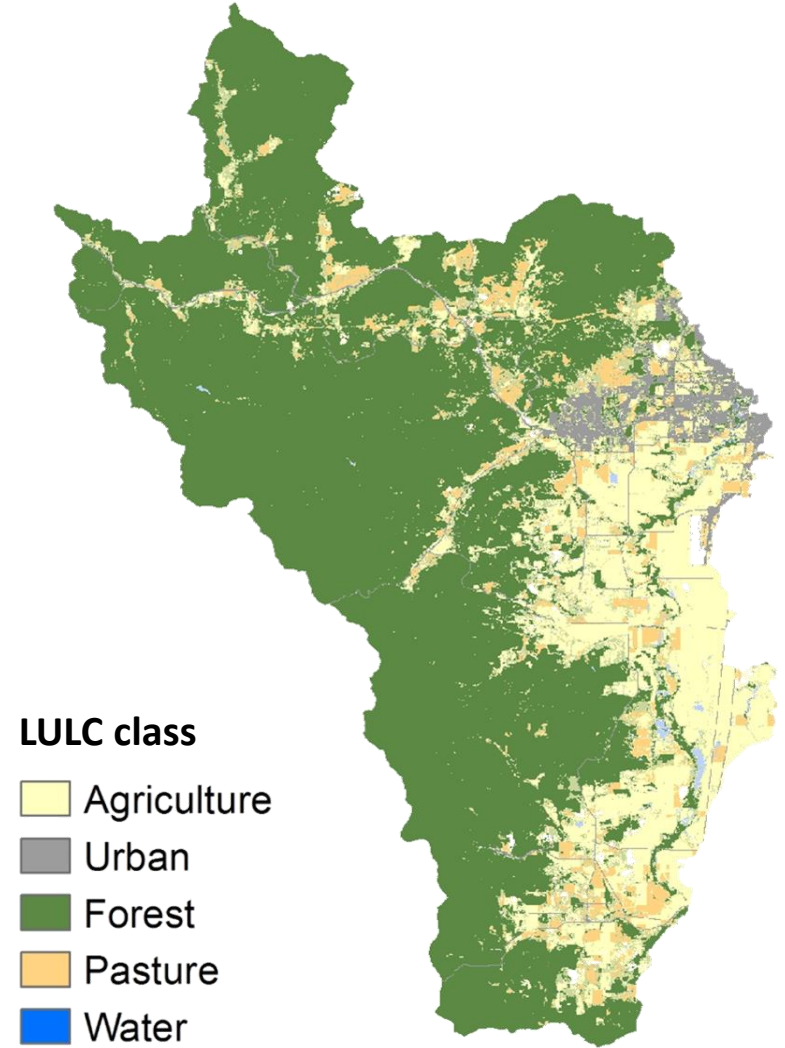
# Model inputs

## Required:

- Land use / land cover (LULC) map
- Table of the 4 carbon pools
- The model simply assigns the values for each carbon pool to the land-use, land-cover classes present.

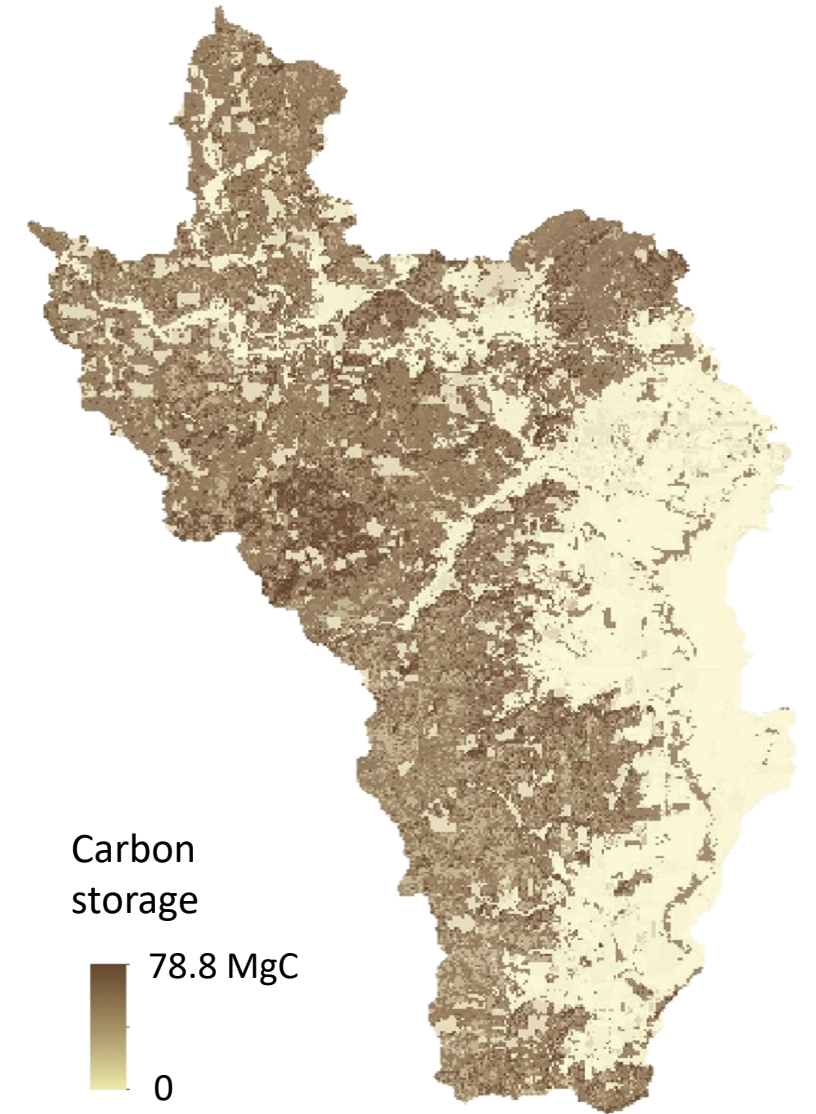
## Optional:

- Timber harvest land parcels
- Future land use map
- REDD policy map
- Economic data
- Carbon pool uncertainty data



# Model outputs

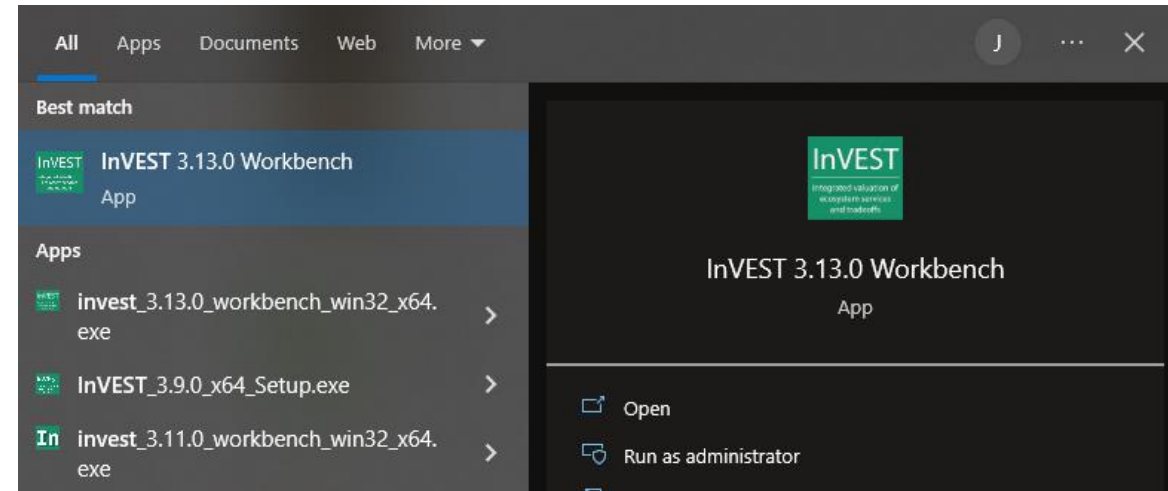
- Current/future carbon storage
- Carbon sequestration
- Sequestration map for REDD scenario
- Economic value of carbon sequestered
- Uncertainty results





# Diving into the software

- Hopefully, everyone here has already installed all of the required software
  - InVEST
  - QGIS
- If you haven't, refer back to your invitation and the setup instructions there.
- Assuming you have installed it, open InVEST!
  - Find wherever you installed it, or (on Windows), just press the start button and type "invest"



## InVEST

Annual Water Yield

Nutrient Delivery Ratio

Carbon Storage and Sequestration

RouteDEM

Coastal Blue Carbon Preprocessor

Scenario Generator: Proximity Based

Coastal Blue Carbon

Scenic Quality

Coastal Vulnerability

Seasonal Water Yield

Crop Pollination

Sediment Delivery Ratio

Crop Production: Percentile

Urban Cooling

Crop Production: Regression

Urban Flood Risk Mitigation

DelineateIt

Urban Stormwater Retention

Forest Carbon Edge Effect

Visitation: Recreation and Tourism

GLOBIO

Wave Energy Production

Habitat Quality

Wind Energy Production

Habitat Risk Assessment

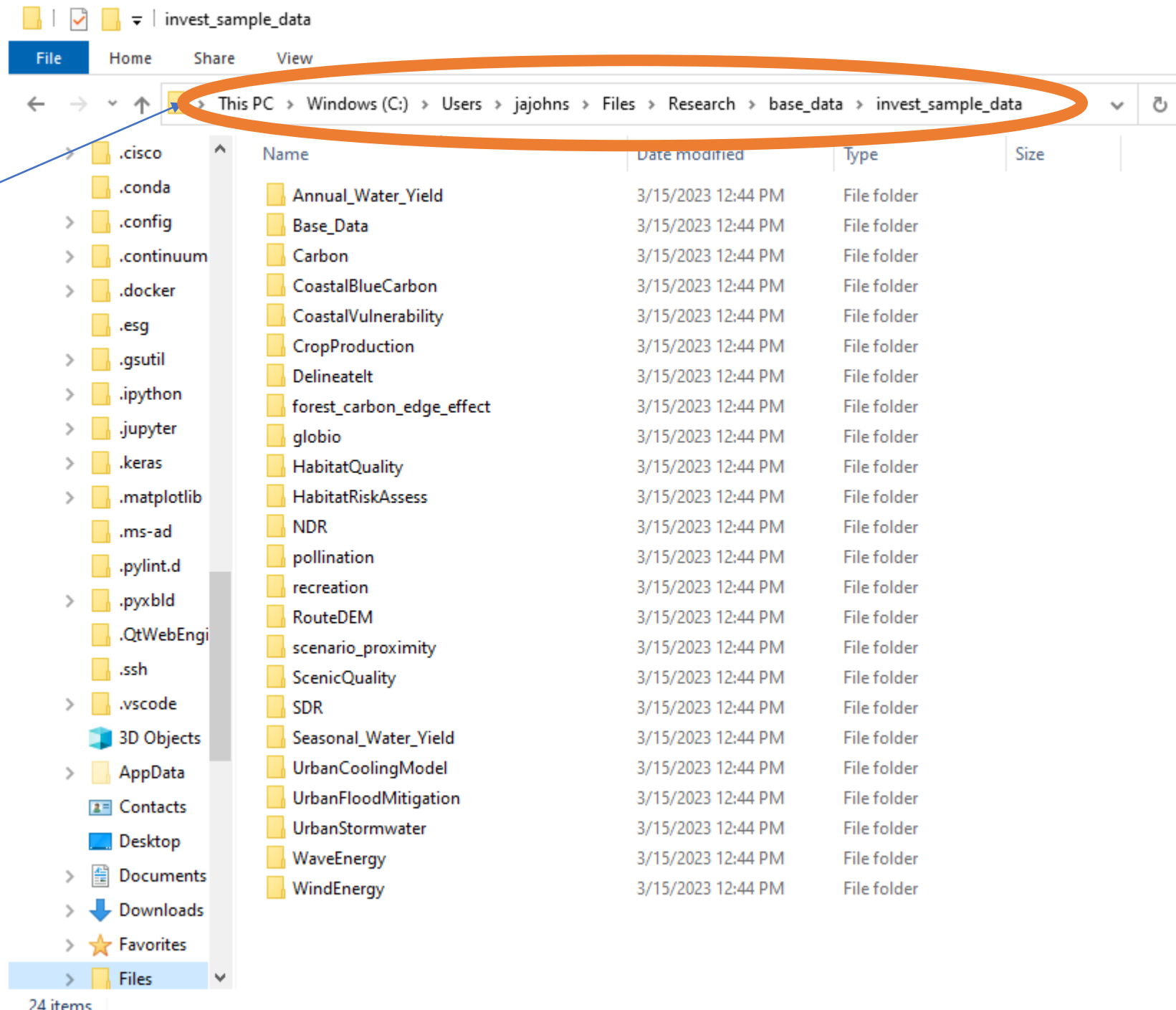
This is the  
InVEST menu of  
models/tools

# Reminder: Download the sample data from the Gear icon.

The screenshot shows the InVEST workbench interface. The top navigation bar includes the InVEST logo and a menu with 'File', 'Edit', 'View', 'Window', and 'About'. On the right side, there is a gear icon for settings, which is circled in orange. A modal dialog titled 'InVEST Settings' is open in the center. It contains three dropdown menus: 'Logging threshold' (set to INFO), 'Taskgraph logging threshold' (set to INFO), and 'Taskgraph n\_workers parameter' (set to Synchronous (-1)). Below these is a 'more info' link. At the bottom of the dialog, there are three buttons: 'Download Sample Data' (highlighted with an orange circle), 'Reset to Defaults', and 'Clear Recent Jobs'. A note at the bottom right of the dialog states 'no invest workspaces will be deleted'. The background shows a sidebar with various tool categories like 'Annual Water Yield', 'Carbon Storage and Sequestration', etc.

Open the folder where you saved it

Each model has a directory. Open the Carbon Folder.



Find the land-use, land-cover file for the current time period

Named  
“lulc\_current\_willamette.tif”

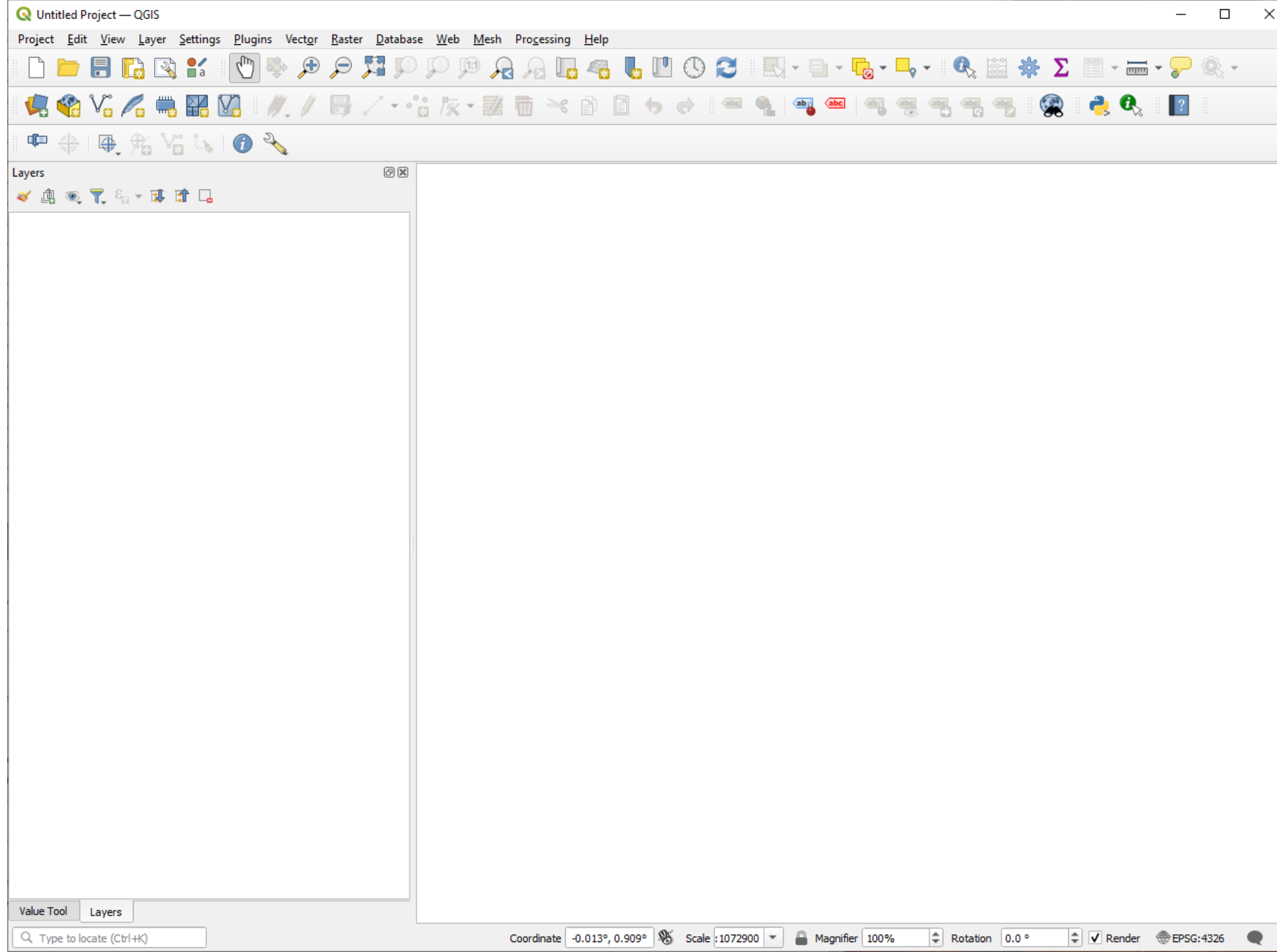
The screenshot shows a Windows File Explorer window titled 'Carbon' with the address bar path: <code>C:\Users\jajohns\Files\Research\base\_data\invest\_sample\_data\Carbon</code>. The left sidebar shows the 'Files' folder selected. The main pane displays a list of files with columns for Name, Date modified, Type, and Size. The file 'lulc\_current\_willamette.tif' is highlighted in blue.

Name	Date modified	Type	Size
carbon_pools_willamette.csv	3/15/2023 12:44 PM	CSV File	3 KB
carbon_willamette.invs.json	3/15/2023 12:44 PM	JSON File	1 KB
<b>lulc_current_willamette.tif</b>	3/15/2023 12:44 PM	TIF File	5,286 KB
lulc_current_willamette.tif.aux.xml	3/15/2023 12:44 PM	XML File	2 KB
lulc_current_willamette.tif.vat.cpg	3/15/2023 12:44 PM	CPG File	1 KB
lulc_current_willamette.tif.vat.dbf	3/15/2023 12:44 PM	DBF File	17 KB
lulc_current_willamette.tif.vat.dbf.xml	3/15/2023 12:44 PM	XML File	2 KB
lulc_future_willamette.tif	3/15/2023 12:44 PM	TIF File	2,646 KB
lulc_future_willamette.tif.aux.xml	3/15/2023 12:44 PM	XML File	2 KB
lulc_future_willamette.tif.vat.cpg	3/15/2023 12:44 PM	CPG File	1 KB
lulc_future_willamette.tif.vat.dbf	3/15/2023 12:44 PM	DBF File	8 KB
lulc_redd_willamette.tif	3/15/2023 12:44 PM	TIF File	9,808 KB
lulc_redd_willamette.tif.vat.cpg	3/15/2023 12:44 PM	CPG File	1 KB
lulc_redd_willamette.tif.vat.dbf	3/15/2023 12:44 PM	DBF File	9 KB

14 items | 1 item selected 5.16 MB

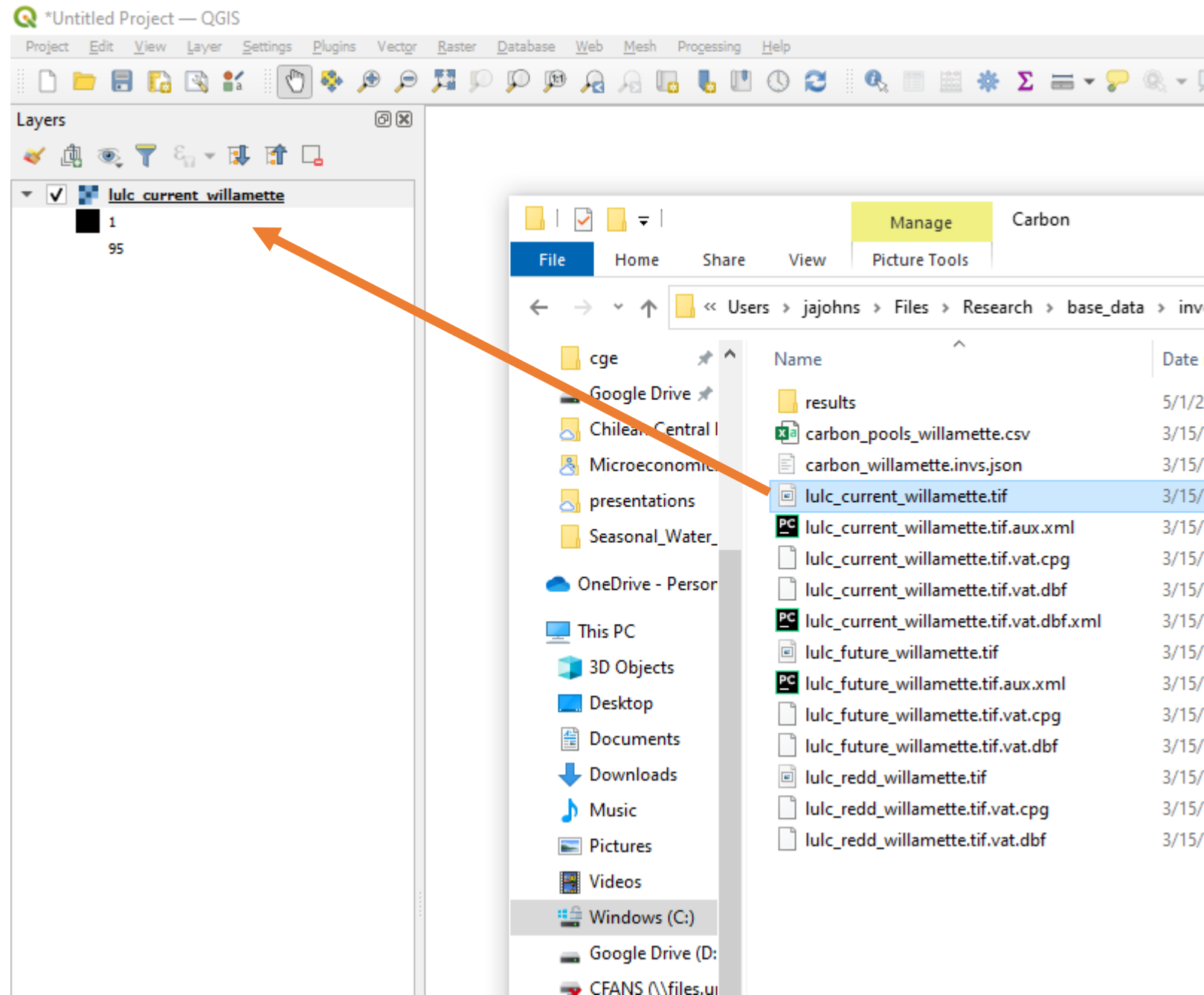
Before we use InVEST, let's take a look at our input data.

- Open QGIS.



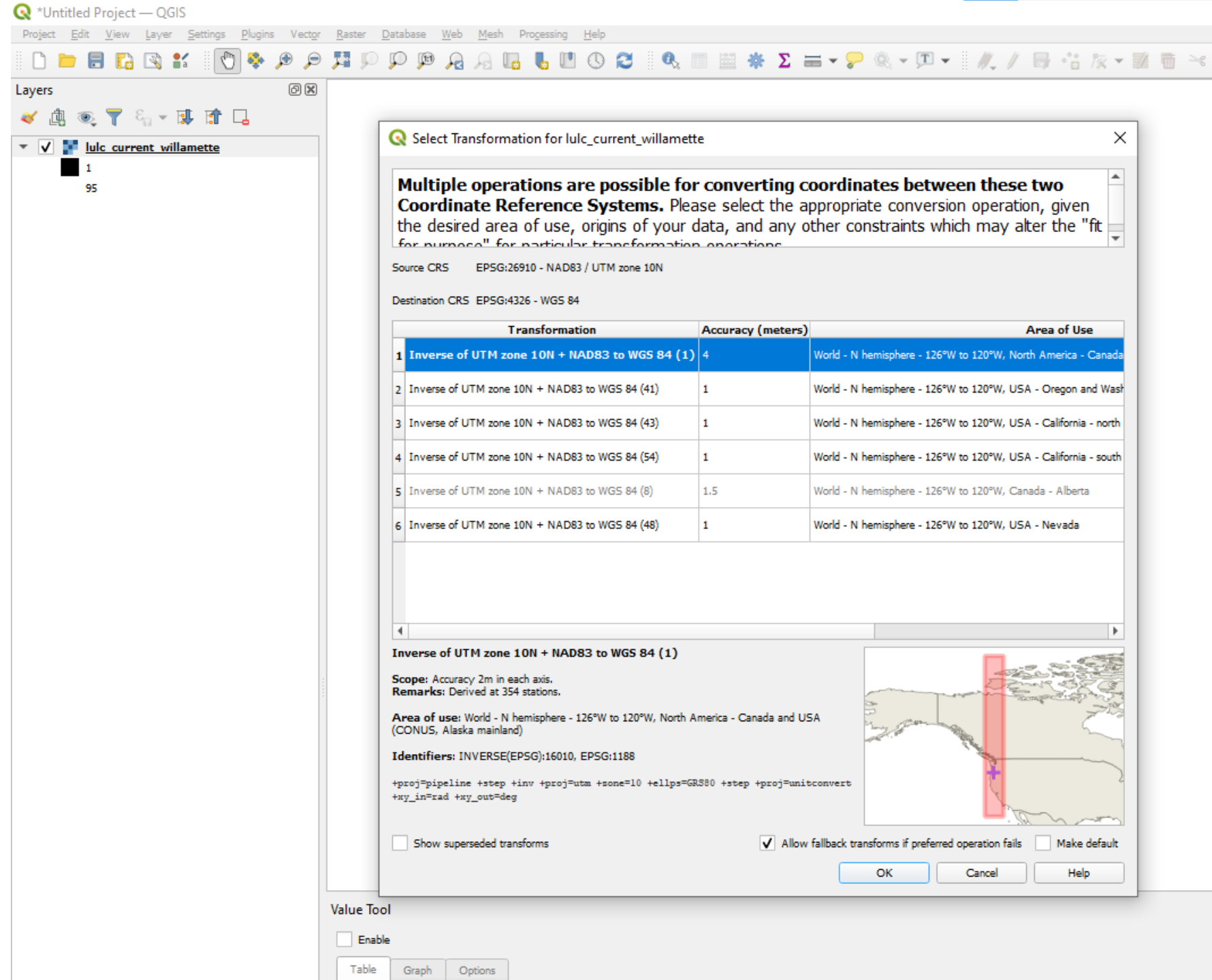
# LULC map

- The easiest way to add data is to just drag it from your sample\_data folder into QGIS
- Add the lulc\_current\_willamette.tif file



# LULC map

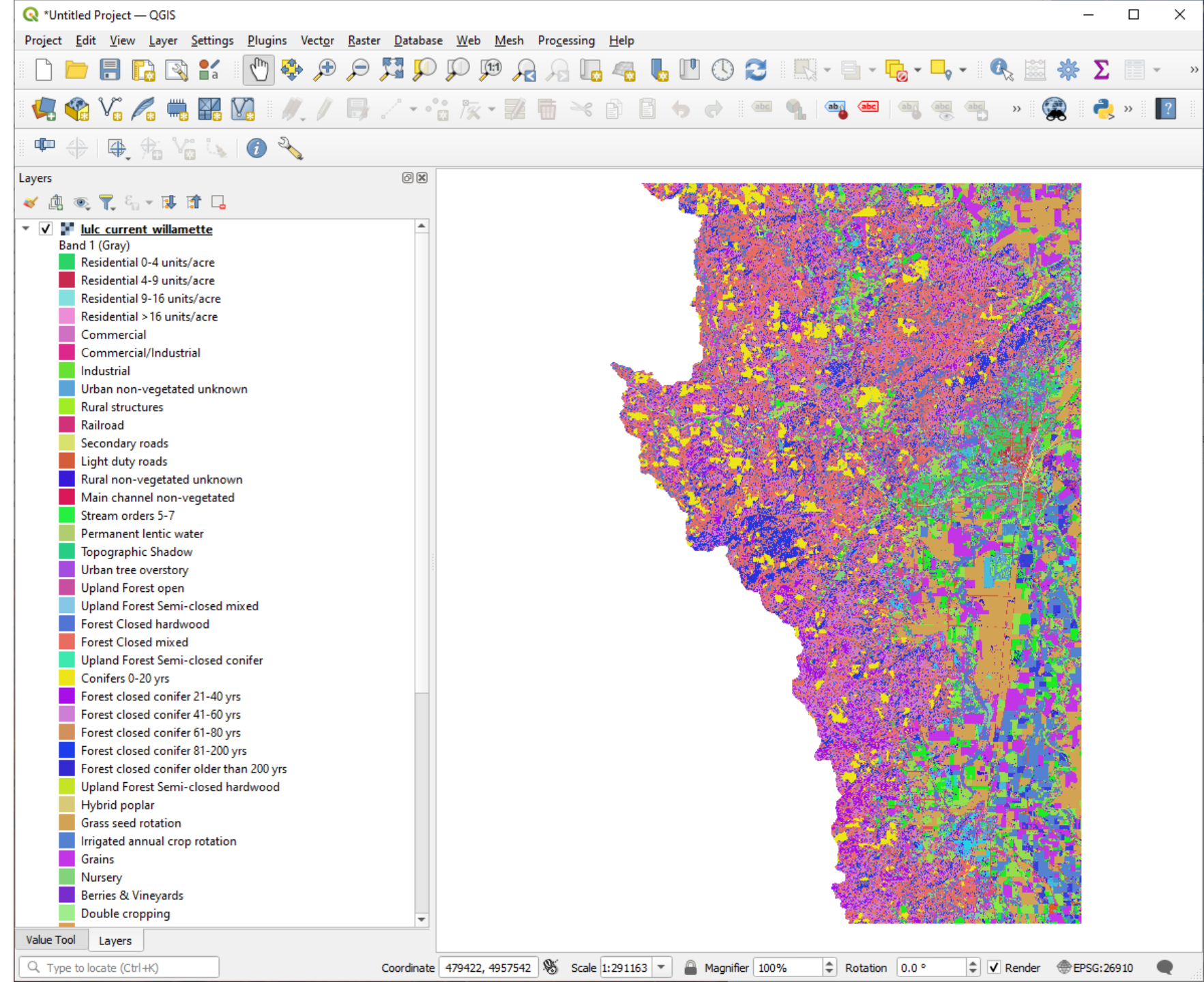
- Depending on your QGIS setup, it may ask you about coordinate reference systems
  - This is almost certainly the most time-consuming and annoying part of GIS
- So we're going to ignore it.
  - Just select the top one if this happens.





# LULC map

- What is an LULC map?
  - A numeric value (a class) in each grid-cell (pixel)
  - Each class corresponds to some type of land-use/land-cover
- Here I have added a legend to the LULC map

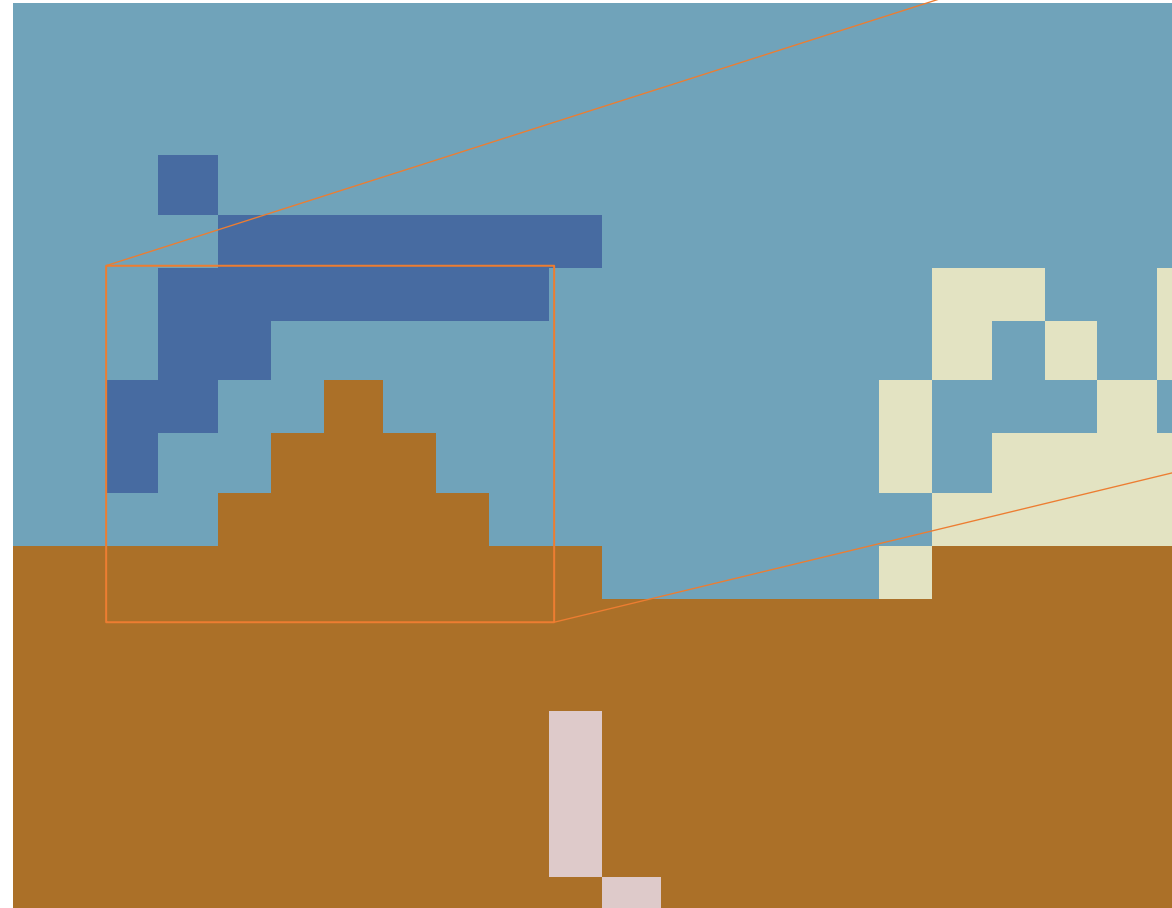


# What is a “.tif” file? What is an LULC map?

NLCD Land Cover Classification Legend

11	Open Water
12	Perennial Ice/ Snow
21	Developed, Open Space
22	Developed, Low Intensity
23	Developed, Medium Intensity
24	Developed, High Intensity
31	Barren Land (Rock/Sand/Clay)
41	Deciduous Forest
42	Evergreen Forest
43	Mixed Forest
51	Dwarf Scrub*
52	Shrub/Scrub
71	Grassland/Herbaceous
72	Sedge/Herbaceous*
73	Lichens*
74	Moss*
81	Pasture/Hay
82	Cultivated Crops
90	Woody Wetlands
95	Emergent Herbaceous Wetlands

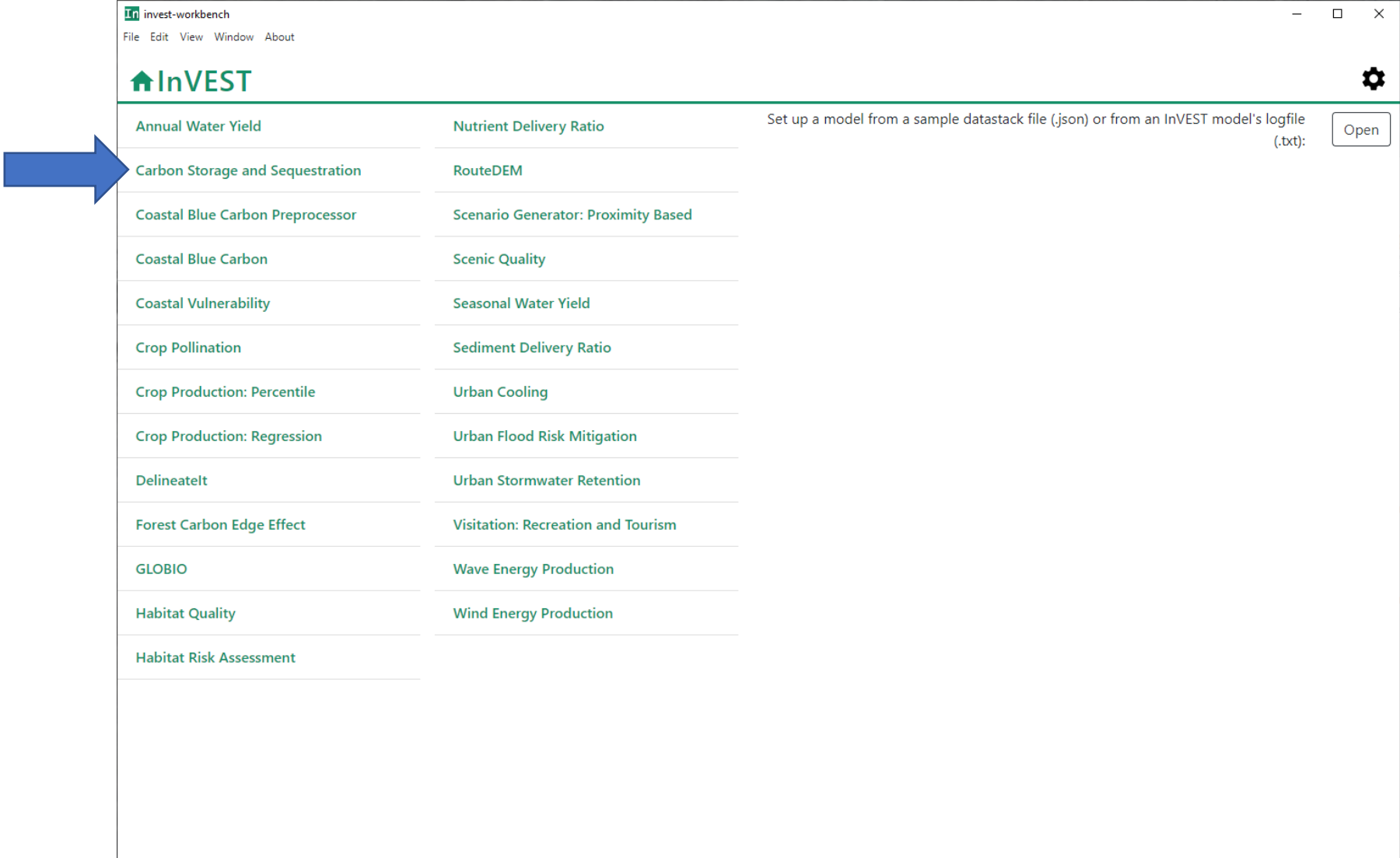
\* Alaska only



90	11	11	11	11	11	11	11
90	11	11	90	90	90	90	90
11	11	90	90	82	90	90	90
11	90	90	82	82	82	90	90
90	90	82	82	82	82	82	90
82	82	82	82	82	82	82	82

- A .tif file is literally just a 2-dimensional array (matrix) of numbers
- Each number corresponds to a type of land-cover

# Open the Carbon Storage and Sequestration Model



The screenshot shows the InVEST software interface. The window title is "invest-workbench" and it includes a menu bar with "File", "Edit", "View", "Window", and "About". The main header displays the InVEST logo and a settings gear icon. A blue arrow points to the "Carbon Storage and Sequestration" model in a list of available models. To the right of the model list, there is a text prompt: "Set up a model from a sample datastack file (.json) or from an InVEST model's logfile (.txt):" followed by an "Open" button.

Model Name
Annual Water Yield
<b>Carbon Storage and Sequestration</b>
Coastal Blue Carbon Preprocessor
Coastal Blue Carbon
Coastal Vulnerability
Crop Pollination
Crop Production: Percentile
Crop Production: Regression
DelineateIt
Forest Carbon Edge Effect
GLOBIO
Habitat Quality
Habitat Risk Assessment
Nutrient Delivery Ratio
RouteDEM
Scenario Generator: Proximity Based
Scenic Quality
Seasonal Water Yield
Sediment Delivery Ratio
Urban Cooling
Urban Flood Risk Mitigation
Urban Stormwater Retention
Visitation: Recreation and Tourism
Wave Energy Production
Wind Energy Production

# Setup the carbon model

- The first thing we're going to do is point InVEST to the Current LULC map we were just looking at.
  - Click the Open button.

The screenshot shows the InVEST software interface for the 'Carbon Storage and Sequestration' model. The window title is 'invest-workbench' and the menu bar includes 'File', 'Edit', 'View', 'Window', and 'About'. The InVEST logo is in the top left, and a settings gear icon is in the top right. The left sidebar contains a 'Setup' menu, a 'Log' menu, and options for 'Load parameters from file' and 'Save as...'. There are also links for 'User's Guide' and 'Frequently Asked Questions'. The main area displays various input fields and options:

- Workspace:** A text input field containing 'directory' with a folder icon button on the right.
- File Suffix (optional):** A text input field containing 'text'.
- Current LULC:** A text input field containing 'raster' with a folder icon button on the right, which is circled in orange.
- Carbon Pools:** A text input field containing 'csv' with a folder icon button on the right.
- Calculate Sequestration:** Radio buttons for 'Yes' and 'No', with 'No' selected.
- Future LULC:** A text input field containing 'raster' with a folder icon button on the right.
- REDD Scenario Analysis (optional):** Radio buttons for 'Yes' and 'No', with 'No' selected.
- REDD LULC:** A text input field containing 'raster' with a folder icon button on the right.
- Run Valuation Model (optional):** Radio buttons for 'Yes' and 'No', with 'No' selected.

A large blue 'Run' button is located at the bottom left of the main area.

- This will open the folder where you installed InVEST.

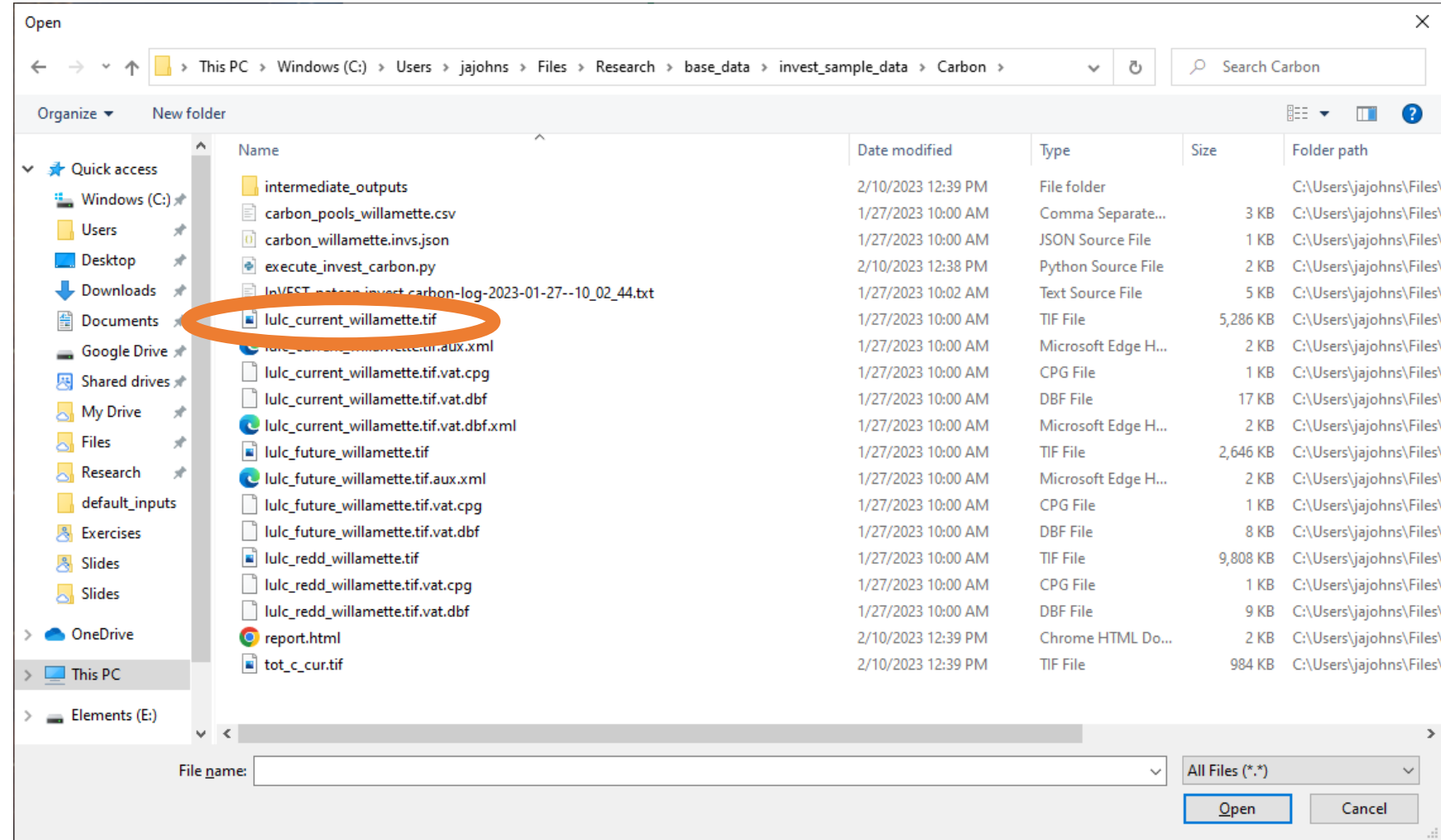
The screenshot displays the InVEST 3.12.1 Workbench application window. The title bar reads "invest-workbench" and the menu bar includes "File", "Edit", "View", "Window", and "About". The main interface is titled "Carbon Storage and Sequestration" and features a left-hand navigation pane with options: "Setup", "Log", "Load parameters from file", "Save as...", "User's Guide", and "Frequently Asked Questions". The main area contains configuration fields for "Workspace" (set to "directory"), "File Suffix (optional)" (set to "text"), "Current LULC" (set to "raster"), and "Carbon Pools" (set to "csv"). Each field has an information icon and a folder selection icon.

An "Open" file dialog is overlaid on the application, showing the path "AppData > Local > Programs > InVEST 3.12.1 Workbench". The dialog lists the following files and folders:

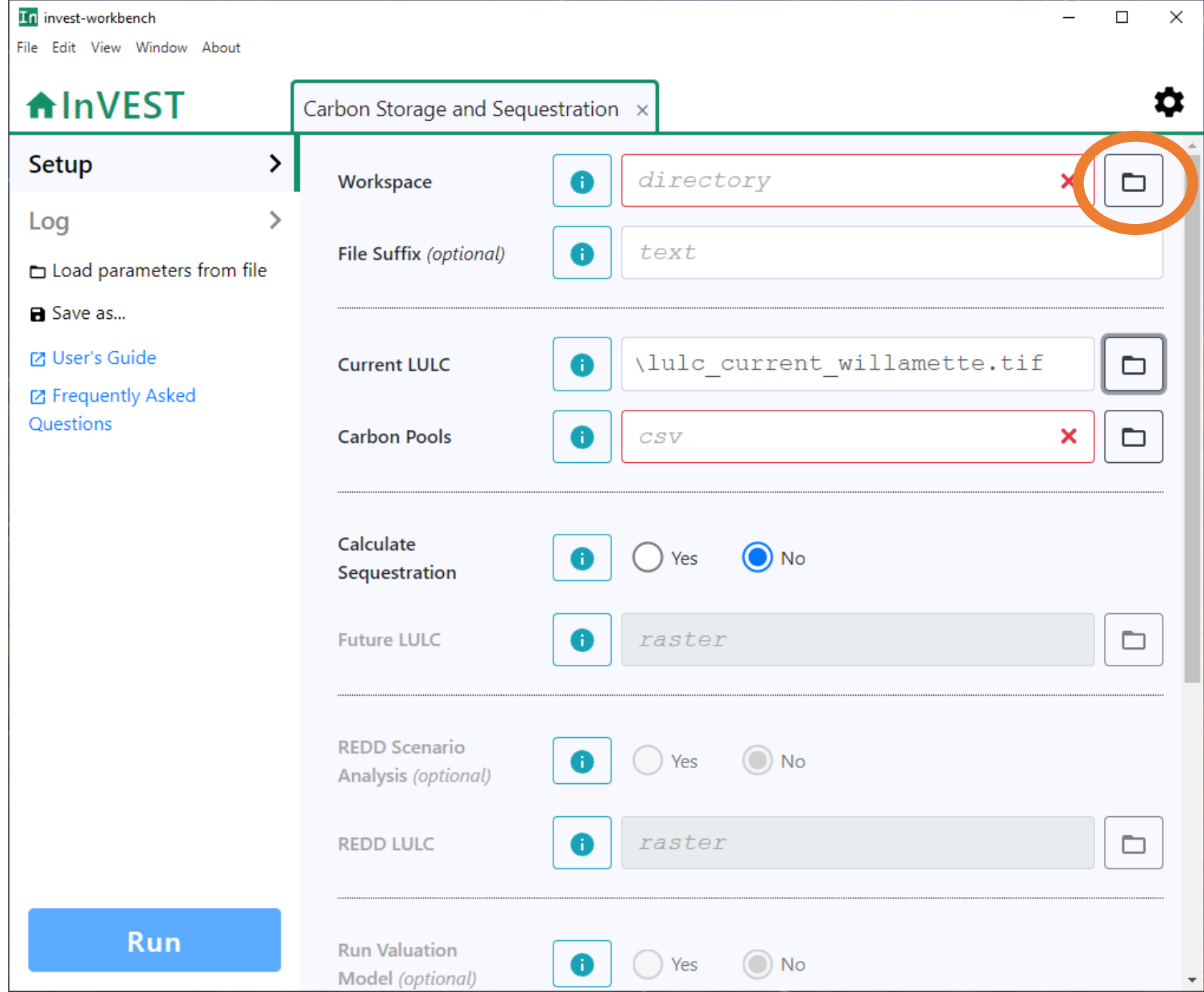
Name	Date modified
locales	1/27/2023 9:59 AM
resources	1/27/2023 9:59 AM
swiftshader	1/27/2023 9:59 AM
chrome_100_percent.pak	12/16/2022 1:45 PM
chrome_200_percent.pak	12/16/2022 1:45 PM
d3dcompiler_47.dll	12/16/2022 1:45 PM
ffmpeg.dll	12/16/2022 1:45 PM

The "File name" field is empty, and the file type is set to "All Files (\*.\*)". The "Open" button is highlighted. Below the dialog, a "Run" button is visible, along with a "Run Valuation Model (optional)" section containing an information icon and radio buttons for "Yes" and "No".

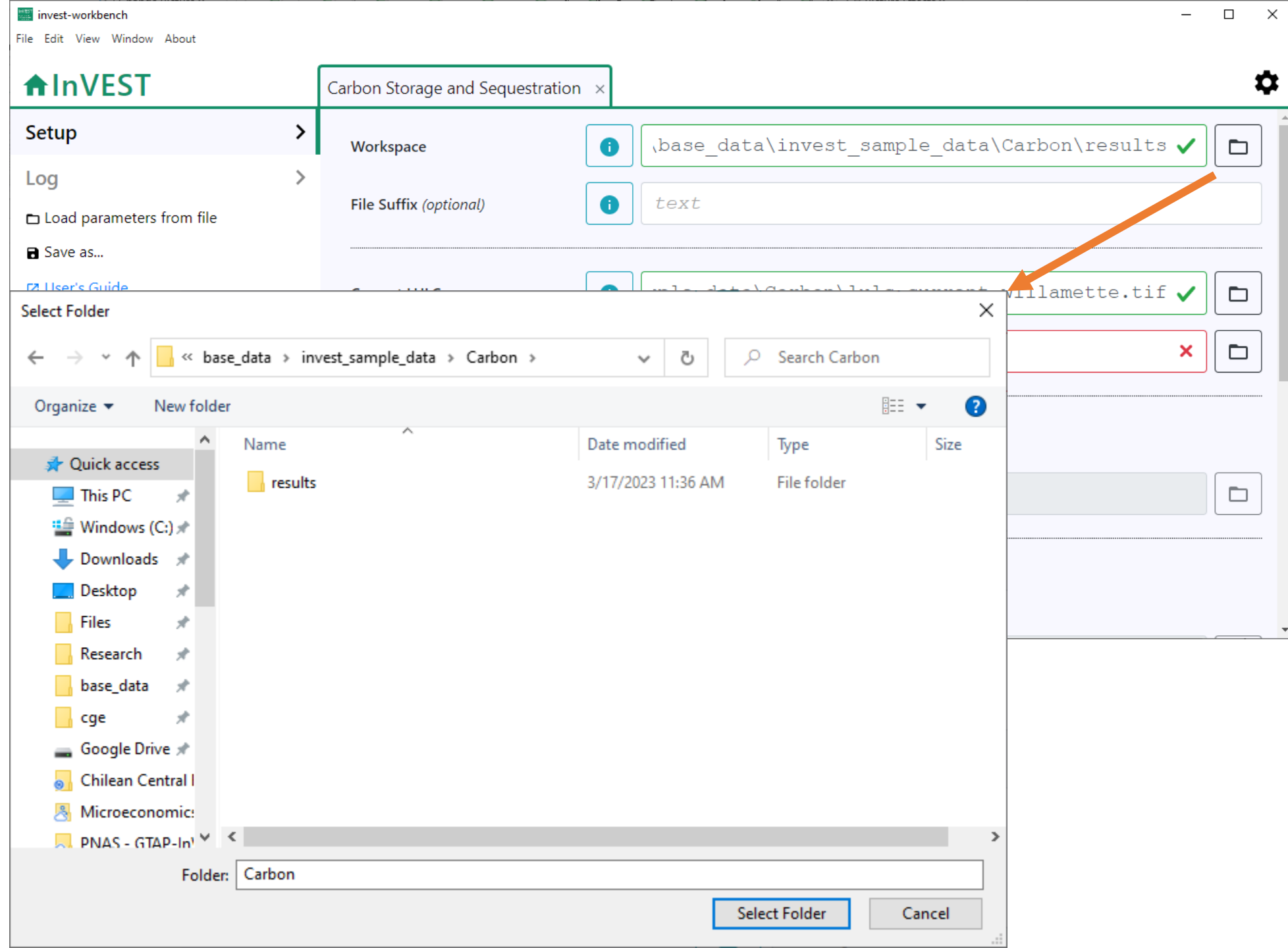
- Navigate to where you downloaded the Sample Data.
- Select the current lulc map.
- Click Open



- Now it have the filename entered correctly.
- Next we will specify the “Workspace”.
  - This is where it will save all the output files.
  - Click the Open button for the Workspace.



- Select the Carbon folder we just used.
- Create a new folder called Results in the carbon folder.
- Set this as our Workspace.





- There is one last file that is required: the carbon pools table.
- Select open for Carbon Pools and select “carbon\_pools\_willamette.csv”

The screenshot shows the InVEST software interface for the Carbon Storage and Sequestration module. The window title is "invest-workbench" and the menu bar includes "File", "Edit", "View", "Window", and "About". The InVEST logo is in the top left, and a settings gear icon is in the top right. The main window title is "Carbon Storage and Sequestration".

The interface is divided into a left sidebar and a main configuration area. The sidebar contains "Setup" (selected), "Log", "Load parameters from file", "Save as...", "User's Guide", and "Frequently Asked Questions".

The main configuration area has the following settings:

- Workspace:** ta\invest\_sample\_data\Carbon
- File Suffix (optional):** text
- Current LULC:** \lulc\_current\_willamette.tif
- Carbon Pools:** \carbon\_pools\_willamette.csv (highlighted with a red box)
- Calculate Sequestration:** Yes (unselected), No (selected)
- Future LULC:** raster
- REDD Scenario Analysis (optional):** Yes (unselected), No (selected)
- REDD LULC:** raster
- Run Valuation Model (optional):** Yes (unselected), No (selected)

A large blue "Run" button is located at the bottom left of the configuration area.

# Look at the carbon pools table

- Open up the carbon pools CSV file in Excel (or whatever).
- Notice two key columns:
  - Lucode: This is the lucode that was saved in our LULC map!.
  - C\_above: This is the carbon stored in the above-ground carbon pool for this LULC type.
    - Where did these values come from? A massive literature review (Ruesch and Gibbs 2008) of field studies.

	A	B	C	D	E	F
1	lucode	LULC_Name	C_above	C_below	C_soil	C_dead
2	1	Residential 0-4 units/acre	15	10	60	1
3	2	Residential 4-9 units/acre	5	3	20	0
4	3	Residential 9-16 units/acre	2	1	5	0
5	4	Residential >16 units/acre	0	0	0	0
6	5	Vacant	10	20	10	5
7	6	Commercial	0	0	0	0
8	7	Commercial/Industrial	0	0	0	0
9	8	Industrial	0	0	0	0
10	9	Industrial & Commercial	0	0	0	0
11	10	Residential & Commercial	0	0	0	0
12	11	Urban non-vegetated unknown	0	0	10	0
13	16	Rural structures	0	0	50	0
14	18	Railroad	0	0	25	0
15	19	Primary roads	0	0	50	0
16	20	Secondary roads	0	0	25	0
17	21	Light duty roads	0	0	35	0
18	24	Rural non-vegetated unknown	0	0	0	0
19	29	Main channel non-vegetated	0	0	0	0
20	32	Stream orders 5-7	0	0	0	0
21	33	Permanent lentic water	0	0	0	0
22	39	Topographic Shadow	100	5	65	50
23	40	Snow	0	0	0	0
24	42	Barren	0	0	0	0
25	49	Urban tree overstory	135	50	75	1
26	51	Upland Forest open	75	45	85	20
27	52	Upland Forest Semi-closed mixed	90	60	110	30
28	53	Forest Closed hardwood	180	120	120	55
29	54	Forest Closed mixed	200	130	130	65
30	55	Upland Forest Semi-closed conifer	90	60	95	29
31	56	Conifers 0-20 yrs	10	7	76	2.5
32	57	Forest closed conifer 21-40 yrs	88	59	96	29
33	58	Forest closed conifer 41-60 yrs	165	110	115	50
34	59	Forest closed conifer 61-80 yrs	225	150	124	65
35	60	Forest closed conifer 81-200 yrs	300	200	135	85
36	61	Forest closed conifer older than 200 yrs	375	250	150	100
37	62	Upland Forest Semi-closed hardwood	80	50	100	25
38	66	Hybrid poplar	75	25	90	2
39	67	Grass seed rotation	1	1	10	0
40	68	Irrigated annual crop rotation	2	1	10	0
41	71	Grains	3	2	10	0

- Running the InVEST model here will combine the information from the table with the LULC map to calculate how much carbon is present.
- Do it by selecting Run!

The screenshot shows the InVEST software interface for the 'Carbon Storage and Sequestration' model. The window title is 'invest-workbench' and the menu bar includes 'File', 'Edit', 'View', 'Window', and 'About'. The InVEST logo is in the top left, and a settings gear icon is in the top right. The main window is titled 'Carbon Storage and Sequestration' and has a sidebar on the left with 'Setup' and 'Log' sections. The 'Setup' section includes options for 'Load parameters from file' and 'Save as...', along with links to 'User's Guide' and 'Frequently Asked Questions'. The main area contains several input fields and options:

- Workspace:** A text box containing 'ta\invest\_sample\_data\Carbon' with a folder icon to its right.
- File Suffix (optional):** A text box containing 'text'.
- Current LULC:** A text box containing '\lulc\_current\_willamette.tif' with a folder icon to its right.
- Carbon Pools:** A text box containing '\carbon\_pools\_willamette.csv' with a folder icon to its right.
- Calculate Sequestration:** A radio button group with 'Yes' and 'No' options. The 'No' option is selected.
- Future LULC:** A text box containing 'raster' with a folder icon to its right.
- REDD Scenario Analysis (optional):** A radio button group with 'Yes' and 'No' options. The 'No' option is selected.
- REDD LULC:** A text box containing 'raster' with a folder icon to its right.
- Run Valuation Model (optional):** A radio button group with 'Yes' and 'No' options. The 'No' option is selected.

At the bottom of the window, a large blue button labeled 'Run' is circled in orange.

- A bunch of math just happened.
- You should now see a Log from the code that was just run.
- If it was successful, you should see “Execution Finished.”
- Now click on the Open Workspace button.

The screenshot shows the InVEST software interface. At the top, there is a menu bar with 'File', 'Edit', 'View', 'Window', and 'About'. Below the menu bar is the InVEST logo and a tab titled 'Carbon Storage and Sequestration'. The main area is divided into a left sidebar and a right log window. The sidebar contains 'Setup', 'Log', 'Load parameters from file', 'Save as...', 'User's Guide', and 'Frequently Asked Questions'. The log window displays a series of messages from the 'natcap.invest.carbon' module, including 'Mapping carbon from 'lulc\_cur\_path' to 'c\_soil\_cur' scenario.' and 'Mapping carbon from 'lulc\_cur\_path' to 'c\_dead\_cur' scenario.'. The log also shows progress updates from 'pygeoprocessing.geoprocessing' and 'stats\_worker' threads, indicating 100.0% completion. At the bottom of the log, it states 'Elapsed time: 1.2s' and 'Execution finished'. A blue arrow points from the 'Open Workspace' button in the 'Model Complete' notification to the 'Run' button. Another blue arrow points from the 'Execution finished' message in the log to the 'Run' button.

invest-workbench  
File Edit View Window About

InVEST  Carbon Storage and Sequestration x

Setup > raster stats worker result.  
03/15/2023 13:42:11 natcap.invest.carbon INFO Mapping carbon from  
'lulc\_cur\_path' to 'c\_soil\_cur' scenario.

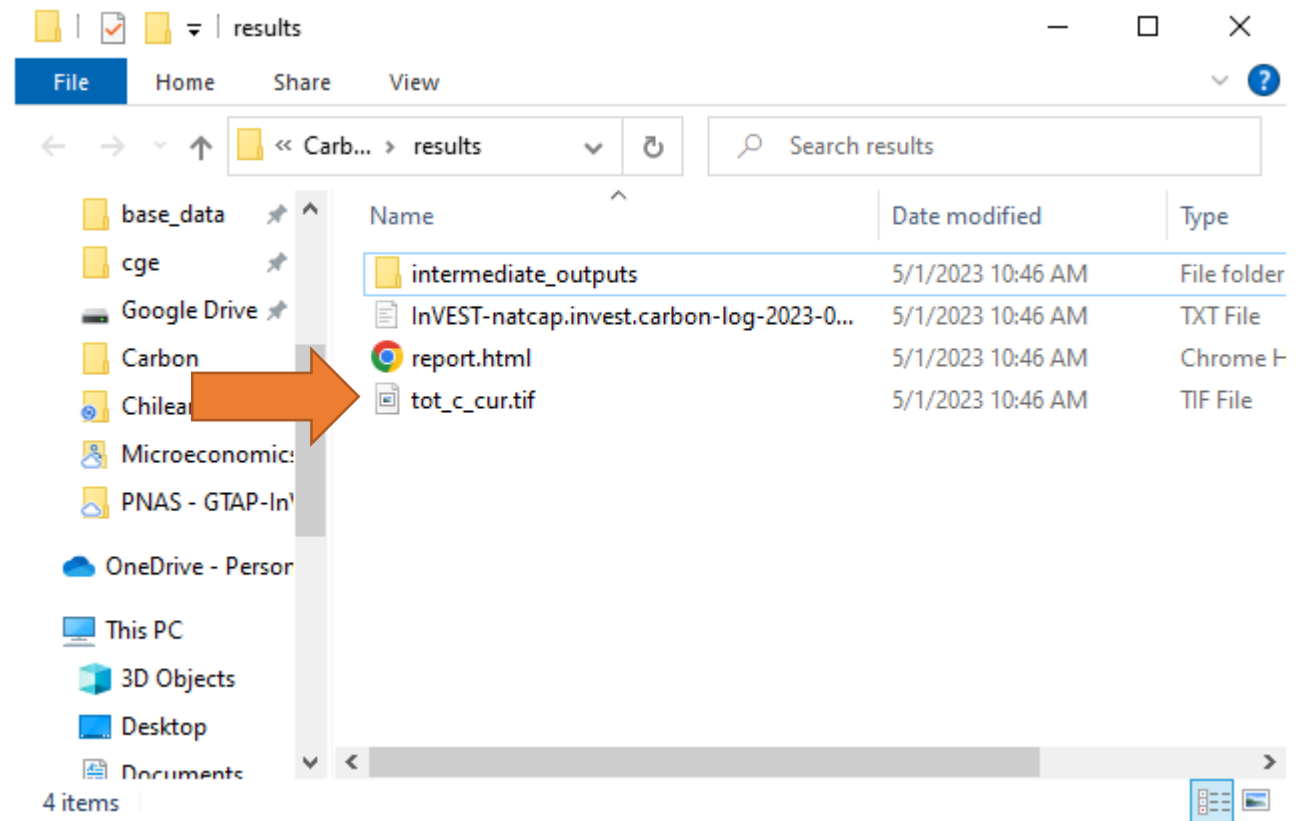
Log > 03/15/2023 13:42:11 pygeoprocessing.geoprocessing INFO starting  
stats\_worker  
03/15/2023 13:42:11 pygeoprocessing.geoprocessing INFO started  
stats\_worker <Thread(Thread-3 (stats\_worker), started daemon 12716)>  
03/15/2023 13:42:12 pygeoprocessing.geoprocessing INFO 100.0% complete  
03/15/2023 13:42:12 pygeoprocessing.geoprocessing INFO Waiting for  
raster stats worker result.  
03/15/2023 13:42:12 natcap.invest.carbon INFO Mapping carbon from  
'lulc\_cur\_path' to 'c\_dead\_cur' scenario.  
03/15/2023 13:42:12 pygeoprocessing.geoprocessing INFO starting  
stats\_worker  
03/15/2023 13:42:12 pygeoprocessing.geoprocessing INFO started  
stats\_worker <Thread(Thread-4 (stats\_worker), started daemon 6208)>  
03/15/2023 13:42:12 pygeoprocessing.geoprocessing INFO 100.0% complete  
03/15/2023 13:42:12 pygeoprocessing.geoprocessing INFO Waiting for  
raster stats worker result.  
03/15/2023 13:42:12 natcap.invest.carbon INFO Calculate carbon storage  
for 'tot\_c\_cur'  
03/15/2023 13:42:12 pygeoprocessing.geoprocessing INFO starting  
stats\_worker  
03/15/2023 13:42:12 pygeoprocessing.geoprocessing INFO started  
stats\_worker <Thread(Thread-5 (stats\_worker), started daemon 28200)>  
03/15/2023 13:42:12 pygeoprocessing.geoprocessing INFO 100.0% complete  
03/15/2023 13:42:12 pygeoprocessing.geoprocessing INFO Waiting for  
raster stats worker result.  
03/15/2023 13:42:12 natcap.invest.utils INFO Elapsed time: 1.2s  
03/15/2023 13:42:12 natcap.invest.utils INFO Execution finished

Model Complete  
Open Workspace

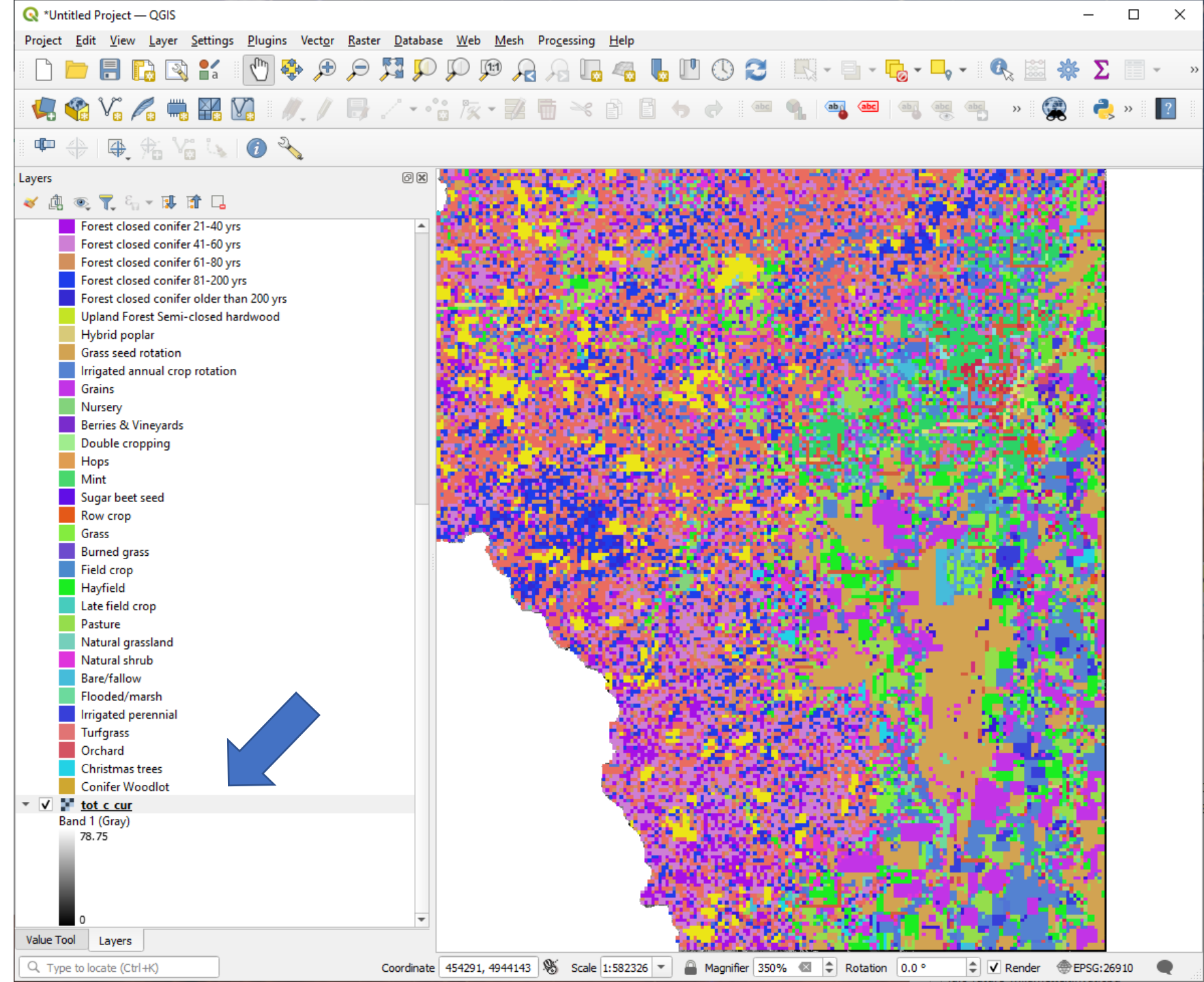
Run

- The Open Workspace button opened the folder where it saved all the results

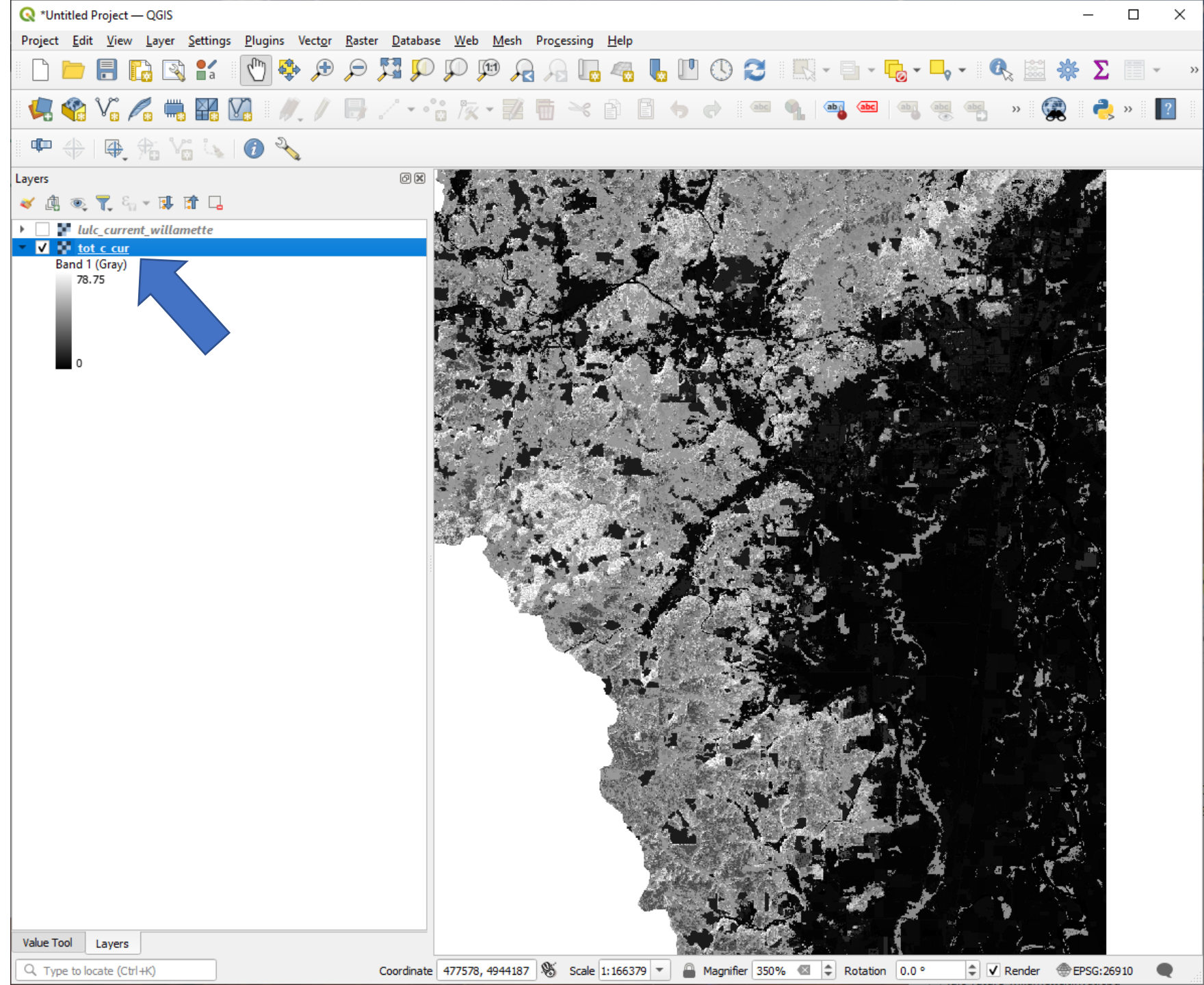
- Because we set our workspace to be the same as the where the Sample Data was, you should now see that folder.
- But, it has new files added
- Such as “tot\_c\_cur.tif”



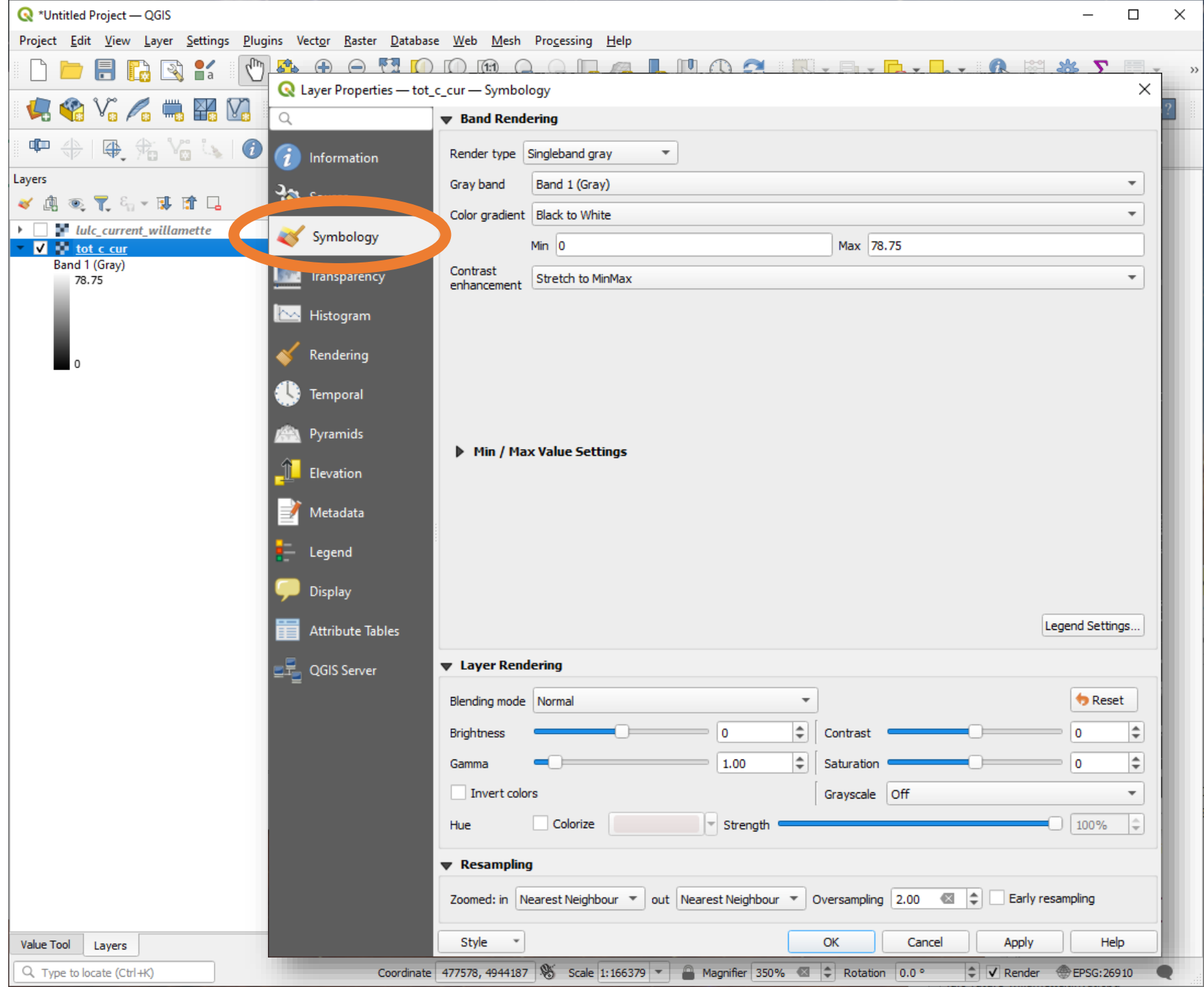
- Add “tot\_c\_cur.tif” to QGIS by dragging the file into QGIS.
- It will add it to the Layers tab.
- Depending on where you dropped the file, it might be hidden by the LULC map.
  - Scroll up in the Layers window and unselect anything above the new map.



- Here I unselected the LULC layer and collapsed the legend so we could see the tot\_c\_cur layer.
- We get a slightly ugly map by default.
- Let's pretty-it-up.
  - Double click on the layer-name in the Layers window.

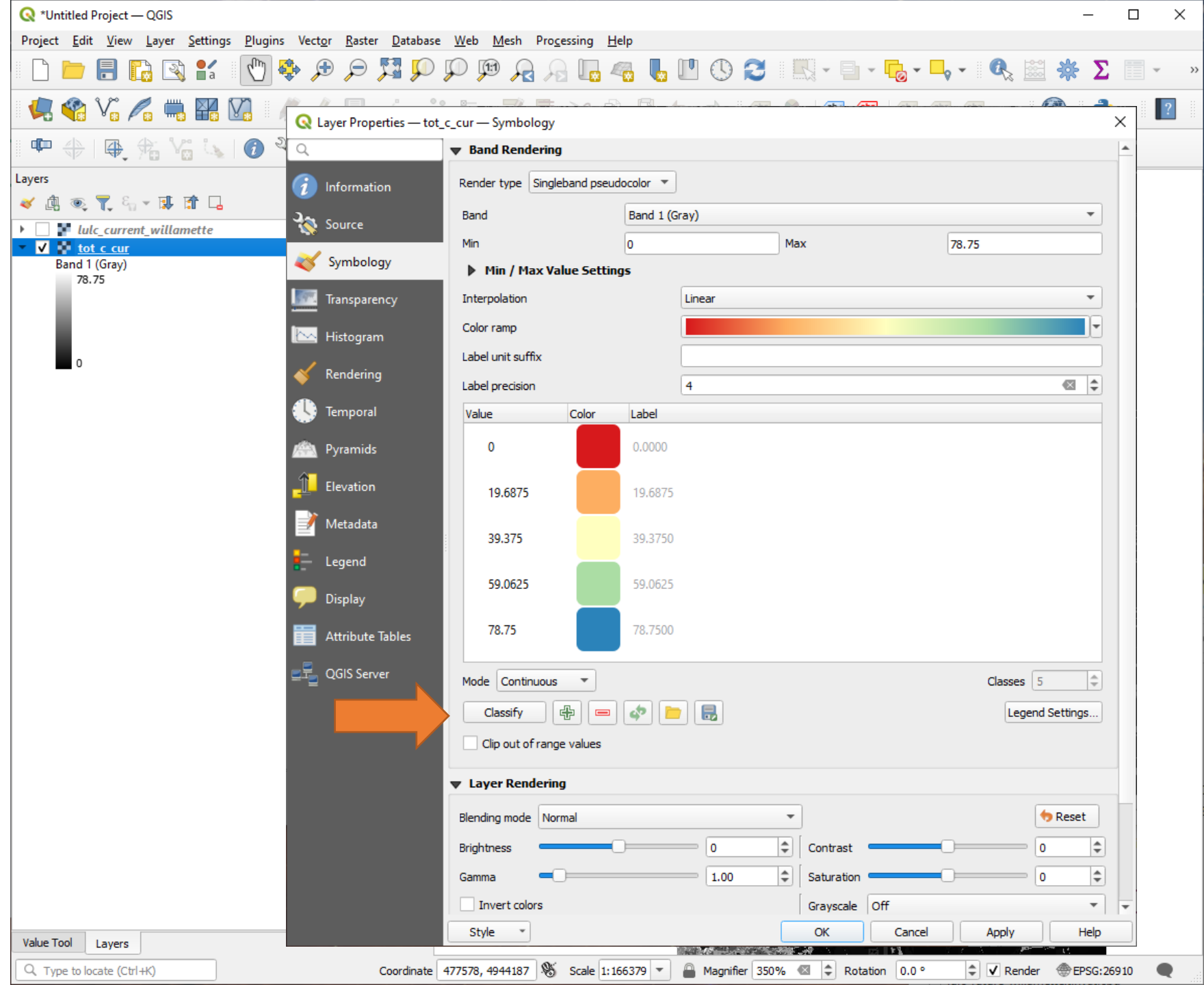


- Here I unselected the LULC layer and collapsed the legend so we could see the tot\_c\_cur layer.
- We get a slightly ugly map by default.
- Let's pretty-it-up.
  - Double click on the layer-name in the Layers window.
  - Then click the Symbology tab.

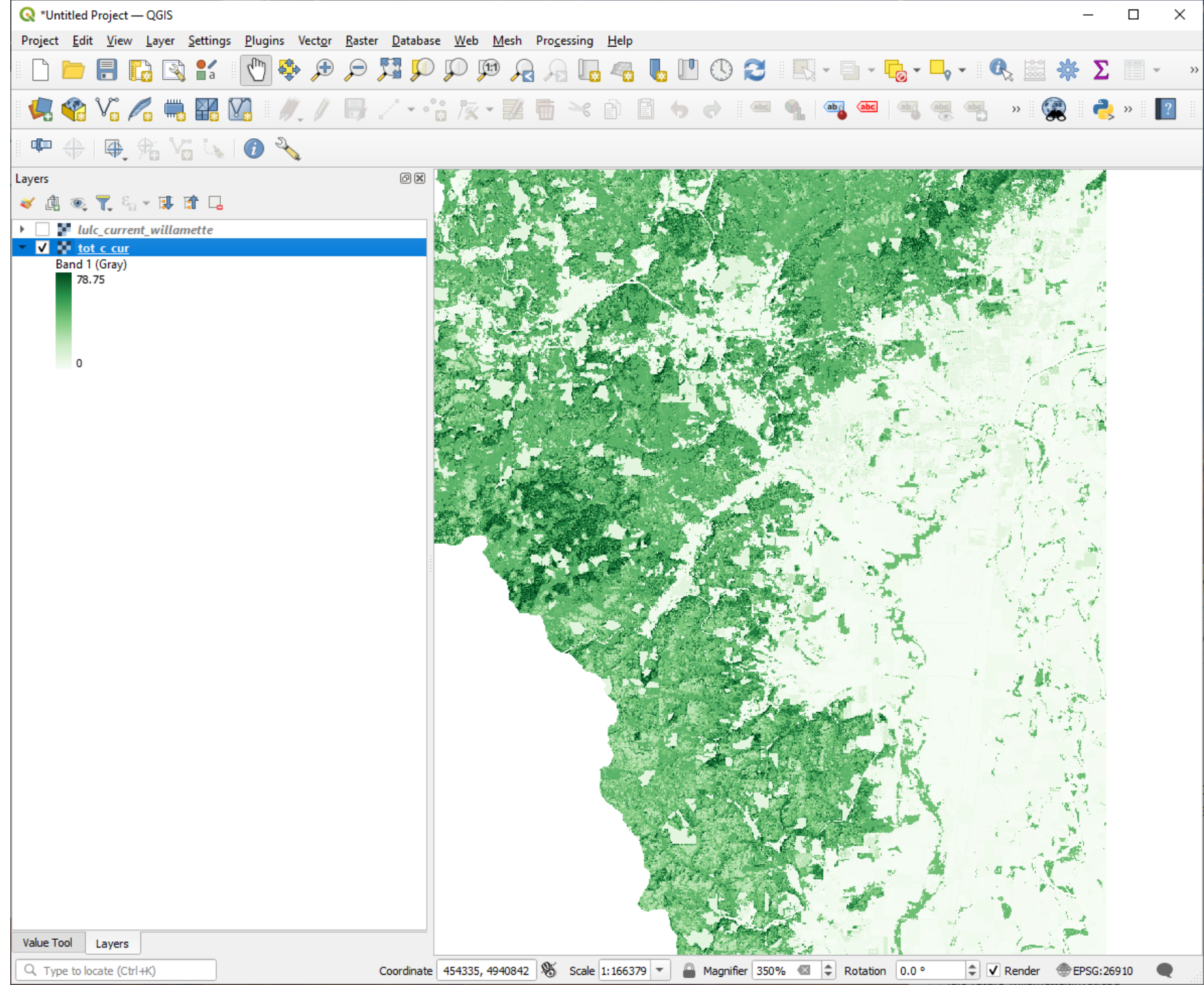




- For Render type, select Singleband pseudocolor.
- Press the Classify button.
- It will suggest some new colors and new break-points for the colorbar.
- More colorful, but still not pretty enough. Change the Color ramp option until you get something nice.
- Hit “Ok.”



- I chose green.
  - I like green.
- Now it is easier to interpret.
  - Discussion question: Based on carbon storage, where (roughly speaking) would it be most damaging to Climate Change to develop the land into agriculture? Why?



# Exercise (and time for me to check that everyone's computer is setup correctly)

- Question 1: Rerun the Carbon model, but this time calculate carbon sequestration.
  - This will use `lulc_future_willamette.tif`
  - Assume the year for the current LULC map was 2023 and the future LULC was 2050.
  - Assume that the price of Carbon is \$187 (based on the \$51 per ton of Carbon Dioxide that the Biden administration uses).
  - Assume a discount rate of 0.03
  - Assume an Annual Price Change of 0
  - What is the total change in carbon between these time periods?
- Optional Question 2: Suppose that the future LULC map represents a policy of allowing logging in the area. Suppose that the value (net present value) of the timber is \$50 million dollars. Use the information you've generated to make an argument that you could send to a legislator on whether or not this logging policy should be accepted.
- Hint: look for a `report.html` file that is generated in your Workspace directory.

# What did we learn?

- InVEST is useful because we can **Quantify Tradeoffs**.
  - This is useful for policy makers to identify good policy.
- Important point: If we had not calculated the value of the carbon, the Cost-Benefit analysis would still have been run.
  - It just would have assigned a value of \$0 to the lost carbon storage.

# Extensions and improvements

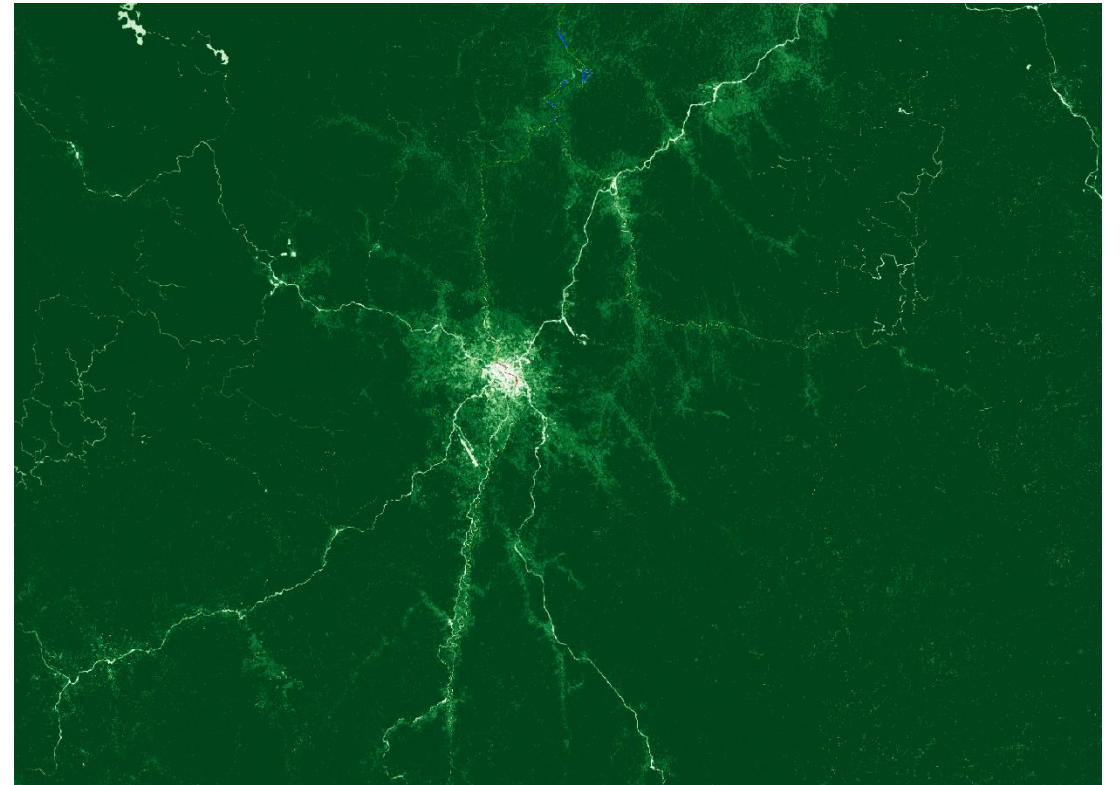
- The Edge-Effects Carbon model
- The carbon model from Global InVEST
- Machine-learning approaches to improve carbon estimates

# Forest edge effects carbon model

- Accounts for forest carbon stock degradation due to the creation of forest edges.
- Extrapolates literature on the relationship between carbon storage and distance from forest edge to calculate edge effects in carbon storage
  - Combines these estimates with carbon inventory data to construct the overall carbon map.
- Identifies where there is “missing carbon”

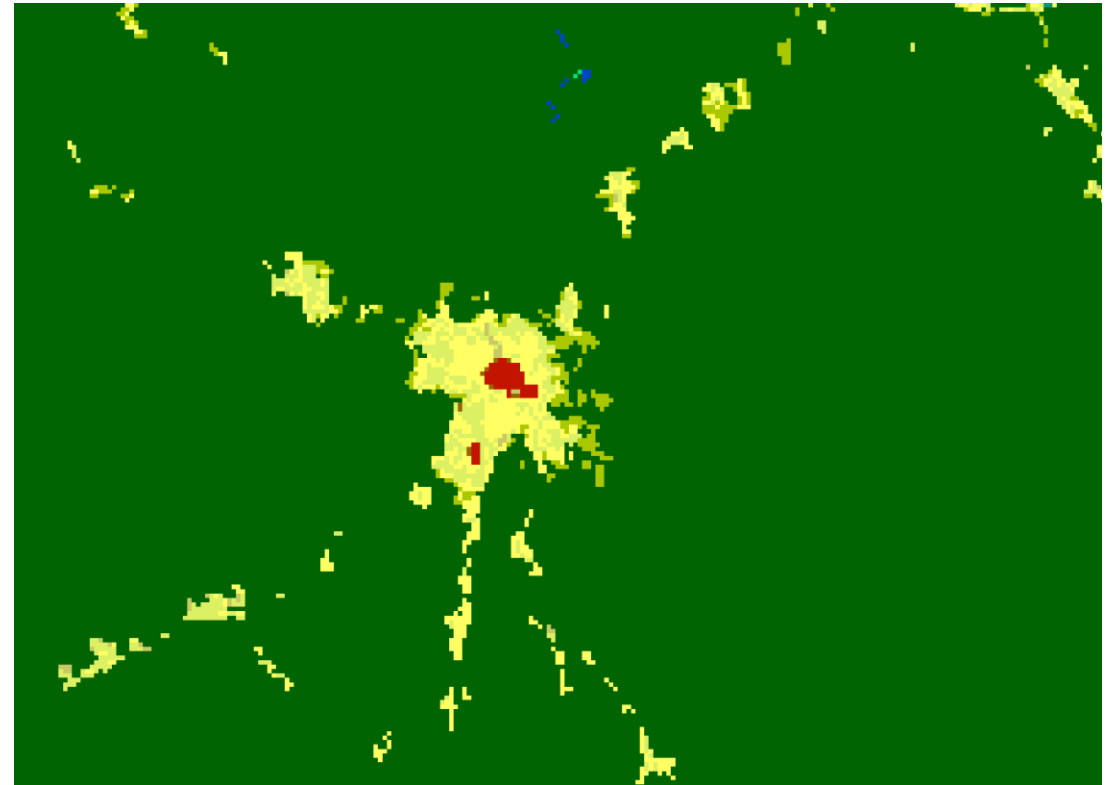
# Edge effects around a city

- Example of potential complexity in the carbon spatial relationship we could address:
  - There's an obvious ring of less carbon near the city. If those areas had the same LULC class as areas further out, there is a clear edge effect.
  - What parameters best predict this lower value in the intermediate ring?



# Edge effects around a city

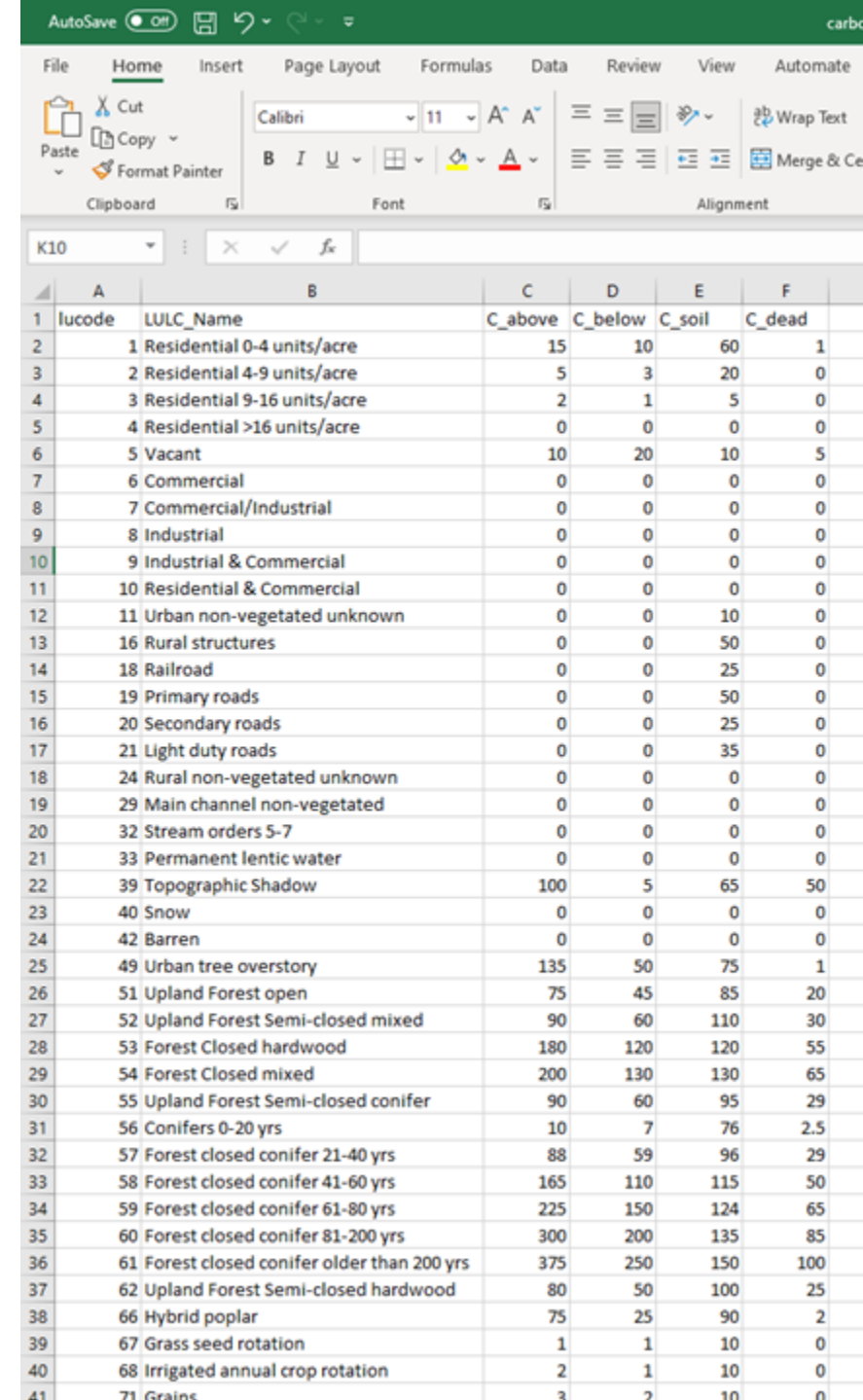
- Example of potential complexity in the carbon spatial relationship we could address:
  - There's an obvious ring of less carbon near the city. If those areas had the same LULC class as areas further out, there is a clear edge effect.
  - What parameters best predict this lower value in the intermediate ring?





# The “Global InVEST” carbon model

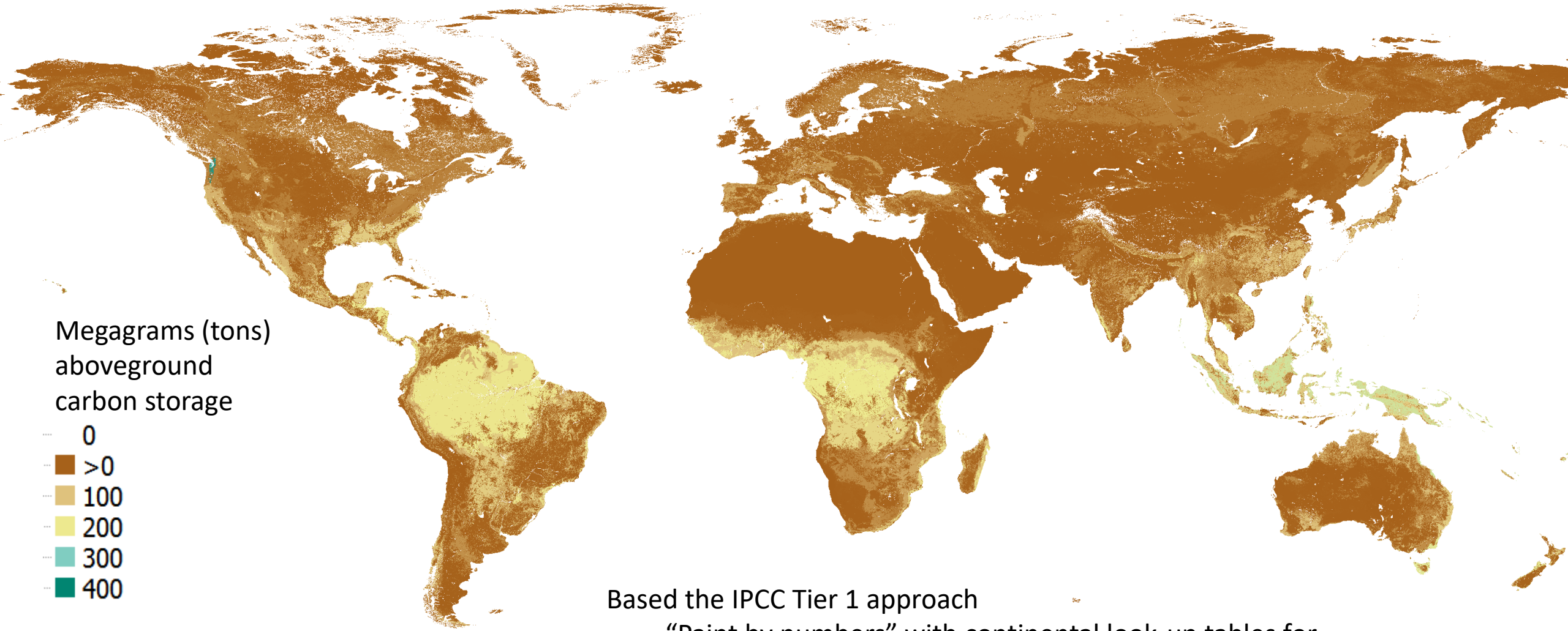
- The default carbon model is parameterized by a biophysical table.
  - Ideally drawn from local studies
  - Often falls back to the “IPCC Tier 1 carbon methodology” (Ruesch and Gibbs 2008)
    - This was a comprehensive review of the field studies that directly measured carbon
- The values in these tables are different in each ecofloristic regions, frontier forests, and continents
  - In reality, *most* areas would require 2 or more lookup tables
- The Global InVEST Carbon Model instead combines all of the different biophysical tables for all carbon zones and then recategorizes global LULC maps based on which zone they are in.



The image shows a screenshot of an Excel spreadsheet with a biophysical table. The table has columns for LULC codes, LULC names, and four carbon storage parameters: C\_above, C\_below, C\_soil, and C\_dead. The rows list various land use categories such as Residential, Commercial, Industrial, and Forest types.

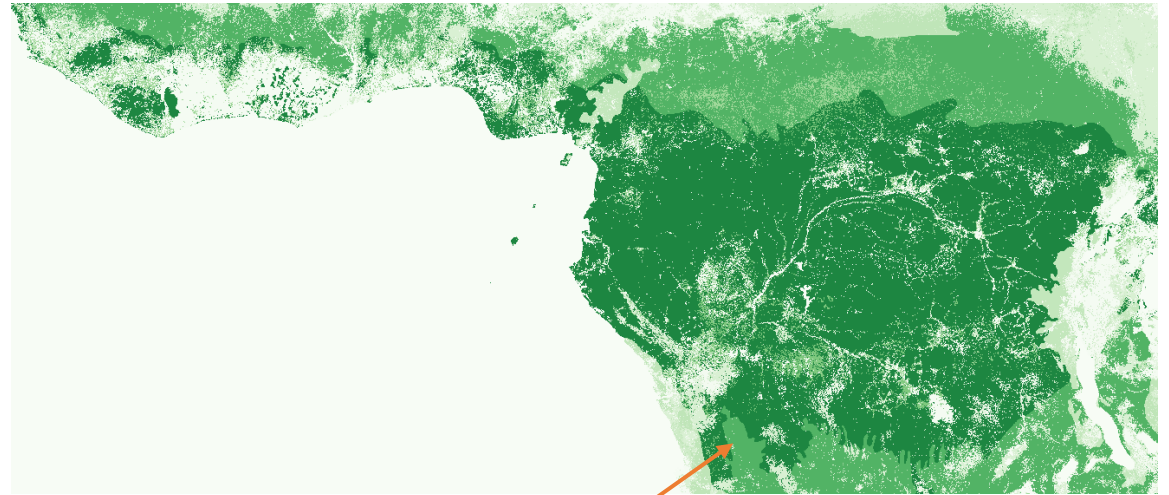
	A	B	C	D	E	F
1	lucode	LULC_Name	C_above	C_below	C_soil	C_dead
2	1	Residential 0-4 units/acre	15	10	60	1
3	2	Residential 4-9 units/acre	5	3	20	0
4	3	Residential 9-16 units/acre	2	1	5	0
5	4	Residential >16 units/acre	0	0	0	0
6	5	Vacant	10	20	10	5
7	6	Commercial	0	0	0	0
8	7	Commercial/Industrial	0	0	0	0
9	8	Industrial	0	0	0	0
10	9	Industrial & Commercial	0	0	0	0
11	10	Residential & Commercial	0	0	0	0
12	11	Urban non-vegetated unknown	0	0	10	0
13	16	Rural structures	0	0	50	0
14	18	Railroad	0	0	25	0
15	19	Primary roads	0	0	50	0
16	20	Secondary roads	0	0	25	0
17	21	Light duty roads	0	0	35	0
18	24	Rural non-vegetated unknown	0	0	0	0
19	29	Main channel non-vegetated	0	0	0	0
20	32	Stream orders 5-7	0	0	0	0
21	33	Permanent lentic water	0	0	0	0
22	39	Topographic Shadow	100	5	65	50
23	40	Snow	0	0	0	0
24	42	Barren	0	0	0	0
25	49	Urban tree overstory	135	50	75	1
26	51	Upland Forest open	75	45	85	20
27	52	Upland Forest Semi-closed mixed	90	60	110	30
28	53	Forest Closed hardwood	180	120	120	55
29	54	Forest Closed mixed	200	130	130	65
30	55	Upland Forest Semi-closed conifer	90	60	95	29
31	56	Conifers 0-20 yrs	10	7	76	2.5
32	57	Forest closed conifer 21-40 yrs	88	59	96	29
33	58	Forest closed conifer 41-60 yrs	165	110	115	50
34	59	Forest closed conifer 61-80 yrs	225	150	124	65
35	60	Forest closed conifer 81-200 yrs	300	200	135	85
36	61	Forest closed conifer older than 200 yrs	375	250	150	100
37	62	Upland Forest Semi-closed hardwood	80	50	100	25
38	66	Hybrid poplar	75	25	90	2
39	67	Grass seed rotation	1	1	10	0
40	68	Irrigated annual crop rotation	2	1	10	0
41	71	Grains	3	2	10	0

# Ruesch and Gibbs 2008 (IPCC Tier 1)



Based the IPCC Tier 1 approach  
“Paint by numbers” with continental look-up tables for  
different Land Use, Land Cover classes

InVEST Carbon Model is essentially a simplified version of the IPCC method



- Table values are heavily dependent on “Ecofloristic Zone”

# First paper figure

- Lowest hanging fruit: creates projections that are accurate in aggregate
- SSE (Sum of Squared Errors) is about 3x higher in IPCC than Model 1

