**Supplementary materials**

1. **Code used for analysis**

All the code used for analysis is available at the project GitHub found here: https://github.com/SamValman/Public\_RiverTwin

This repository also includes the model runs which were carried out in the research and the training graphs which correspond to these model runs.

**2.0 Satellite imagery used in this study**

Table. 1. List of images used as test and training data in this study These data cannot be supplied due to their proprietary nature. However, the images can be downloaded using the information provided here. A quota of free Planet imagery is available for researchers should you wish to download these images (<https://www.planet.com/markets/education-and-research>).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| River Name | country | Biome | Training/test | Date acquired | Planet Image ID |
| Amazon | Brazil | Tropical Moist Broadleaf forest | Train | 2022-07-06 | 20220706\_125524\_75\_2445 |
| Amazon | Brazil | Tropical Moist Broadleaf forest | Train | 2022-07-16 | 20220716\_131542\_78\_2464 |
| Amazon | Brazil | Tropical Moist Broadleaf forest | Test | 2021-11-05 | 20211105\_111447\_1054 |
| Xi | China | Tropical Moist Broadleaf forest | Train | 2022-04-09 | 20220409\_030306\_34\_227c |
| Xi | China | Tropical Moist Broadleaf forest | Train | 2021-01-19 | 20210119\_023111\_86\_227e |
| Xi | China | Tropical Moist Broadleaf forest | Test | 2021-12-07 | 20211207\_022020\_30\_2453 |
| Betsiboka | Madagascar | Tropical Moist Broadleaf forest | Train | 2022-06-17 | 20220617\_064055\_64\_24a4 |
| Betsiboka | Madagascar | Tropical Moist Broadleaf forest | Train | 2021-11-11 | 20211111\_070200\_06\_240c |
| Betsiboka | Madagascar | Tropical Moist Broadleaf forest | Test | 2022-04-17 | 20220417\_064234\_00\_249e |
| Bermejo | Argentina | Tropical Dry Broadleaf forest | Train | 2022-07-25 | 20220725\_135140\_27\_24a4 |
| Bermejo | Argentina | Tropical Dry Broadleaf forest | Train | 2022-01-17 | 20220117\_132552\_66\_2431 |
| Bermejo | Argentina | Tropical Dry Broadleaf forest | Test | 2021-10-31 | 20211031\_135636\_1034 |
| Rio Grande | Bolivia | Tropical Dry Broadleaf forest | Train | 2022-07-26 | 20220726\_132712\_26\_2429 |
| Rio Grande | Bolivia | Tropical Dry Broadleaf forest | Train | 2022-02-07 | 20220207\_133047\_86\_2434 |
| Rio Grande | Bolivia | Tropical Dry Broadleaf forest | Test | 2021-10-21 | 20211021\_133611\_20\_242d |
| Narmada | India | Tropical Dry Broadleaf forest | Train | 2022-06-23 | 20220623\_051040\_51\_2477 |
| Narmada | India | Tropical Dry Broadleaf forest | Train | 2022-04-05 | 20220405\_044004\_89\_2429 |
| Narmada | India | Tropical Dry Broadleaf forest | Test | 2021-12-20 | 20211220\_052711\_57\_227b |
| San Miguel | Bolivia | Tropical Dry Broadleaf forest | Test | 2022-07-26 | 20220726\_132656\_20\_2429 |
| Rhine | Germany | Temperate Broadleaf forest | Train | 2022-07-22 | 20220722\_100205\_98\_249b |
| Rhine | Germany | Temperate Broadleaf forest | Train | 2021-03-07 | 20210307\_095519\_0e0f |
| Rhine | Germany | Temperate Broadleaf forest | Test | 2022-07-18 | 20220718\_093952\_58\_2465 |
| Thames | UK | Temperate Broadleaf forest | Train | 2021-11-25 | 20211125\_100804\_19\_2465 |
| Thames | UK | Temperate Broadleaf forest | Train | 2022-07-17 | 20220717\_104938\_61\_227a |
| Thames | UK | Temperate Broadleaf forest | Test | 2021-03-09 | 20210309\_111845\_70\_1057 |
| Trent | UK | Temperate Broadleaf forest | Train | 2022-06-21 | 20220621\_101140\_08\_242b |
| Trent | UK | Temperate Broadleaf forest | Train | 2022-07-19 | 20220719\_101243\_08\_2451 |
| Trent | UK | Temperate Broadleaf forest | Test | 2019-09-19 | 20190919\_103841\_03\_106a |
| Columbia | USA | Temperate Coniferous forest | Train | 2017-10-16 | 20171016\_181958\_0f35 |
| Columbia | USA | Temperate Coniferous forest | Train | 2022-07-25 | 20220725\_184659\_98\_2424 |
| Columbia | USA | Temperate Coniferous forest | Test | 2022-02-11 | 20220211\_181759\_66\_2421 |
| Heilong Jiang | China/Russia border | Temperate Coniferous forest | Train | 2022-07-01 | 20220701\_014731\_26\_2455 |
| Heilong Jiang | China/Russia border | Temperate Coniferous forest | Train | 2021-08-15 | 20210815\_020257\_04\_2262 |
| Heilong Jiang | China/Russia border | Temperate Coniferous forest | Test | 2022-07-12 | 20220712\_022715\_18\_2483 |
| Heilong Jiang | China/Russia border | Temperate Coniferous forest | Test | 2022-07-14 | 20220714\_155105\_59\_2274 |
| Saint Johns | USA | Temperate Coniferous forest | Train | 2021-03-07 | 20210307\_151418\_31\_245d |
| Saint Johns | USA | Temperate Coniferous forest | Train | 2021-12-24 | 20211224\_155921\_71\_227c |
| Saint Johns | USA | Temperate Coniferous forest | Test | 2022-02-18 | 20220218\_015311\_70\_2439 |
| Mackenzie | Canada | Taiga | Train | 2022-07-07 | 20220707\_202018\_41\_2274 |
| Mackenzie | Canada | Taiga | Train | 2022-07-24 | 20220724\_194947\_23\_2482 |
| Mackenzie | Canada | Taiga | Test | 2021-09-01 | 20210901\_191800\_13\_245d |
| Slave | Canada | Taiga | Train | 2022-05-30 | 20220530\_181855\_14\_2477 |
| Slave | Canada | Taiga | Train | 2022-07-23 | 20220723\_175248\_45\_2420 |
| Slave | Canada | Taiga | Test | 2022-07-15 | 20220715\_182609\_05\_2473 |
| Thlewiaza | Canada | Taiga | Train | 2022-06-17 | 20220617\_164423\_37\_2435 |
| Thlewiaza | Canada | Taiga | Train | 2022-07-16 | 20220716\_173515\_86\_2426 |
| Thlewiaza | Canada | Taiga | Test | 2022-07-12 | 20220712\_172951\_37\_248f |
| Thlewiaza | Canada | Taiga | Test | 2022-05-27 | 20220527\_164907\_13\_2431 |
| Congo | DRC | Tropical Grasslands | Train | 20220610 | 20220610\_085239\_31\_248b |
| Congo | DRC | Tropical Grasslands | Train | 2021-04-05 | 20210405\_093343\_75\_1063 |
| Congo | DRC | Tropical Grasslands | Test | 2022-06-20 | 20220620\_082133\_49\_2453 |
| Niger | Mali | Tropical Grasslands | Train | 2022-07-19 | 20220719\_104504\_31\_2414 |
| Niger | Mali | Tropical Grasslands | Train | 2022-01-30 | 20220130\_100330\_57\_2458 |
| Niger | Mali | Tropical Grasslands | Test | 2022-06-24 | 20220624\_104805\_35\_2414 |
| Victoria | Australia | Tropical Grasslands | Train | 2022-07-23 | 20220723\_010321\_62\_2231 |
| Victoria | Australia | Tropical Grasslands | Train | 2021-12-29 | 20211229\_004331\_22\_2458 |
| Victoria | Australia | Tropical Grasslands | Test | 2021-12-30 | 20211230\_012938\_55\_2405 |
| Murray | Australia | Temperate Grasslands | Train | 2022-07-06 | 20220706\_233834\_92\_2435 |
| Murray | Australia | Temperate Grasslands | Train | 2022-07-16 | 20220716\_001310\_54\_247b |
| Murray | Australia | Temperate Grasslands | Test | 2022-02-23 | 20220223\_001223\_1035 |
| Volga | Russia | Temperate Grasslands | Train | 2022-07-11 | 20220711\_073248\_94\_248c |
| Volga | Russia | Temperate Grasslands | Train | 2022-04-08 | 20220408\_071508\_16\_2251 |
| Volga | Russia | Temperate Grasslands | Test | 2022-07-12 | 20220712\_070053\_61\_2434 |
| Rio Negro | Argentina | Temperate Grasslands | Train | 2022-07-10 | 20220710\_133544\_12\_2262 |
| Rio Negro | Argentina | Temperate Grasslands | Train | 2022-07-11 | 20220711\_135404\_73\_2479 |
| Rio Negro | Argentina | Temperate Grasslands | Test | 2022-02-08 | 20220208\_131957\_43\_2430 |
| Nile | Egypt | Flooded Grasslands | Train | 2022-07-24 | 20220724\_073602\_36\_245c |
| Nile | Egypt | Flooded Grasslands | Train | 2022-03-31 | 20220331\_075137\_37\_2262 |
| Nile | Egypt | Flooded Grasslands | Test | 2022-04-05 | 20220405\_080717\_65\_2478 |
| Bahr El Jebel | South Sudan | Flooded Grasslands | Train | 2022-07-06 | 20220706\_082021\_71\_2426 |
| Bahr El Jebel | South Sudan | Flooded Grasslands | Train | 2021-10-24 | 20211024\_073405\_47\_2451 |
| Bahr El Jebel | South Sudan | Flooded Grasslands | Test | 2021-12-23 | 20211223\_081903\_29\_227c |
| Tigris | Iraq | Flooded Grasslands | Train | 2022-07-16 | 20220716\_073503\_17\_2402 |
| Tigris | Iraq | Flooded Grasslands | Train | 2022-02-08 | 20220208\_073230\_97\_2307 |
| Tigris | Iraq | Flooded Grasslands | Test | 2022-03-29 | 20220329\_064915\_23\_242d |
| Tongtian | China | Montane Grasslands | Train | 2022-07-20 | 20220720\_032418\_16\_2427 |
| Tongtian | China | Montane Grasslands | Train | 2022-04-08 | 20220408\_035750\_13\_2477 |
| Tongtian | China | Montane Grasslands | Test | 2022-07-20 | 20220720\_032551\_72\_2430 |
| Ahuriri | New Zealand | Montane Grasslands | Train | 2022-01-15 | 20220115\_215234\_09\_2262 |
| Ahuriri | New Zealand | Montane Grasslands | Train | 2021-11-08 | 20211108\_223115\_40\_240a |
| Ahuriri | New Zealand | Montane Grasslands | Test | 2022-04-14 | 20220414\_214014\_57\_2458 |
| Ahuriri | New Zealand | Montane Grasslands | Test | 2022-07-25 | 20220725\_075546\_96\_247e |
| Vaal | South Africa | Montane Grasslands | Train | 2022-02-22 | 20220222\_075850\_36\_249c |
| Vaal | South Africa | Montane Grasslands | Train | 2021-11-19 | 20211119\_072949\_13\_241f |
| Vaal | South Africa | Montane Grasslands | Test | 2021-12-10 | 20211210\_081521\_04\_2416 |
| Vaal | South Africa | Montane Grasslands | Test | 2022-05-02 | 20220502\_213534\_99\_2435 |
| Pyasina | Russia | Tundra | Train | 2022-07-13 | 20220713\_045717\_09\_2427 |
| Pyasina | Russia | Tundra | Train | 2022-07-15 | 20220715\_142742\_00\_2485 |
| Pyasina | Russia | Tundra | Test | 2022-07-17 | 20220717\_052622\_28\_2458 |
| Popigay | Russia | Tundra | Train | 2021-07-06 | 20210706\_224530\_104a |
| Popigay | Russia | Tundra | Train | 2021-08-03 | 20210803\_035151\_34\_2465 |
| Popigay | Russia | Tundra | Test | 2022-06-23 | 20220623\_035535\_81\_241f |
| Burnside | Canada | Tundra | Train | 2022-07-11 | 20220711\_182806\_57\_2483 |
| Burnside | Canada | Tundra | Train | 2022-07-10 | 20220710\_181416\_84\_2251 |
| Burnside | Canada | Tundra | Test | 2020-06-19 | 20200619\_183133\_1009 |
| Ebro | Spain | Mediterranean | Train | 2022-04-18 | 20220418\_103813\_73\_2403 |
| Ebro | Spain | Mediterranean | Train | 2021-10-24 | 20211024\_111931\_21\_105d |
| Ebro | Spain | Mediterranean | Test | 2022-07-26 | 20220726\_103902\_88\_2402 |
| Tevere | Italy | Mediterranean | Train | 2022-07-24 | 20220724\_092104\_12\_2276 |
| Tevere | Italy | Mediterranean | Train | 2022-01-29 | 20220129\_093254\_1011 |
| Tevere | Italy | Mediterranean | Test | 2022-06-30 | 20220630\_093746\_78\_2488 |
| Ceyhan | Turkey | Mediterranean | Train | 2022-07-26 | 20220726\_080140\_19\_2484 |
| Ceyhan | Turkey | Mediterranean | Train | 2021-12-24 | 20211224\_072800\_71\_2420 |
| Ceyhan | Turkey | Mediterranean | Test | 2021-10-10 | 20211010\_081830\_73\_2254 |
| Amu Darya | Uzbekistan/ Turkmenistan | Desert | Train | 2022-07-25 | 20220725\_053752\_55\_241e |
| Amu Darya | Uzbekistan/ Turkmenistan | Desert | Train | 2022-03-03 | 20220303\_061045\_47\_2495 |
| Amu Darya | Uzbekistan/ Turkmenistan | Desert | Test | 2022-04-12 | 20220412\_053946\_15\_2457 |
| Syr Darya | Kazakhstan | Desert | Train | 2022-07-26 | 20220726\_054111\_09\_2435 |
| Syr Darya | Kazakhstan | Desert | Train | 2022-05-22 | 20220522\_061420\_42\_24a5 |
| Syr Darya | Kazakhstan | Desert | Test | 2021-11-26 | 20211126\_063258\_42\_227c |
| Syr Darya | Kazakhstan | Desert | Test | 2022-02-21 | 20220221\_054227\_30\_245d |
| Rio Grande | Mexico | Desert | Train | 2022-07-06 | 20220706\_162417\_43\_2430 |
| Rio Grande | Mexico | Desert | Train | 2022-03-29 | 20220329\_171715\_45\_2407 |
| Rio Grande | Mexico | Desert | Test | 2022-02-17 | 20220217\_163226\_45\_2435 |
| Fine tuning images | | | | | |
| Ottawa | Canada | Taiga | Train | 2022-10-23 | 20221023\_152737\_75\_247b |
| Ottawa | Canada | Taiga | Train | 2022-09-08 | 20220908\_153330\_63\_24a4 |
| Ottawa | Canada | Taiga | Train | 2022-04-30 | 20220430\_153703\_03\_2478 |
| Ottawa | Canada | Taiga | Train | 2022-10-11 | 20221011\_153825\_10\_2478 |
| Ottawa | Canada | Taiga | Train | 2022-06-18 | 20220618\_154454\_04\_247b |
| Ottawa | Canada | Taiga | Test | 2022-12-08 | 20221208\_154626\_85\_2413 |
| Ottawa | Canada | Taiga | Test | 2022-11-03 | 20221103\_152940\_35\_247c |
| Ottawa | Canada | Taiga | Test | 2022-08-06 | 20220806\_153204\_93\_2477 |
| Ottawa | Canada | Taiga | Test | 2022-07-22 | 20220722\_150150\_58\_2420 |
| Ottawa | Canada | Taiga | Test | 2022-06-25 | 20220625\_153845\_41\_2495 |
| Ottawa | Canada | Taiga | Test | 2022-05-13 | 20220513\_153508\_86\_247c |
| Ottawa | Canada | Taiga | Test | 2022-10-29 | 20221029\_153811\_44\_2461 |
| Ottawa | Canada | Taiga | Test | 2022-10-11 | 20221011\_153825\_10\_2478 |
| Ottawa | Canada | Taiga | Test | 2022-08-10 | 20220810\_155545\_45\_2426 |
| Ottawa | Canada | Taiga | Test | 2022-05-18 | 20220518\_154513\_99\_2473 |
| Ottawa | Canada | Taiga | Test | 2022-11-08 | 20221108\_154357\_63\_247c |
| Ottawa | Canada | Taiga | Test | 2022-10-24 | 20221024\_152838\_39\_2251 |
| Ottawa | Canada | Taiga | Test | 2022-10-24 | 20221024\_155832\_66\_241c |
| Ottawa | Canada | Taiga | Test | 2022-11-08 | 20221108\_154357\_63\_247c |
| Ottawa | Canada | Taiga | Test | 2022-10-30 | 20221030\_154953\_91\_247a |

**3.0 Examples of label data and training curves**

A purple and black object with green and black designs

Description automatically generated with medium confidence

Figure. 1: Examples of the simplicity of training data created for this study. By contrast the training data for the FCN was required to be at the pixel level for the entire image and therefore required the use of a semi-automatic classifier. This image took between 3-5 minutes to classify in this way.

**A group of graphs showing different types of data

Description automatically generated with medium confidence**

Figure. 2: Loss curves for the three main CSC models run. The training was stopped early for these models. It is likely the causes of this high variation in validation response is because of the very simple binary classification task applied and the relatively limited training set. Regardless these models were sufficient for the task at hand and provided good inputs for the ANN section of the CSC models.

**4.0 Images which performed poorly in this study**

A picture containing qr code

Description automatically generated

Figure. 3: The nine isolated images that make up some of the worst performing images in the study. These are the raw satellite images.

Shape, square

Description automatically generated

Figure. 4: The predictions of these worst images made by the M20 model. There are clear issues in these images, and some are not predicted at all. However, there are encouraging signs that many of these images can be improved upon with additional fine tuning.

A picture containing text

Description automatically generated

Figure. 5: Some more difficult images which we expected the model to struggle with, were downloaded to test the limits of the model. These included: shadow, increased snow and clear sensor issues.

A satellite image of a river

Description automatically generated

Figure. 6: The two fine tuning images that did not improve with fine tuning. Image a has some potentially shallow water or error that is only visible in the RGB bands. Whereas image b has a dam and baffle system which may be poorly represented in the training data.

A black and white image of a broken window

Description automatically generated with medium confidence

Figure. 7: The only images predicted by the Tiramisu FCN that achieved visible river channels. a)Rio Negro, temperate grasslands. b) Victoria, tropical grasslands. c)Bermejo, tropical dry broadleaf. d) Betsiboka, tropical moist broadleaf.