Workflow, data and computer codes for:
Messager ML, Olden JD. 2018

Individual-based models forecast the spread and inform the management of an emerging riverine invader.

Diversity & Distribution | https://doi.org/10.1111/ddi.12829

Introduction

This document describes the data and computer codes used to reproduce the results and figures presented in Messager & Olden (2018). A fair bit of data cleaning, processing, and mapping was performed by hand in Excel, shiny apps, and ArcGIS for this study so the files cannot automatically reproduce all the outputs presented in the study. The original folder structure was conserved to correspond to paths in computer codes and may thus seem redundant. Please contact messamat@uw.edu for help with troubleshooting, additional information, and to point out errors in the documentation or data. Also find updated computer codes at: https://github.com/messamat/SEIBM_rustycrayfish

For additional help for modelling with HexSim, refer to:

- Schumaker, N.H. & Brookes, A. (2018) HexSim: a modeling environment for ecology and conservation Landscape Ecology, 33, 197-211. https://doi.org/10.1007/s10980-017-0605-9
- http://www.hexsim.net/
- https://groups.google.com/forum/#!forum/hexsim

Directory content

MessagerOlden2018_SEIBM_rustycrayfish/bin: compiled programs

- *bin/HexSim Aquatic Mar 07 2016.zipdata*: HexSim software used for analysis (beta-version of HexSim 4.0)
- *bin/Help.zip:* Miscellaneous files explaining how to use HexSim networks + old user guide website

MessagerOlden2018_SEIBM_rustycrayfish/data: original spatial and field data (including manually produced intermediate results)

- *data/Crayfish_occurrence*: Survey data of rusty crayfish distribution in 2005 and 2010/11
    - *data/Crayfish_occurrence/Adams:* 2005 survey data provided by Jeff Adams (Washington Sea Grant), used in Olden, J. D., Adams, J. W., & Larson, E. R. (2009). First record of Orconectes rusticus (Girard, 1852) (Decapoda, Cambaridae) west of the Great Continental Divide in North America. Crustaceana, 82, 1347–1351. https://doi.org/10.1163/156854009X448934

    - *data/Crayfish_occurrence/Sorenson_Olden:* 2010/11 survey data provided by Keith Sorenson and Julian Olden , used in Sorenson, K. L., Bollens, S., & Counihan, T. (2012). Rapid range expansion of rusty crayfish Orconectes rusticus (Girard, 1852) in the John Day River, Oregon, USA. Aquatic Invasions, 7, 291–294. https://doi.org/10.3391/ai.2012.7.2.017
- *data/Field_work_data*: August 2016 survey data collected as part of this project
    - *CPUE_OR.csv*: crayfish catch-per-unit-effort (CPUE) at each site
    - *CPUE_OR_stat.csv:* mean and standard deviation of crayfish catch-per-unit-effort at each site
    - *Sampled_sites_gps_streamdist_edit.csv:* distance from JDR mouth of each site — used in analysis workflow
    - *Sampled_sites_notes.shp*: location of all sampling sites
    - *Sampled_sites_notes_CPUE_kick_join.shp:* location of sampling sites with kick-netting CPUE
    - *Sampled_sites_notes_noCPUEdata.shp:* location of sampling sites with no CPUE data
    - *Sampled_sites_notes_network20_join.csv:* sampling sites with HexSim network identifier — used in analysis workflow
    - *Site_info.csv*: general field data for each site
    - *Wet-Dry mapping.xlsx:* results from cursory wet-dry survey of creeks crossing Highway 19 and draining to the mainstem of the John Day River performed on 08/22/2016
- *data/ISEMP*: data used for modelling water temperature for each reach of the HexSim network
    - *data/ISEMP/collated*: spatial and attribute data for all water temperature sensors. Produced with src/ LST_download_and_format.py, src/ ISEMP_format_9.R, and ISEMP_MODIS_TempOutput_3.R — used in analysis workflow
    - *data/ISEMP/Daily_mean_data*: collated and manually cleaned water temperature data — used in analysis workflow
    - *data/ISEMP/HexSim_ready:* temperature data used in HexSim modelling (rid column corresponds to HexSim network identifier)
    - *data/ISEMP/ISEMP_data:* original raw water temperature data
    - *data/ISEMP/NOAA_weatherstation_data:* original raw air temperature data
    - *data/ISEMP/Temp_graphs:* time series of water temperature for each sensor.
    - *data/IMSEP/WaterTemp_JDR_models.xlsx:* description and summary statistics for each tested model of water temperature (See Table S2.1 in Supplementary Information)
- *data/width_model:* data used for modelling river width for each reach of the HexSim network:

- *data/width_model/edges_1_withfields.csv:* network attribute data used in modelling weeted width in src/width_calc_20180901.R
- *data/width_model/Network_points_select_merge.shp:* centroids of each reach in the HexSim network used to measured wetted width, Width_1, Width_2, and Width_3 fields contain the wetted width measured from ArcGIS satellite imagery.
- *data/width_model/Network_points_select_width.csv:* attribute data used in modelling wetted width in src/ width_calc_20180901.R
- *data/width_model/Network_points_select_width_Jan21st2017.csv:* attribute data used in modelling wetted width in src/ width_calc_20180901.R

MessagerOlden2018_SEIBM_rustycrayfish/src: source computer code and HexSim model structure and outputs

- *src/Crayfish_model:* HexSim analysis core directory, includes scenarios, direct HexSim outputs, and processed outputs for subsequent analysis:
  - *src/Crayfish_model/HexSim_ready_data/Network_module:* spatial and attribute data used to create HexSim network. intro_point.shp corresponds to the putative introduction site of rusty crayfish in the John Day River.
  - *src/Crayfish_model/Network_23*: Core HexSim directory — do not modify directory structure. Refer to MessagerOlden2018_SEIBM_rustycrayfish/HexSim_Parameters_sensitivity_selected_final.xlsx for scenario description. **Final scenario used in this study is Network23_test16_2025.** Refer to http://www.hexsim.net/help/overview#TOC-HexSim-Workspaces for explanation of directory structure.
  - *src/Crayfish_model/Parameters_and_outputs:* intermediate outputs for analysis of results necessary to reproduce figures. *Mapping_basemap_20_replicateoutput_5.mpk* contains a template used to produce Figures 2 and 3 (with Crayfish_model_visualization8.py).
- *src/HexSim Aquatic Mar 07 2016:* Core HexSim directory — do not modify directory structure. HexSim software with final model's project workspace (.snx file).
- *For .R and .py codes, refer to following section and in-line commenting for guidance on implementation.*

MessagerOlden2018_SEIBM_rustycrayfish/HexSim_Parameters_sensitivity_selected_final.xlsx: Summary of parameters, event configuration, and results for all scenarios developed for the calibration of the final HexSim model, sensitivity analysis, and management strategy analysis. The first row (e.g. 'Network23_16_2025_propagule2') refers to the scenario name, the corresponding HexSim XML scenario file can be found in *src/Crayfish_model/Network_23/scenarios* and the processed outputs in *src/Crayfish_model/Parameters_and_outputs/Network_23*
for all scenarios starting with 'Network23_' .

Workflow

All files referred to here can be found in /src.

1. Model river width for each reach in the HexSim network: *width_calc_20180901.R*
2. Model water temperature for each reach in the HexSim network using ISEMP water temperature sensor dataset (http://isemp.org/watersheds/john-day/):
    a. Download MODIS daily land surface temperature data for 2000-2016 and extract landscape predictors of water temperature for each water temperature sensor: *2a_LST_download_and_format.py*
    b. Clean, format, and join water temperature data and land surface temperature data (2000-2016), then develop model of water temperature data based on land surface temperature*: 2b_ISEMP_format_9.R*
    c. Format land surface temperature data and predict water temperature in each reach of the John Day River based on models developed in 2b_ISEMP_format_9.R: *2c_ISEMP_MODIS_TempOutput_3.R*
    d. Clean, format, and join water temperature data and air temperature data (1999). Then develop model of water temperature data based on air temperature. Join water temperature predictions for 1999 and 2000-2016 and output dataset ready for HexSim model: *2d_ISEMP_WeatherStations_TempOutput.R*
3. Run HexSim model: *Crayfish_model*
4. Process HexSim outputs: *4_HexSim_popoutput_visual_11.R*
5. Visualize HexSim outputs spatial (requires ArcGIS Desktop license): *5_Crayfish_model_visualization8.py*
6. Analyze spread and population size of rusty crayfish for a final model (**produce Figure 3)**: *6_Fig3_model_output_graph.R*
7. Analyze and plot cost and effects of strategies to control the population and spread of rusty crayfish (**produce Figure 5 and 6**): *7_Fig5_and_6_control_graphs_6.R*
8. Compare observed and modeled crayfish density throughout the HexSim network (**produce Figure S7.4):** *8_FigS7_4_density_comparison.R*

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Last updated: 09/01/2018