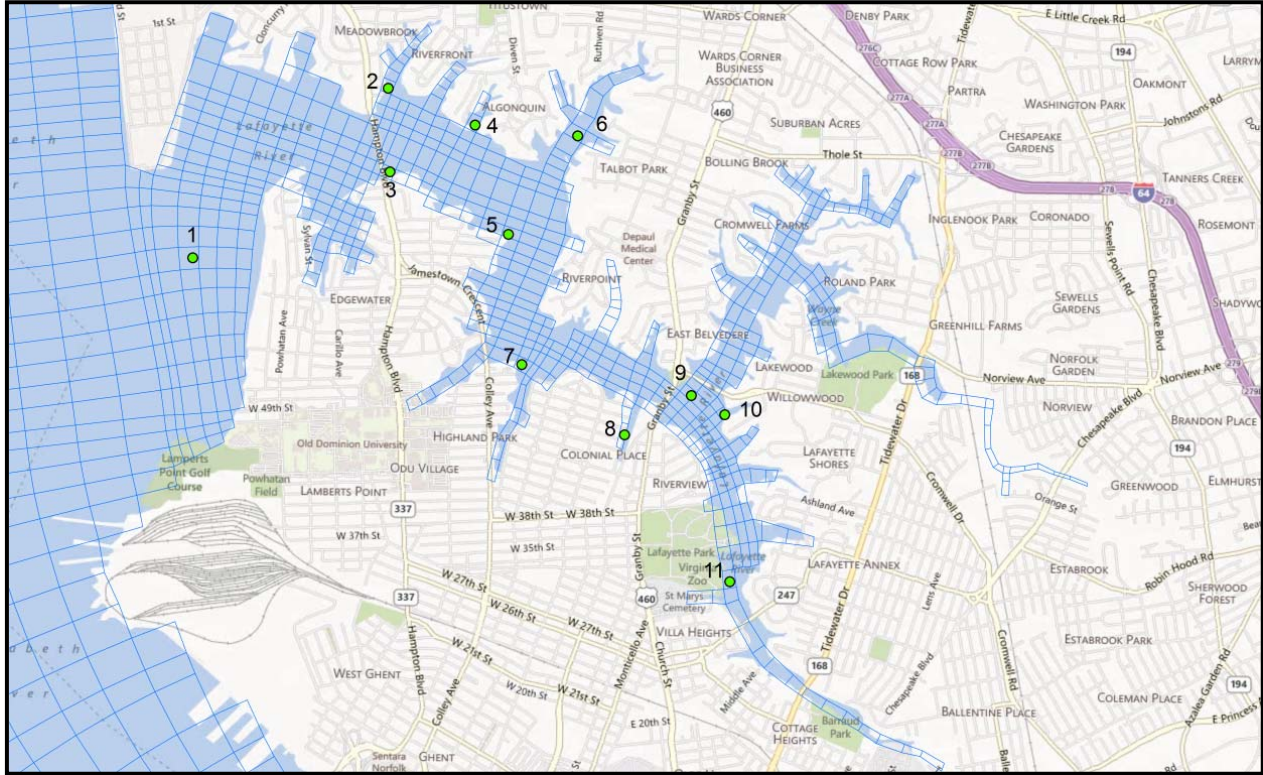


Modeling of Oyster Larval Connectivity for CBF in Support of NOAA'S Community-Based Restoration Program & Restore America's Estuaries Oyster and Reef Balls on Sanctuary Reefs in MD and VA - Phase Three



Mac Sisson and Jian Shen

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Chesapeake Bay Foundation

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Virginia Institute of Marine Science
Department of Physical Sciences
Gloucester Point, Virginia 23062

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EXECUTIVE SUMMARY

1. The overarching goal of the Chesapeake Bay Foundation (CBF) for this project has been to enhance the Chesapeake Bay's oyster population. In Virginia, CBF is working with partners to focus restoration efforts on the Lafayette River in order to bring the river's biomass and reef substrate to a threshold level that will show a systemic response in terms of enhanced spatset. Portions of their grant have funded the hydrodynamic modeling of the Lafayette River recently performed and herein reported.
2. VIMS personnel have modified its existing three-dimensional hydrodynamic model of the Lafayette/Elizabeth/James Rivers to conduct larval connectivity simulations. The model grid was revised to represent the small creeks and tributaries with the Lafayette and to run the model using multiple larval input locations selected by CBF personnel. A total of eleven (11) locations within the Lafayette were selected as larvae release sites for the simulations. These eleven simulations comprised a "set" of simulations, and there were separate sets executed for both "with local runoff" and "without local runoff" cases.
3. For both sets of simulations performed, the spatial distributions of larvae present after 21 days (including a 14-day planktonic larval phase and a 7-day settlement phase) showed that larvae have the potential to settle on these selected release sites. Because the model simulations were conducted under specific hydrodynamic conditions, any extrapolation of the results should be confirmed through field measurements in the Lafayette River.

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I. INTRODUCTION

In the summer of 2012, the Chesapeake Bay Foundation contracted with the numerical modeling group of the Virginia Institute of Marine Science to conduct a series of hydrodynamic simulations to provide information on theoretical larval dispersal in the Lafayette River.

II. DESCRIPTION OF THE HYDRODYNAMIC MODEL AND ITS SIMULATIONS

To evaluate larval dispersal in the Lafayette River, we used a 3D hydrodynamic model to conduct the model simulation. The Virginia Institute of Marine Science three-dimensional Hydrodynamic Eutrophication Model (HEM-3D) was used for the study. HEM-3D has been applied to study larval transport in the James River (Shen et al., 1999; Morse et al., 2011) and recently used to study sea-level rise in the James River (Rice et al., 2012).

The hydrodynamic portion of the HEM-3D model is the Environmental Fluid Dynamics Code (EFDC) (Hamrick, 1992; Park et al., 1995; Hamrick and Wu, 1997). EFDC resembles the widely used Princeton Ocean Model (Blumberg and Mellor, 1987) in both the physics and the computational scheme utilized. The Mellor and Yamada level 2.5 turbulence closure scheme was implemented in this model (Mellor and Yamada, 1982; Galperin et al., 1988). It uses curvilinear, orthogonal horizontal coordinates and sigma vertical coordinates to represent the physical characteristics of a water body. The model has been applied to a wide range of environmental studies in the Chesapeake Bay and other estuarine systems.

Because the dynamics of the James River heavily influence the circulations of the Elizabeth and Lafayette Rivers, the entire James and Elizabeth Rivers were simulated together. In order to simulate the Lafayette River and its associated small creeks, the James River model used previously to assess sea-level rise was refined to have a high resolution for the Lafayette River. Figures 1 and 2 show, respectively, the model grid for the James and Elizabeth Rivers and the Lafayette River. The model resolution inside the Lafayette River is about 50 - 100 m.

The major freshwater inputs to the James River model include the following USGS gages: the James River at Richmond, the Appomattox River, and the Chickahominy River. The mean flow is used for driving the James River model. The open boundary condition was forced by 5 major harmonic tidal constituents, namely M_2 , S_2 , K_1 , O_1 , and N_2 . The salinity open boundary condition was obtained from the large domain Chesapeake Bay model based on hourly salinity in the summer of 2008 (Hong and Shen, 2012). The Elizabeth River basin is dominated by urban land use. The surface runoff of the Elizabeth River depends highly on the precipitation (Morse et al., 2011). Therefore, July 2008 was used as a typical year for model simulation. The precipitation during July 2008 is about equal to the average precipitation in this area (Morse et al., 2011). The flow was estimated based on the precipitation and runoff coefficients.

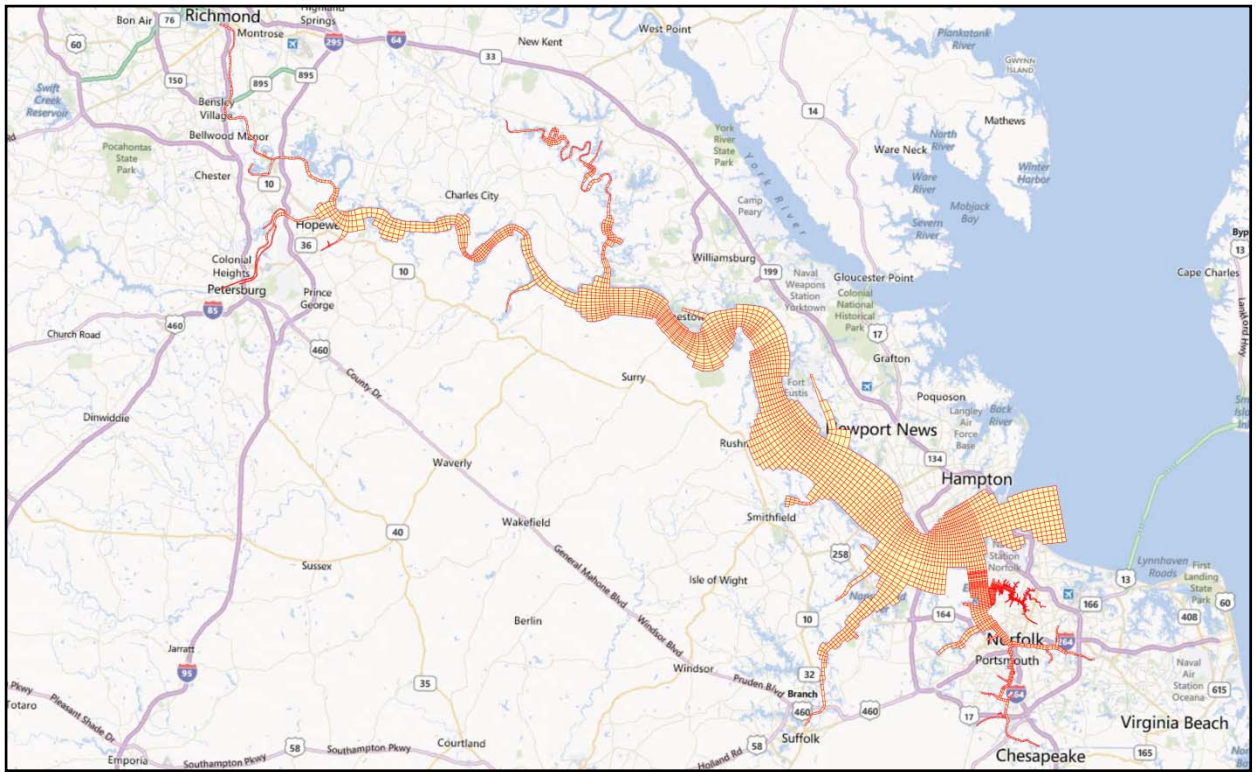


Figure 1. Numerical model grid for the James and Elizabeth Rivers.

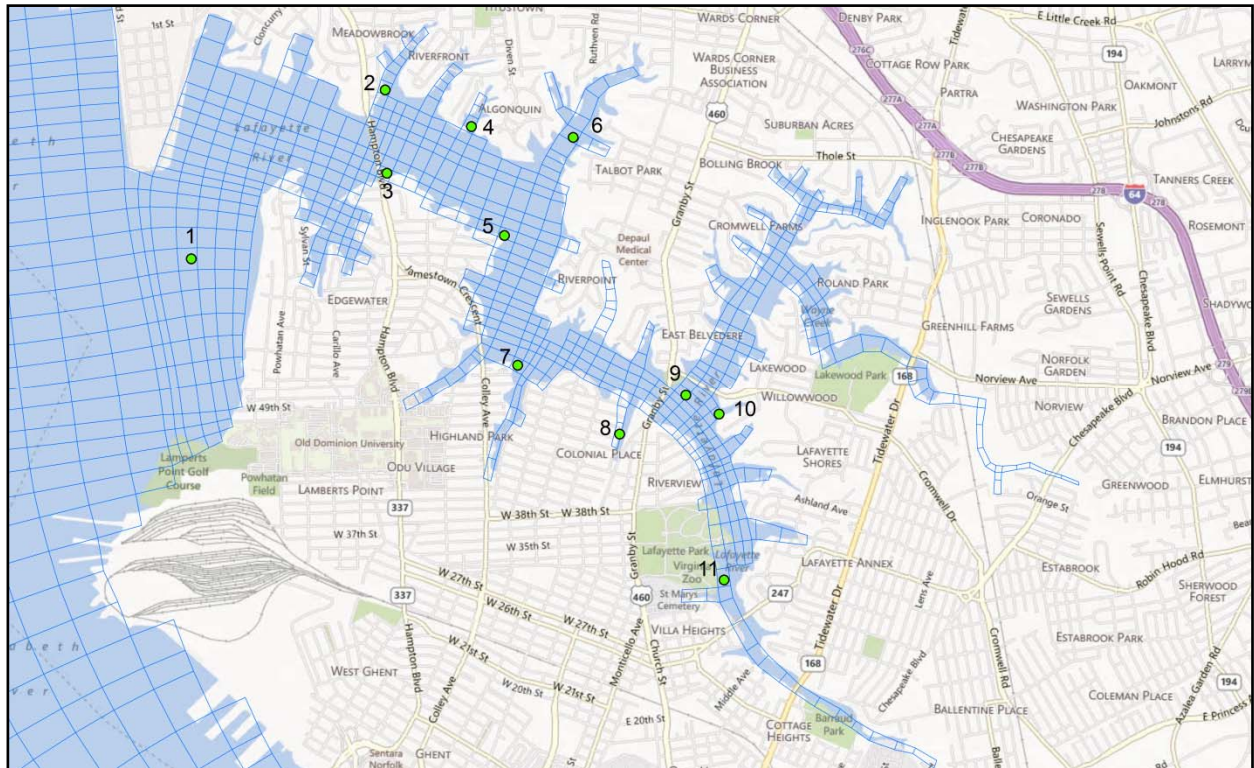


Figure 2. Zoom-in of model grid portion for the Lafayette River.

Eleven larval release locations were selected for the model simulation. Larvae were released at the bottom, and the larval mortality was set at 0.18 day^{-1} . The settling velocity is 0.18 m day^{-1} , which pertains only after the 14-day planktonic phase. The larvae are capable of swimming and the swimming depends on the stratification (North et al., 2008). If the gradient in salinity were greater than a threshold value, then the larvae (*Crassostrea virginica*) were cued to swim upward in that time step. The threshold value ΔS threshold was set as $1.0 \text{ salinity unit m}^{-1}$. Once swimming upward occurs, it is set to continue for 3 time steps. We assume 1,000,000 virtual larvae are available for each square meter area and that the reef size is 1-acre in area for each site. Therefore, a total of 4,046,873,000 larvae are released at each location. For each run, the simulation period started at Day 200 and lasted for 30 days. The settling velocity was applied 2 days after the larvae were released. Larvae could settle onto any of the 11 1-ha sites after the 14-day planktonic larval phase and during the 7-day settlement phase.

III. RESULTS

III.A. Conditions Evaluated

Two sets of model simulations were conducted. The first simulation set assumed that no runoff occurred during the simulation period. The second simulation set assumed there was runoff from the watershed. The runoff distribution is shown in Figure 3.

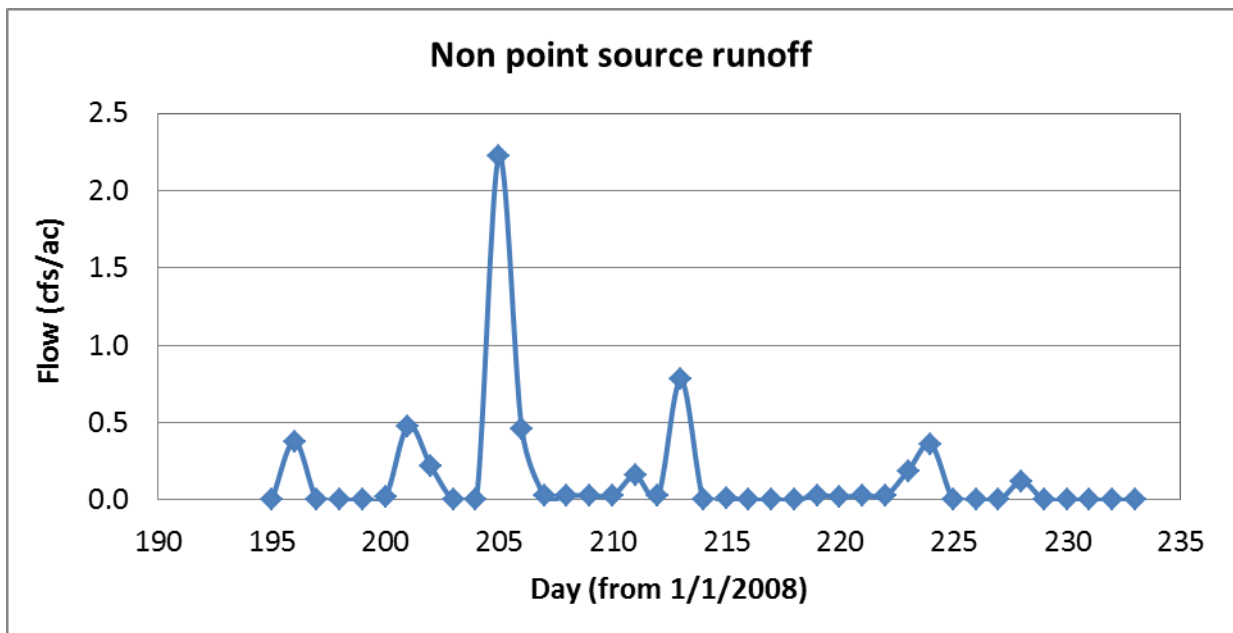


Figure 3. Non-point source runoff from the Lafayette River watershed.

III.B. Spatial Distributions of larval settlements for each release

The model simulation is initiated on Day 200 and an instantaneous release of larvae is invoked on Day 202. It is interesting to trace the rough spatial distribution over the next 3 weeks. One can display “snap-shots” of the spatial distributions of larvae at either the surface or the bottom throughout much of the Elizabeth River. These are shown clockwise from the upper left for model Days 204, 210, 216, and 222 for the surface and bottom, respectively, in Figures 4 and 5.

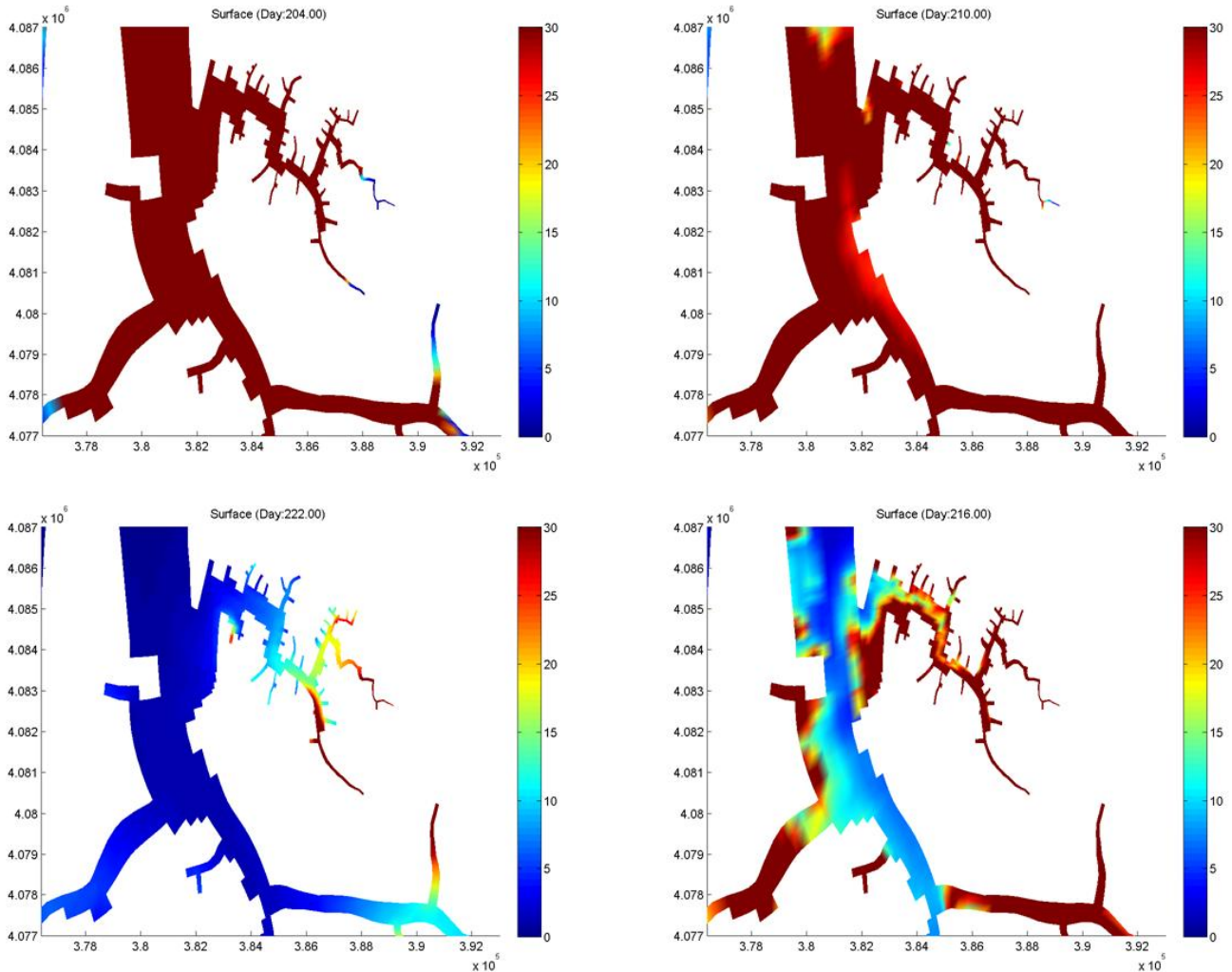


Figure 4. Larval distribution in the Elizabeth River at the surface layer for Days 204, 210, 216, and 222, after an instantaneous release at Lafayette River Location 1 (without local runoff).

In these figures, the x- and y-axis labels represent the UTM (zone 18) coordinate system in meters. Also, it is noted that the units associated with the scale bars for these figures are in larvae concentration per cubic meter and that values exceeding 30 units/m³ appear as brown.

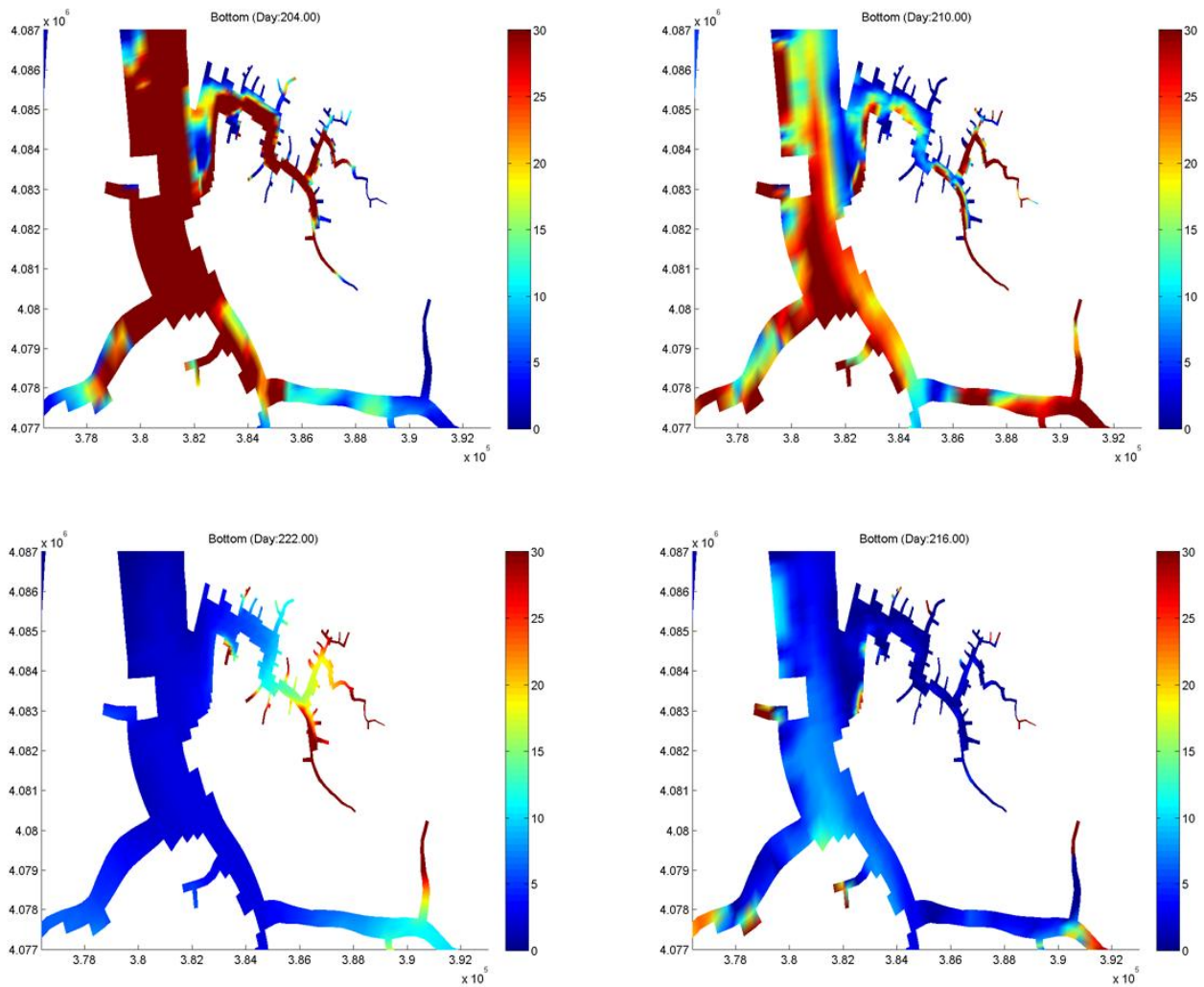


Figure 5. Larval distribution in the Elizabeth River at the bottom layer for Days 204, 210, 216, and 222, after an instantaneous release at Lafayette River Location 1.

Figure 4 shows that surface concentrations exceeding 30 units/m^3 that uniformly cover most of the Elizabeth River at Day 204 but then, starting in the Elizabeth mainstem, decrease to levels of about 25 units/m^3 on Day 210 and 10 units/m^3 on Day 216. By Day 222, the significant concentrations at the surface are confined mainly to the upstream portion of the Lafayette and one other location along the northern shore of the Eastern Branch.

Figure 5 shows a similar evolution for bottom concentrations, with the final values for Day 222 being very similar to those at the surface. Note that more larvae are observed at the surface on Day 216. This is because of the swimming behavior that is simulated. As stratification increases, more larvae will be accumulated near the surface.

The full set of surface and bottom final end-of-run larval distributions for simulations releasing at all 11 release sites are shown in Appendices A and B, respectively, for the “without local runoff” and “with local runoff” conditions.

There are also subtle but important differences that can be shown between surface and bottom spatial distributions. Figures 6 and 7, respectively, show spatial distributions at the surface and bottom for Day 222 for Release Locations 1, 4, 7, and 10 for simulations without local runoff.

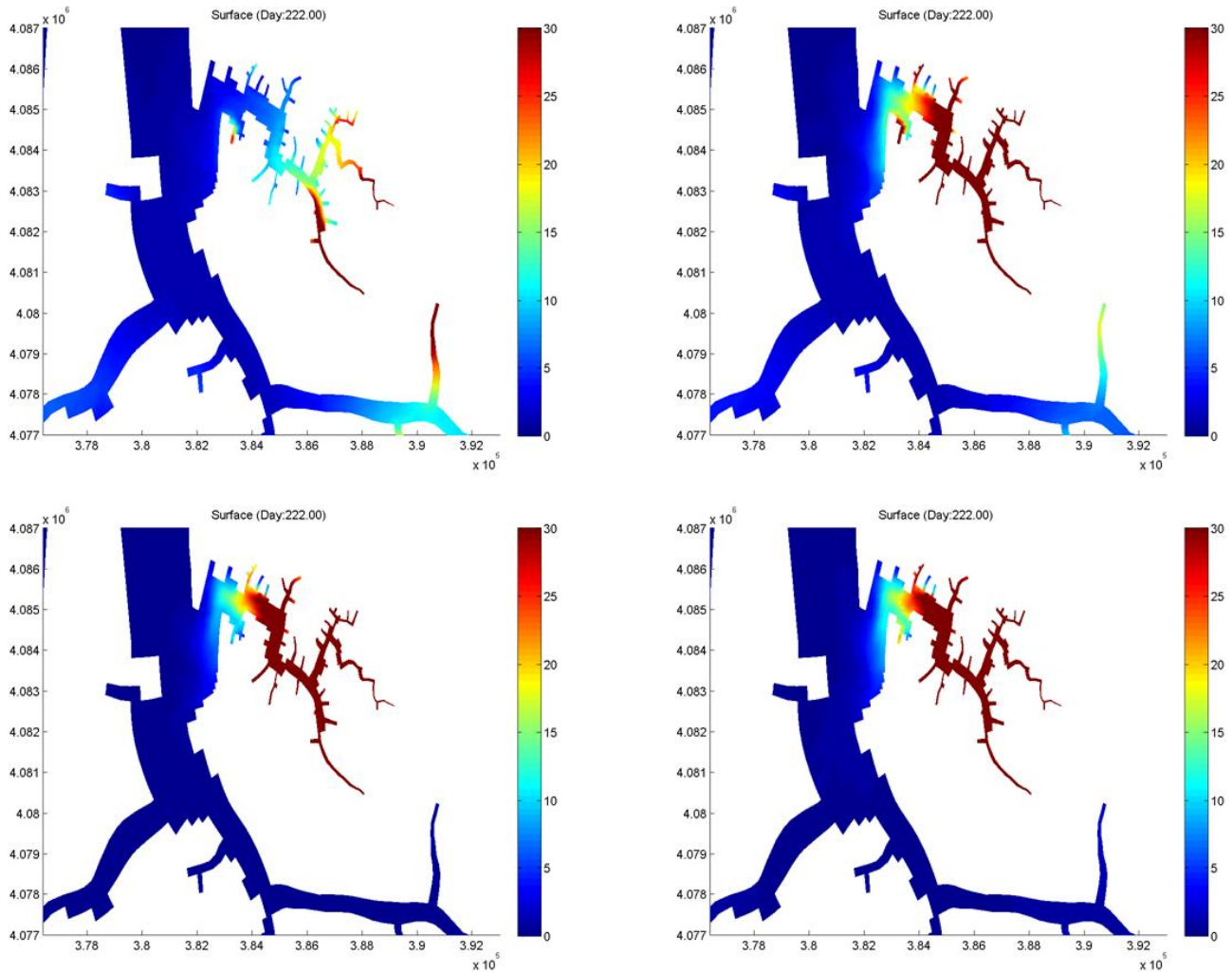


Figure 6. Spatial distributions at the surface for Day 222 for Release Locations 1, 4, 7, and 10 (from upper left, then clockwise) without local runoff.

A close inspection of the different values displayed along the Lafayette River tributaries shows the higher values to be in the bottom layer (Figure 7). This is most likely due to settlement in these regions.

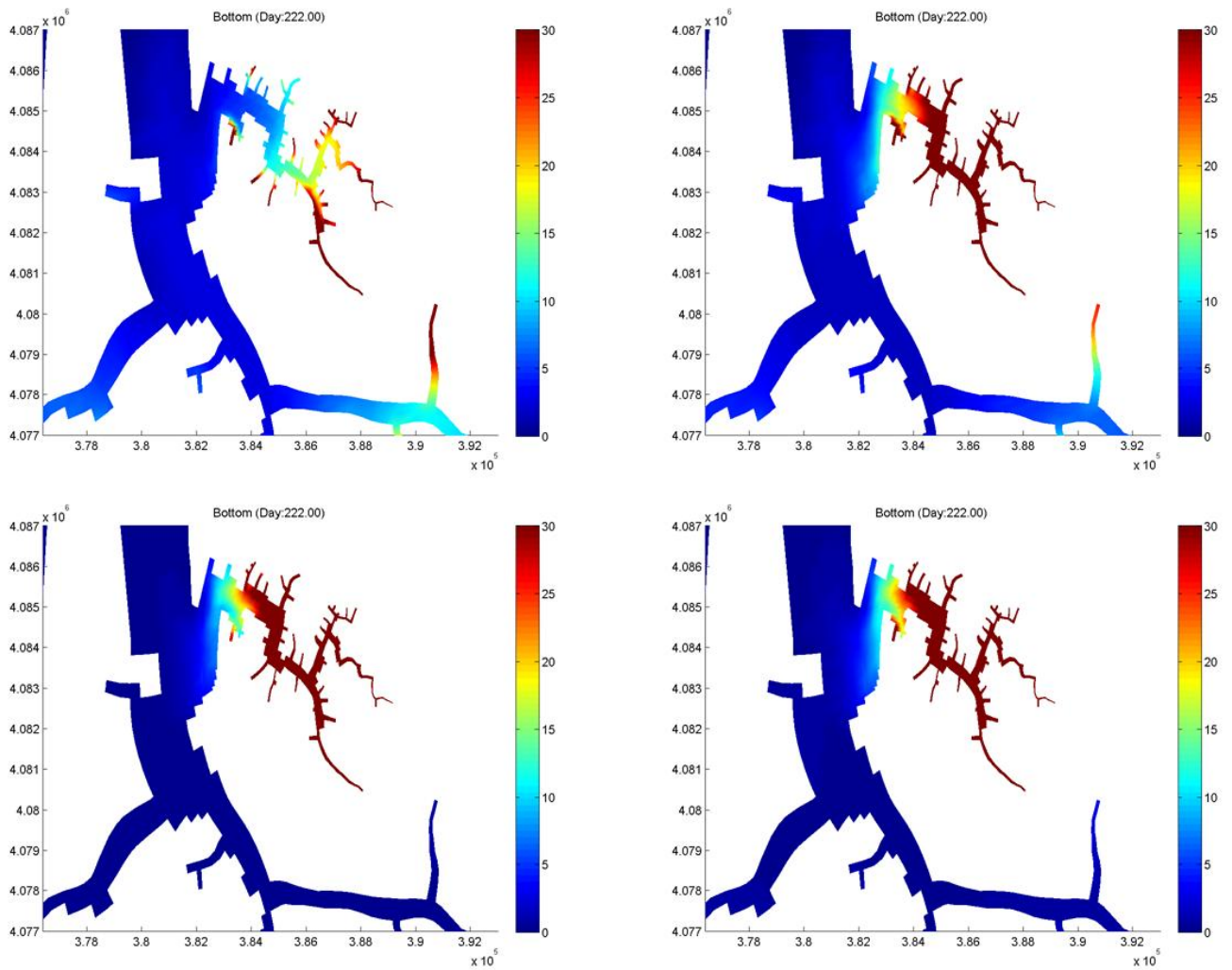


Figure 7. Spatial distributions at the bottom for Day 222 for Release Locations 1, 4, 7, and 10 (from upper left, then clockwise) without local runoff.

Next an effort was made to determine the overall differences caused by releasing upstream versus releasing downstream. For this, we chose to show two 4-panel figures – Figure 8 shows the case for no local runoff and Figure 9 shows the case with local runoff. Both figures follow a sequence (moving clockwise from upper left) showing surface and bottom distributions at Day 222 after a release from Location 1 (most downstream release location) and the surface and bottom distributions at Day 222 after a release form Location 11 (most upstream release location).

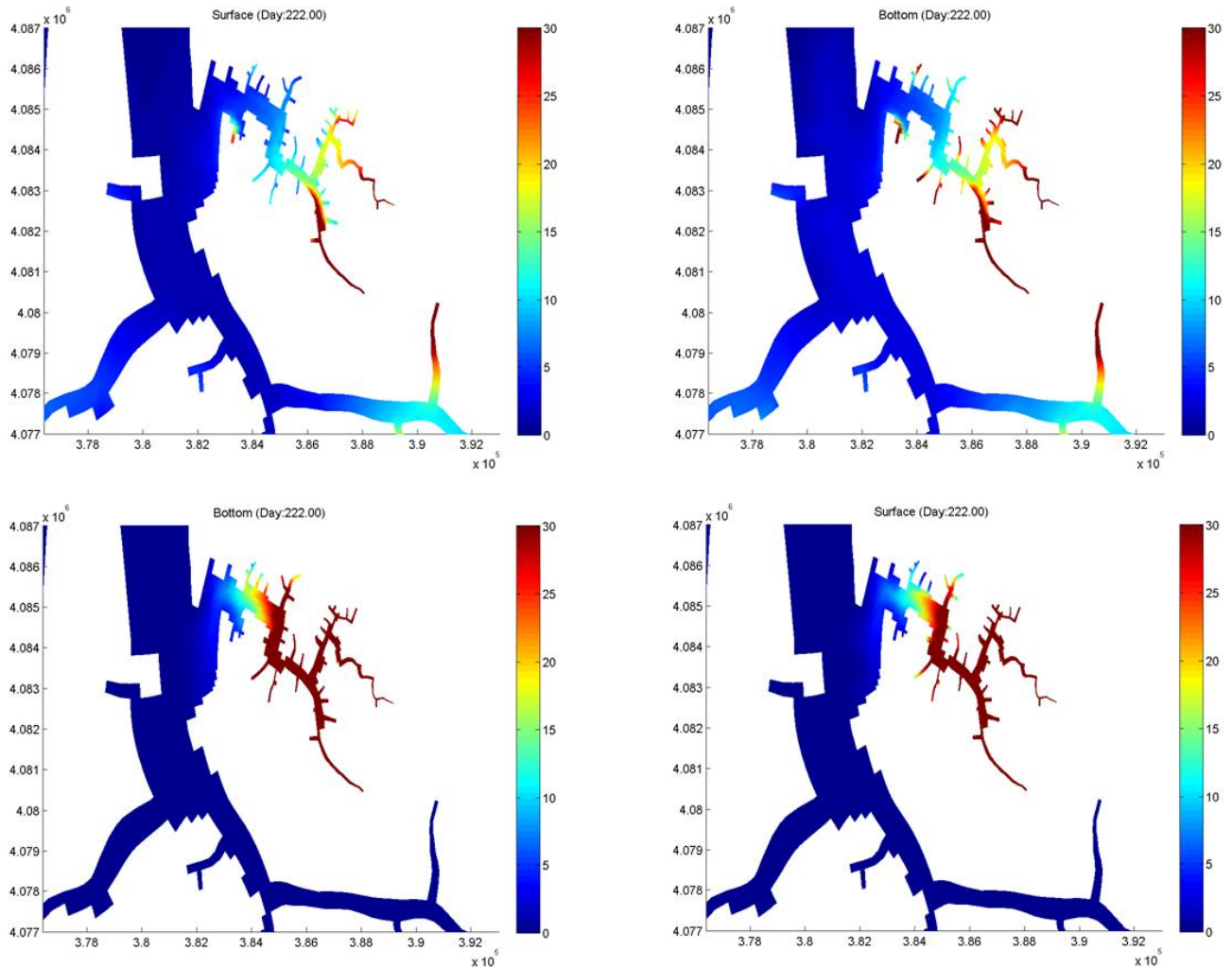


Figure 8. Clockwise from upper left, the 4 spatial distributions at the surface and bottom for Day 222 for release locations 1 (most downstream) and 11 (most upstream) without local runoff.

For both the “without runoff” and the “with runoff” simulations, the results from the upstream release shown in the bottom panels of Figures 8 and 9 indicate that larvae concentrations remain high throughout approximately the upper two-thirds of the distance of the Lafayette. This high concentration protrudes further downstream when runoff is included (Figure 9).

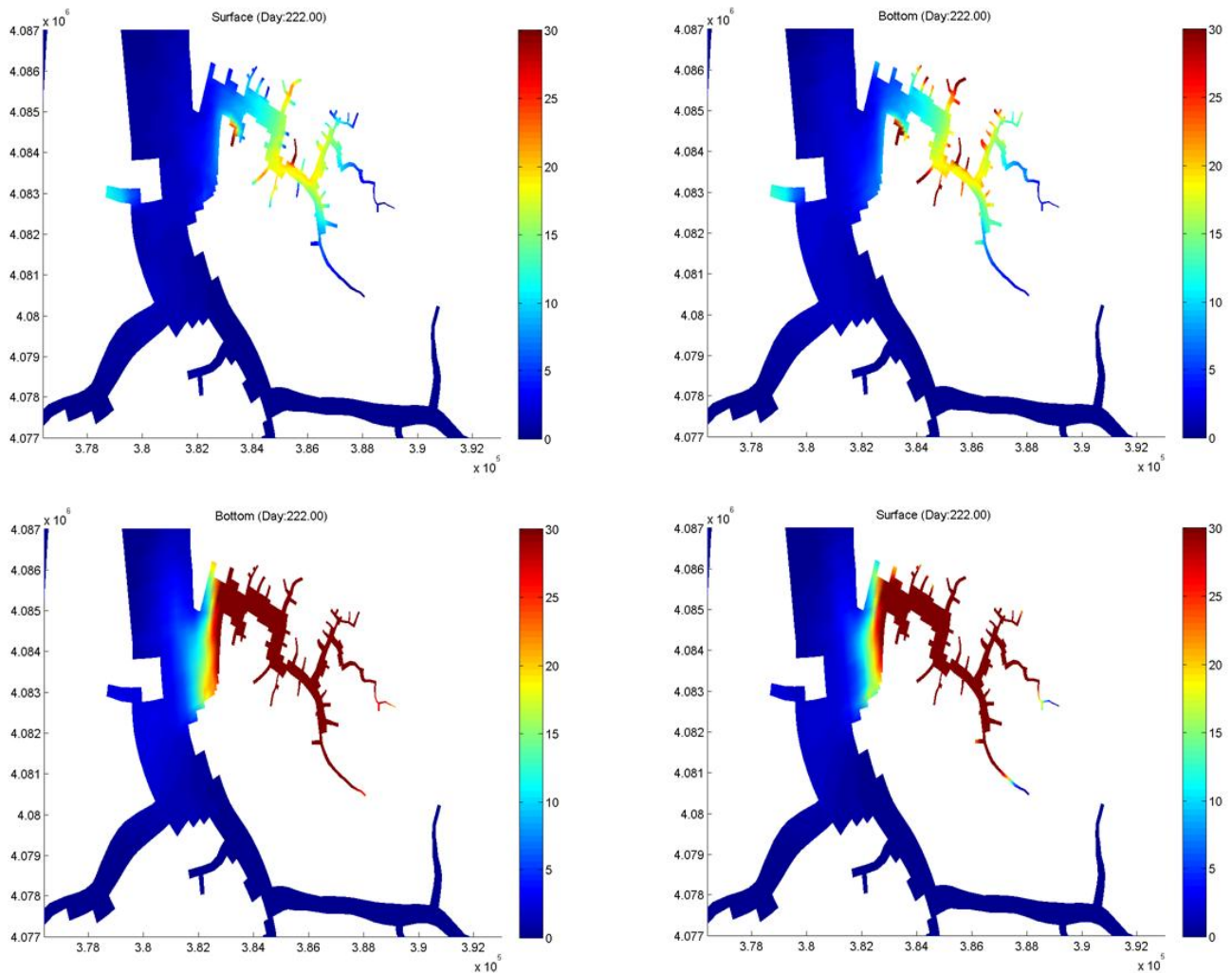


Figure 9. Clockwise from upper left, the 4 spatial distributions at the surface and bottom for Day 222 for release locations 1 (most downstream) and 11 (most upstream) with local runoff.

Surface and bottom larvae distributions from several release locations were then compared without and with local runoff to determine if this runoff had a significant impact on the end-of-run distributions. Figures 10 and 11, respectively, show post-simulation distributions without local runoff and with local runoff for 8 panels of otherwise identical specification. For both figures, the top 4 spatial plots are surface layer concentrations after simulations for Release Locations 1, 4, 7, and 10 and the bottom 4 spatial plots are bottom layer concentrations after these 4 simulations.

The primary effect of local runoff appears to be to move the plume of larvae concentrations downstream.

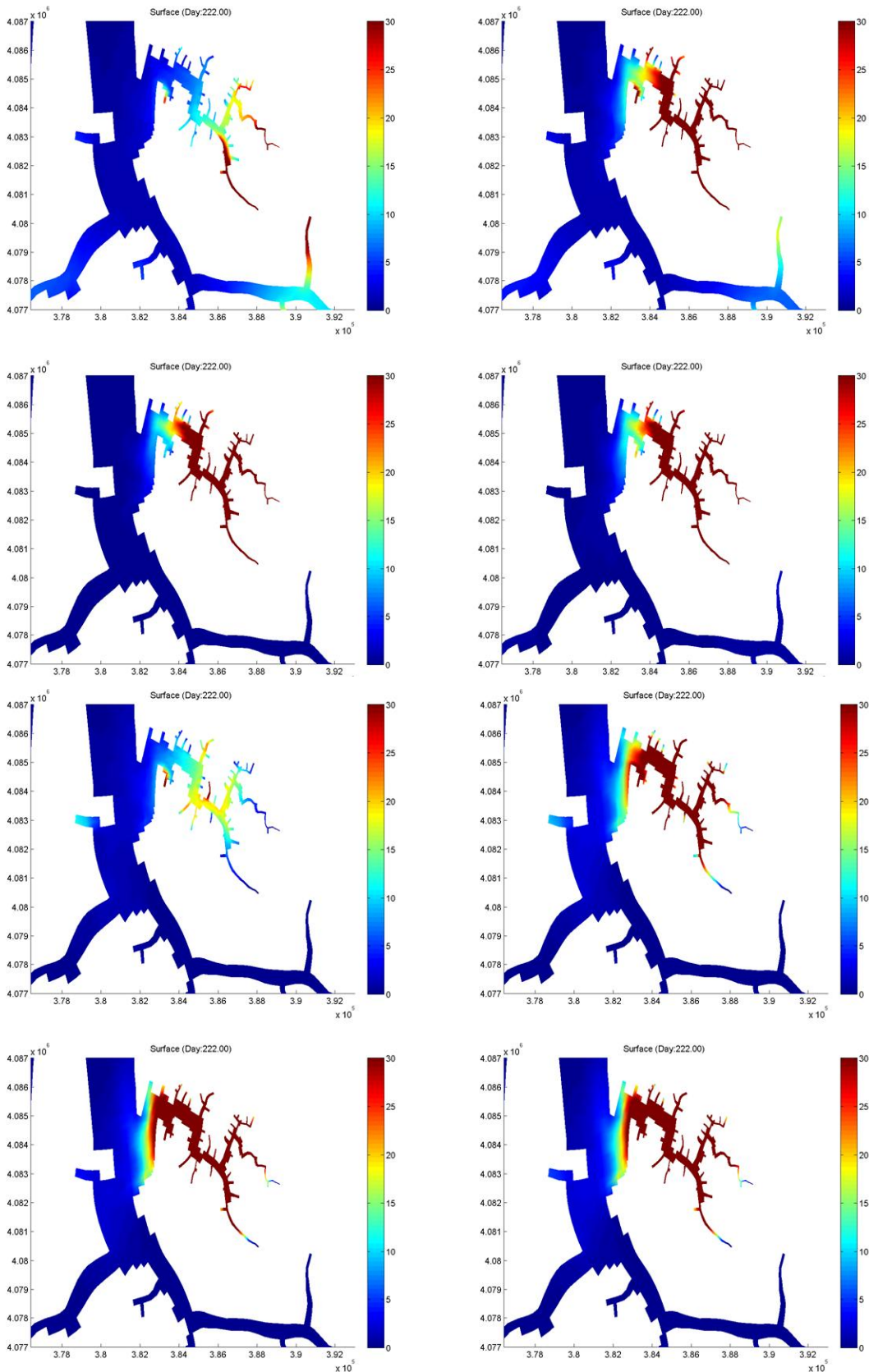


Figure 10. Spatial distributions at the surface for Day 222 for Release Locations 1, 4, 7, and 10 without local runoff (top 4 panels, upper left and then clockwise) and with local runoff (bottom 4 panels, again upper left and then clockwise).

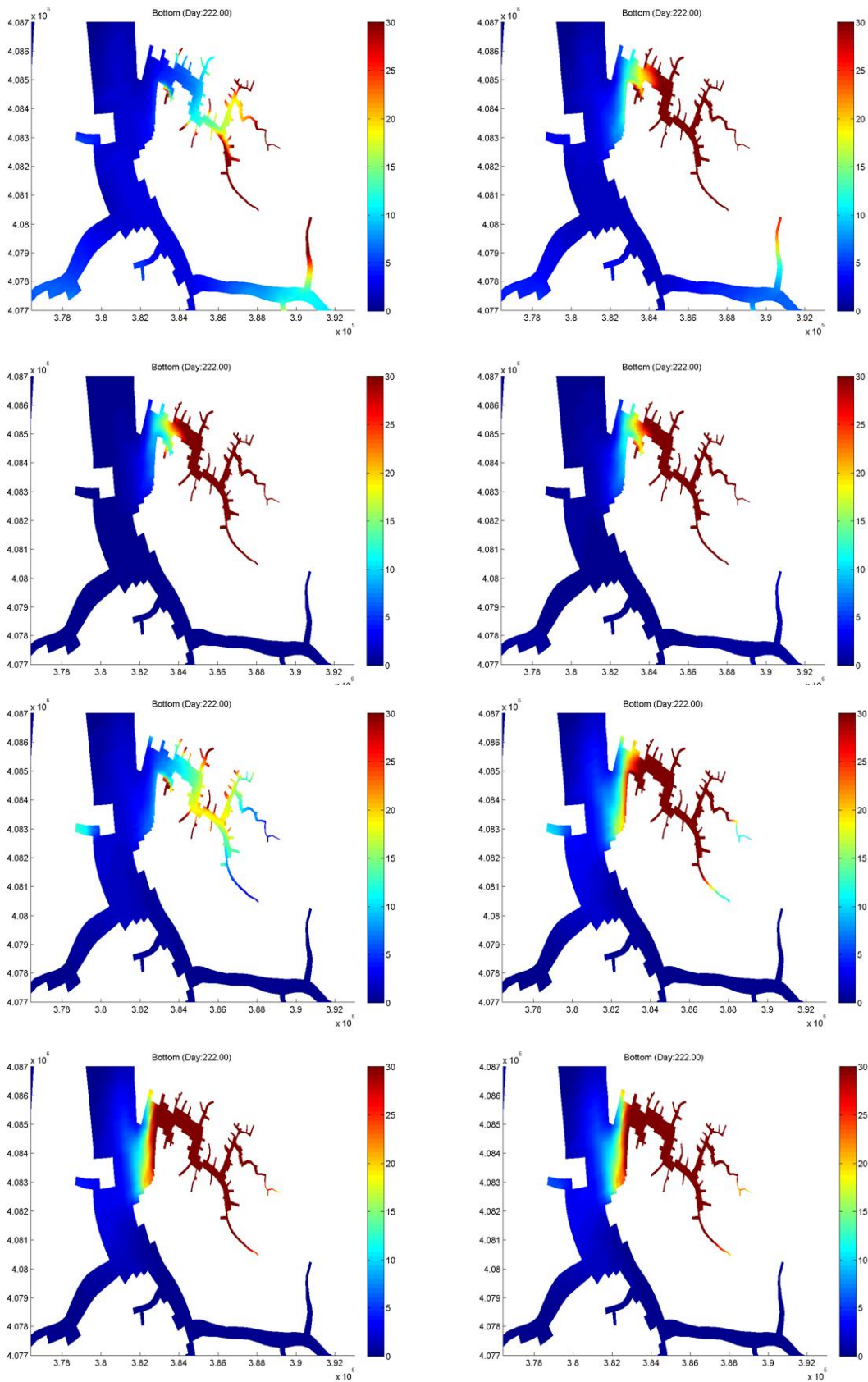


Figure 11. Spatial distributions at the bottom for Day 222 for Release Locations 1, 4, 7, and 10 without local runoff (top 4 panels, upper left and then clockwise) and with local runoff (bottom 4 panels, again upper left and then clockwise).

III.C. Distributions of larval settlement totals at each release site

The settlement of larvae at each location corresponding to the larval release at the location of this example is shown in Figure 12.

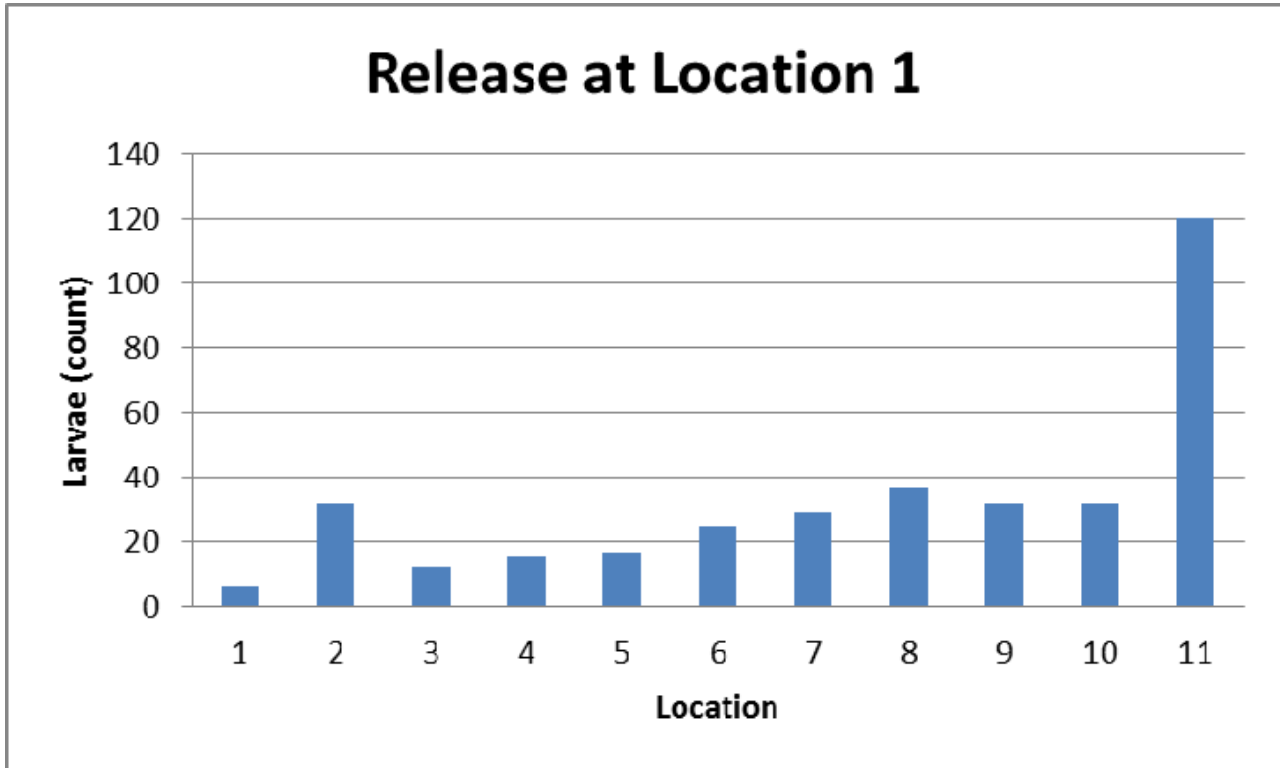


Figure 12. Results of Larvae Settlement Totals at all release points for Day 222, twenty days after an instantaneous release at Lafayette River Location 1.

The full set of larval distributions resulting for simulations that release at each of the 11 release sites are shown in Appendices C and D, respectively, for the “without local runoff” and “with local runoff” conditions. An examination of these figures shows that the larvae will settle sufficiently to all 11 Lafayette River reef locations regardless of where they are released, or whether there is presence or absence of local runoff from the watershed.

The histograms plotted herein provide a good opportunity to compare and contrast the larval accumulations at the selected Lafayette River release locations. How do the larvae settlement totals from a downstream release location compare to those from an upstream location? Figures 13 and 14 below show the distributions resulting from release downstream (Locations 1 and 2) compared to those upstream (Locations 10 and 11) for simulations without local runoff and with local runoff, respectively.

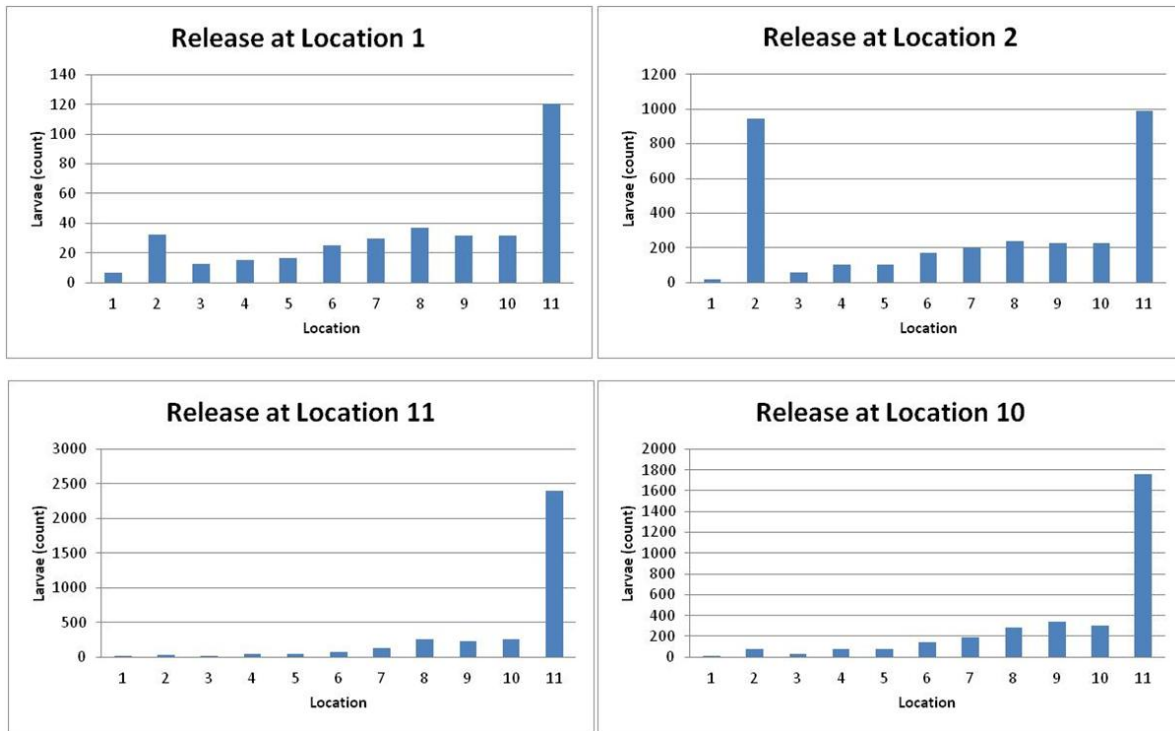


Figure 13. Larvae Settlement Totals at all release points for Day 222 for Release Locations 1 and 2 (downstream) and 10 and 11 (upstream) without local runoff.

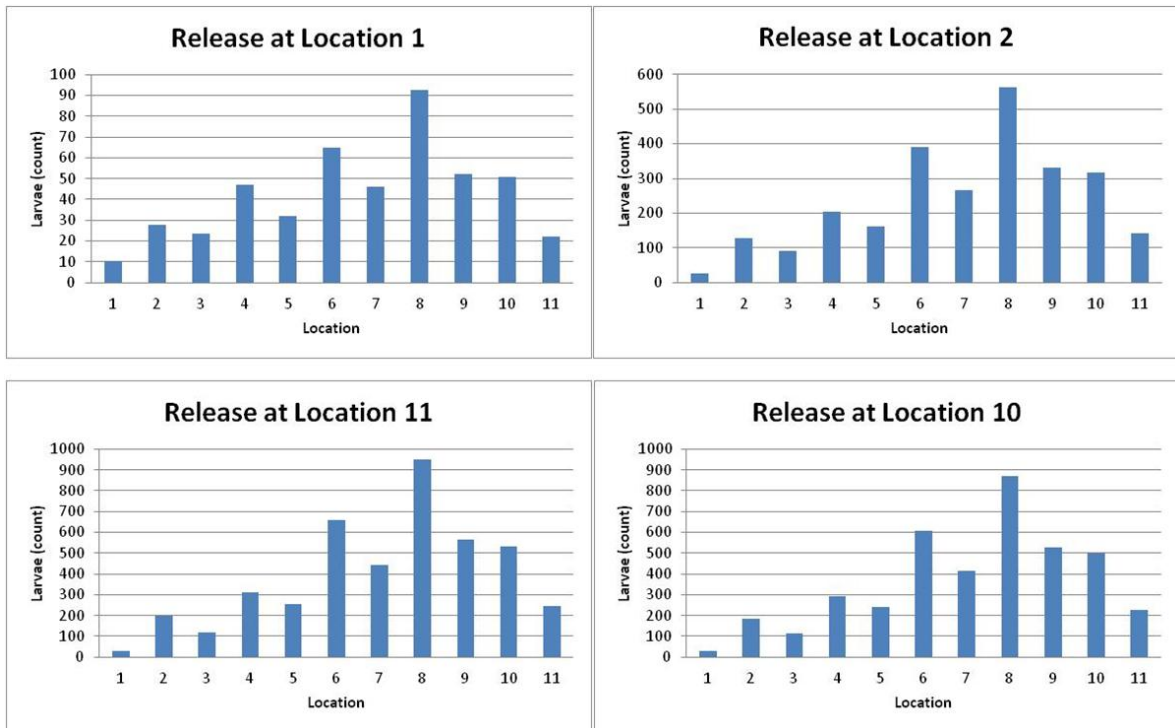


Figure 14. Larvae Settlement Totals at all release points for Day 222 for Release Locations 1 and 2 (downstream) and 10 and 11 (upstream) with local runoff.

Lastly, the effects of the local runoff on the larvae settlements are teased out by contrasting results for simulations without local runoff and those for simulations with local runoff. These comparisons were made at Locations 1, 4, 7, and 10 in an effort to span the full domain of the Lafayette. Figure 15 shows the larvae settlements at these locations for simulations without local runoff and Figure 16 shows these settlements for simulations with local runoff. It can be seen that distribution of settlement location changes with the addition of runoff. Instead of accumulation at the upstream, a high settlement shifted to the middle region and the highest settlement occurred at Stations 6 and 8, regardless of the larvae release location. The model results show that entire Lafayette River has a good connectivity for larvae recruitment.

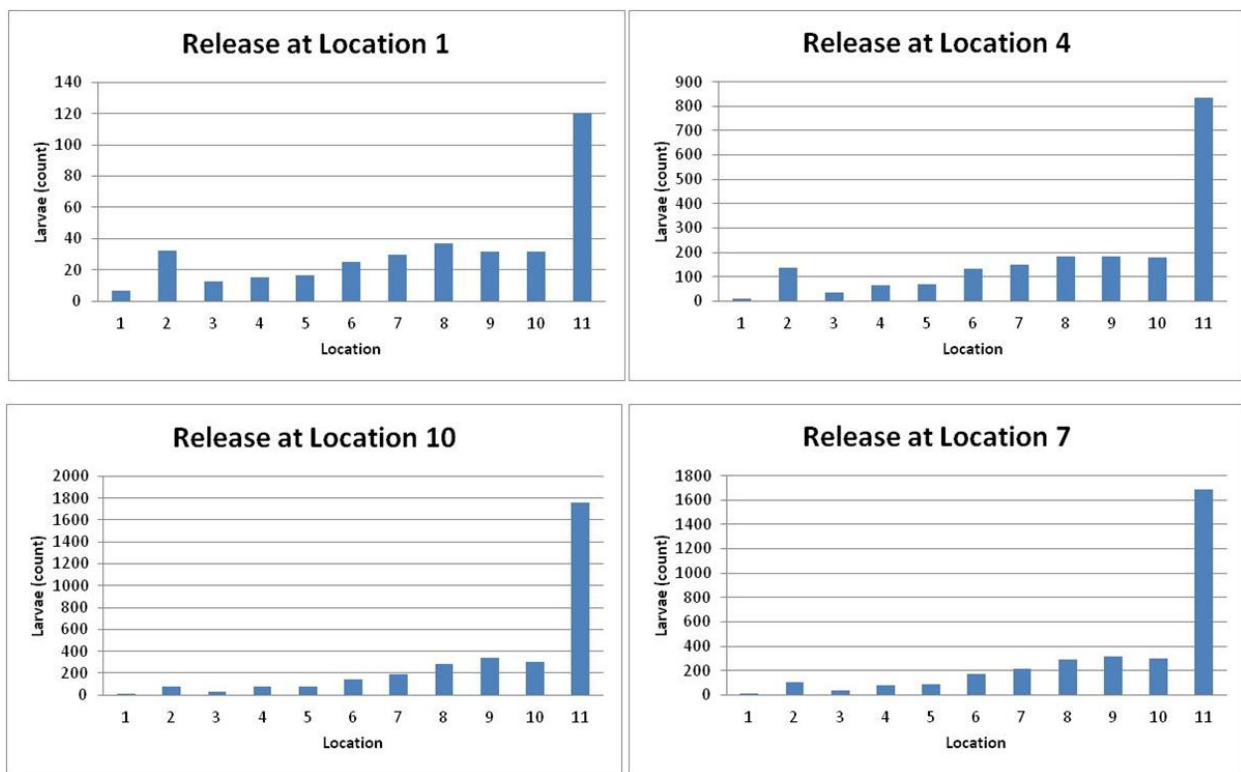


Figure 15. Larvae Settlement Totals at all release points for Day 222 for Release Locations 1, 4, 7, and 10 without local runoff.

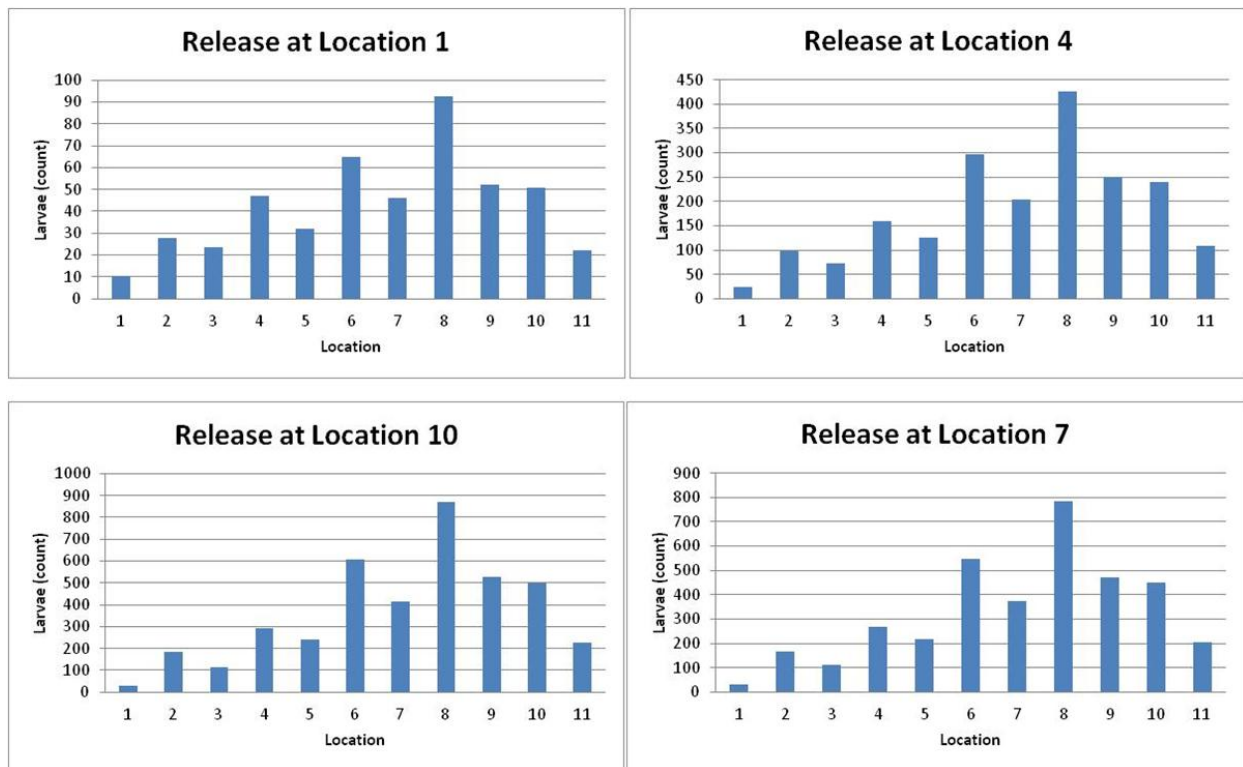


Figure 16. Larvae Settlement Totals at all release points for Day 222 for Release Locations 1, 4, 7, and 10 with local runoff.

IV. SUMMARY AND CONCLUSIONS

Examination of the spatial plots in Appendices A and B and the histograms showing the 21-day accumulated settlements at all release sites for each release simulation shows the potential reef sites of the Lafayette to have larval settlement. The histograms, in particular, show that the recruitment upstream is theoretically higher than downstream, and the highest recruitment is at Release Location 11 without runoff and at Release Location 8 with runoff, respectively.

To maintain this report under a reasonable size, the spatial plots and histograms supplied in the Appendices reported the end-of-run conditions only. For each of the 22 30-day simulations performed, animations showing the day-to-day spatial distributions have been constructed. In viewing these animations, it is immediately seen how many of the downstream release sites transfer the larvae throughout much of the Elizabeth River during the 14-day planktonic phase.

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APPENDIX A

Spatial plots of larvae distributions 20 days after release

Hydrodynamic Simulations without local runoff

11 Release Locations in the Lafayette River (see figure on report cover)

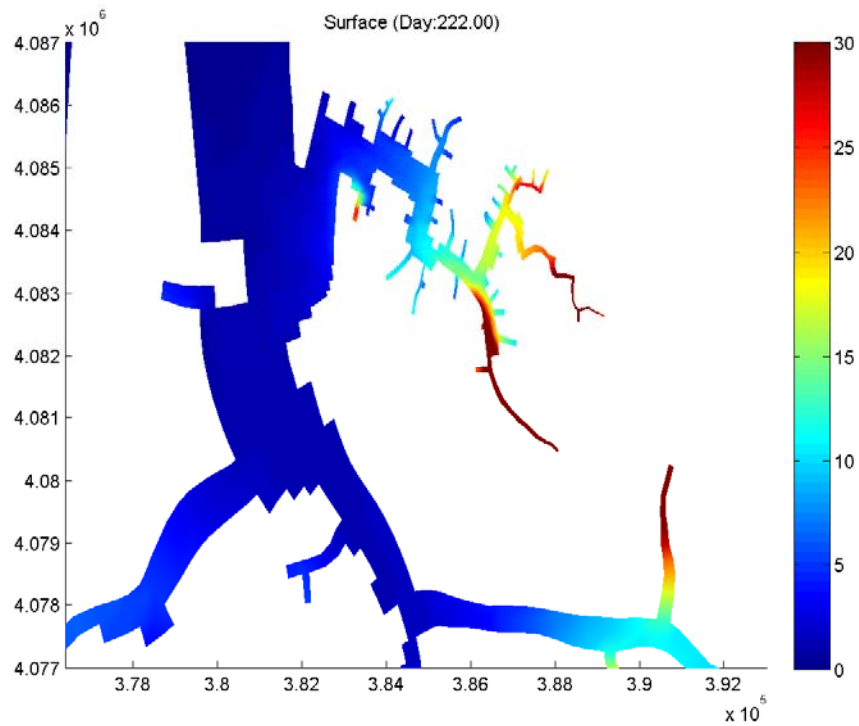


Figure A1. Larval distribution in Elizabeth River at surface layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 1.

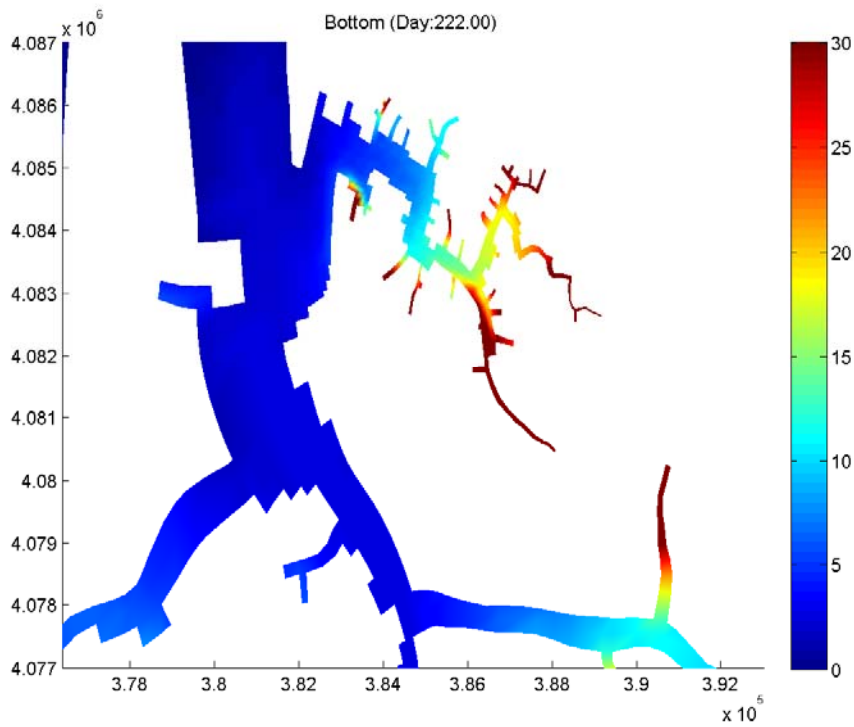


Figure A2. Larval distribution in Elizabeth River at bottom layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 1.

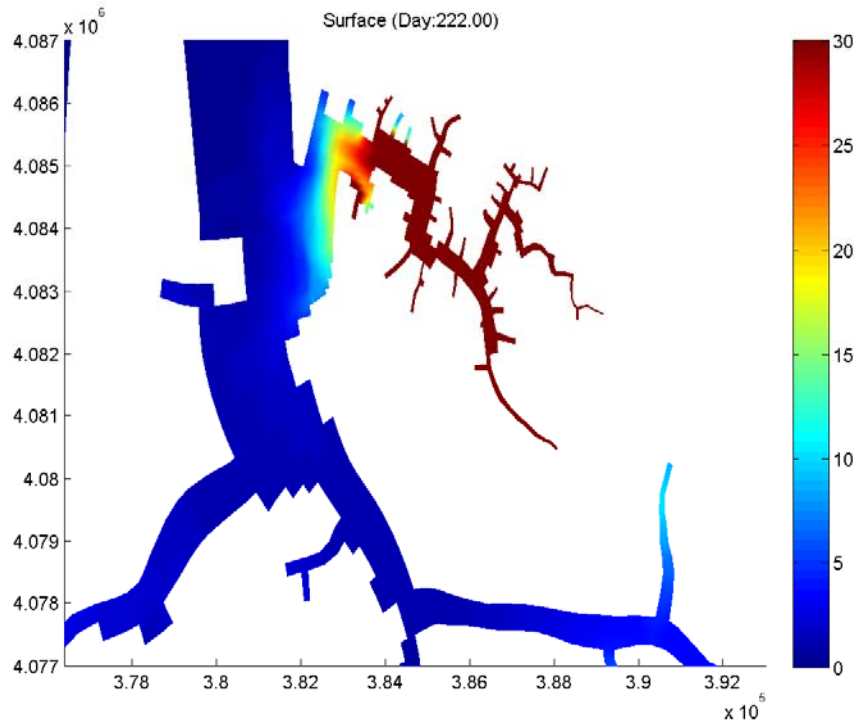


Figure A3. Larval distribution in Elizabeth River at surface layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 2.

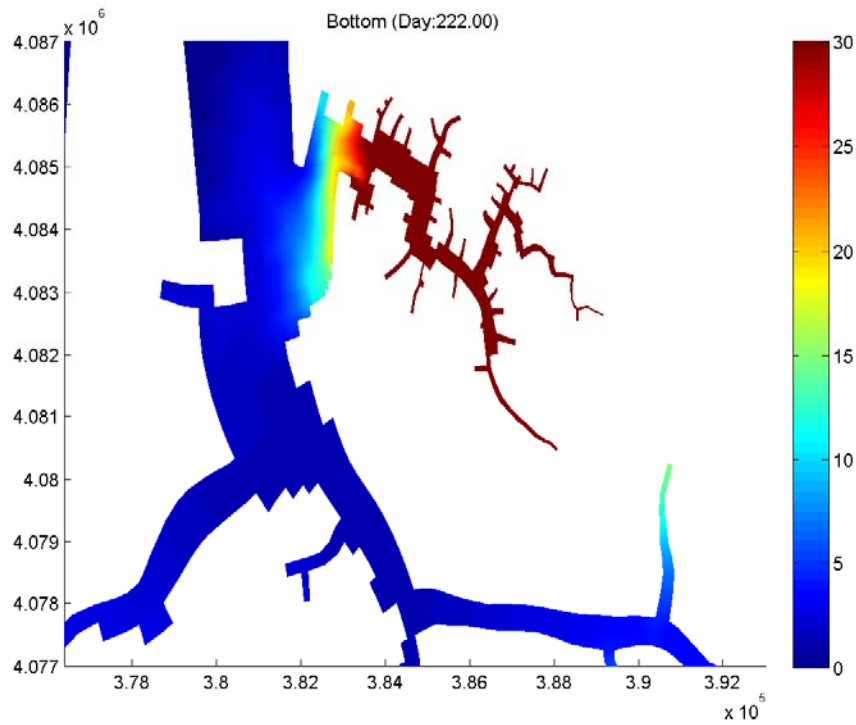


Figure A4. Larval distribution in Elizabeth River at bottom layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 2.

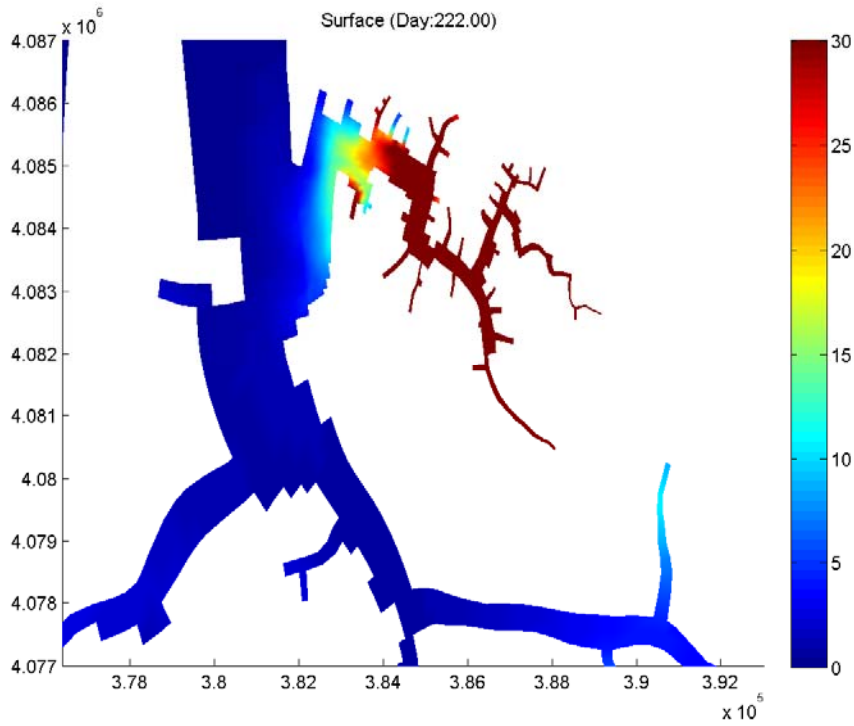


Figure A5. Larval distribution in Elizabeth River at surface layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 3.

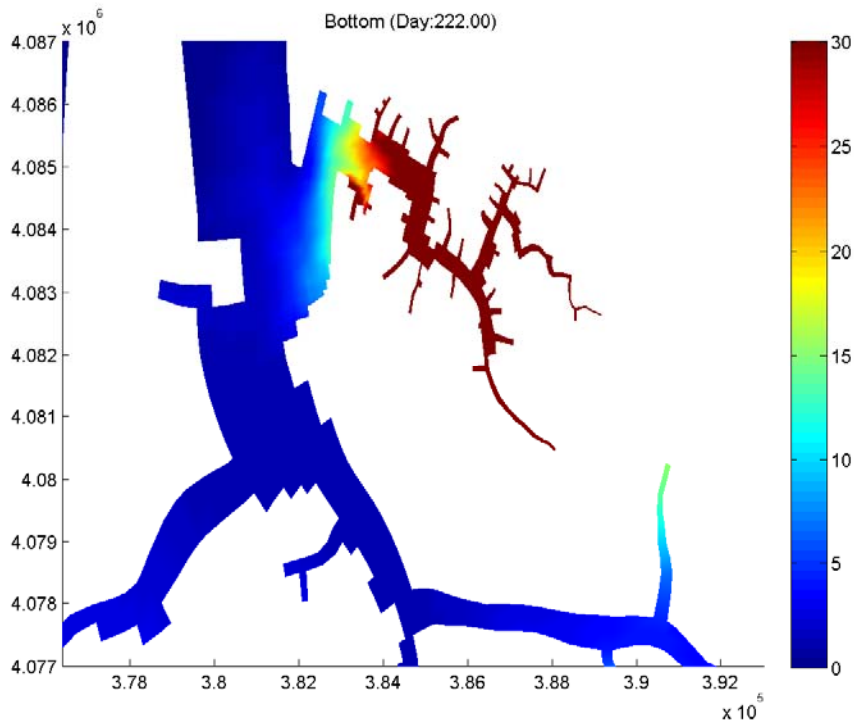


Figure A6. Larval distribution in Elizabeth River at bottom layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 3.

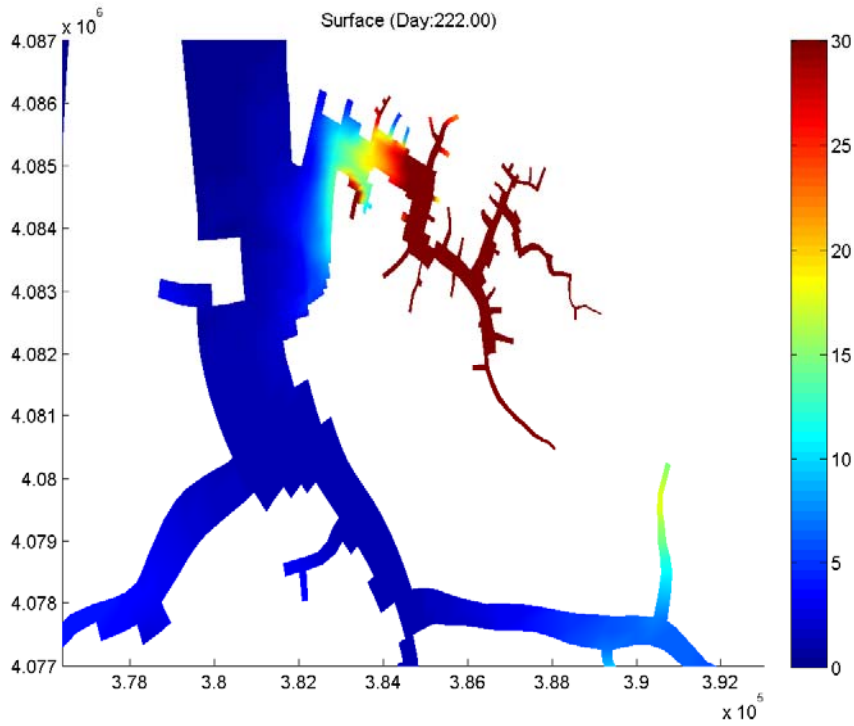


Figure A7. Larval distribution in Elizabeth River at surface layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 4.

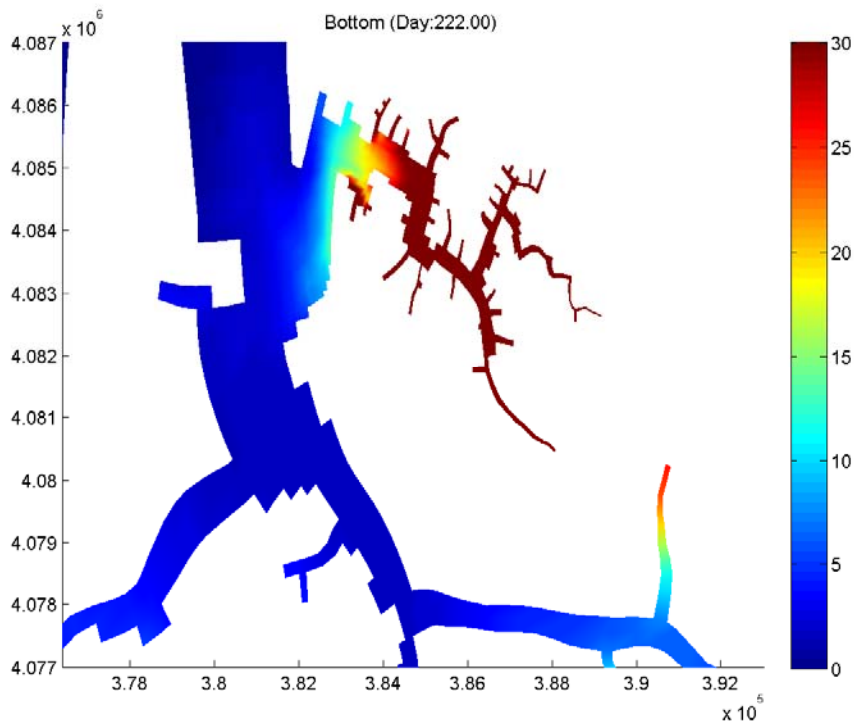


Figure A8. Larval distribution in Elizabeth River at bottom layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 4.

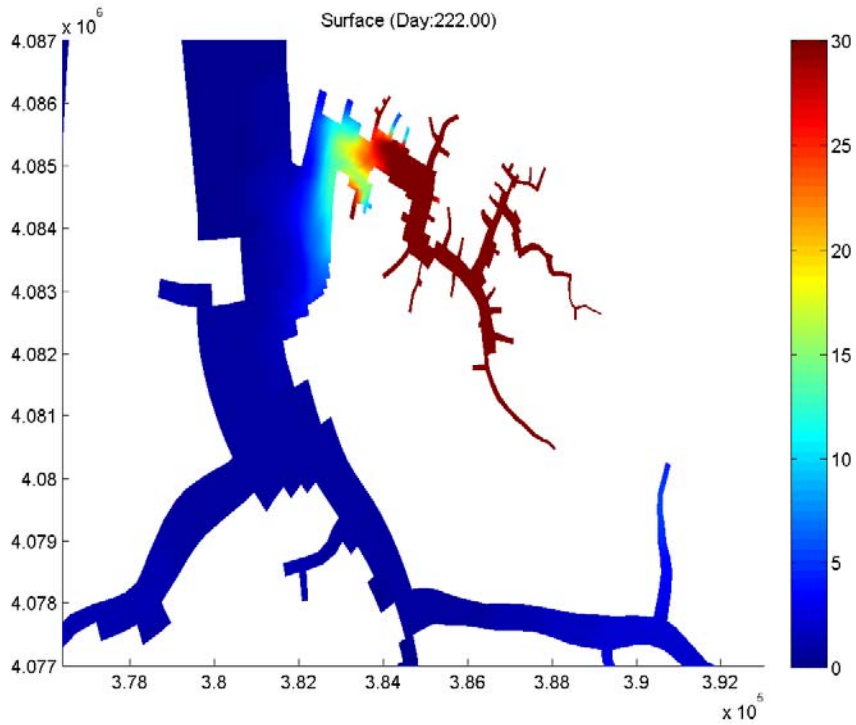


Figure A9. Larval distribution in Elizabeth River at surface layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 5.

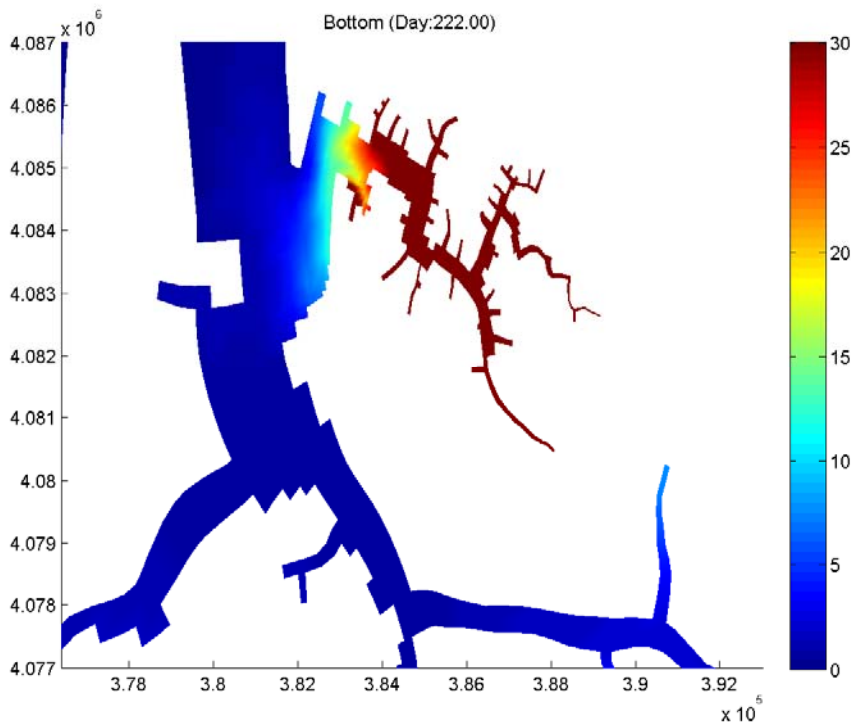


Figure A10. Larval distribution in Elizabeth River at bottom layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 5.

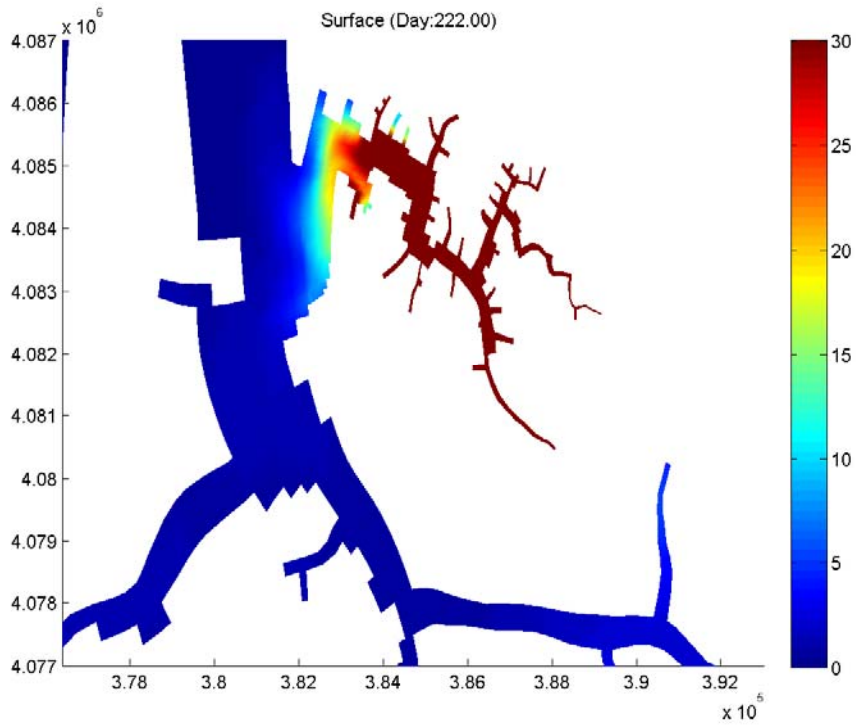


Figure A11. Larval distribution in Elizabeth River at surface layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 6.

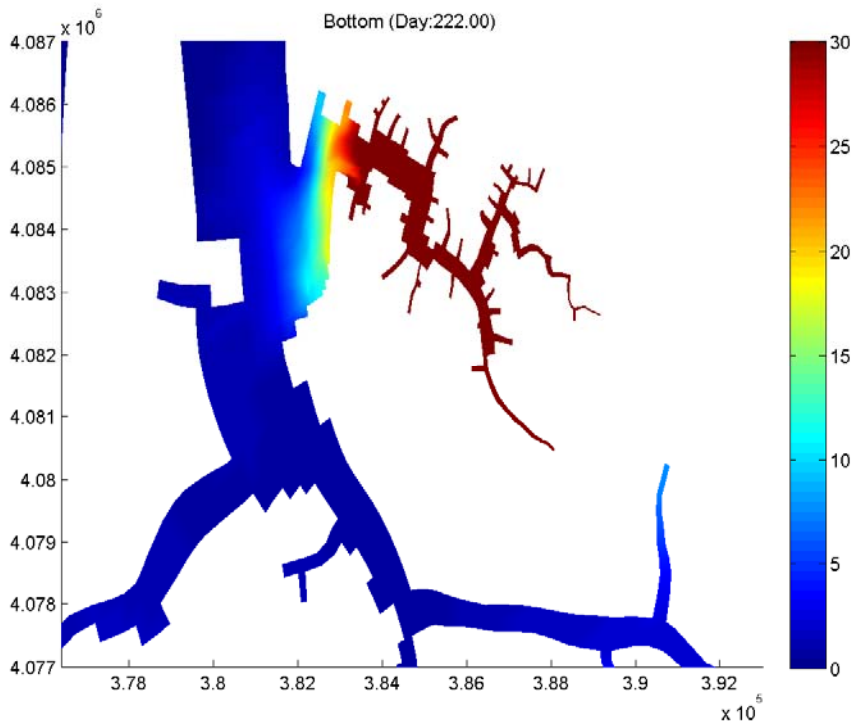


Figure A12. Larval distribution in Elizabeth River at bottom layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 6.

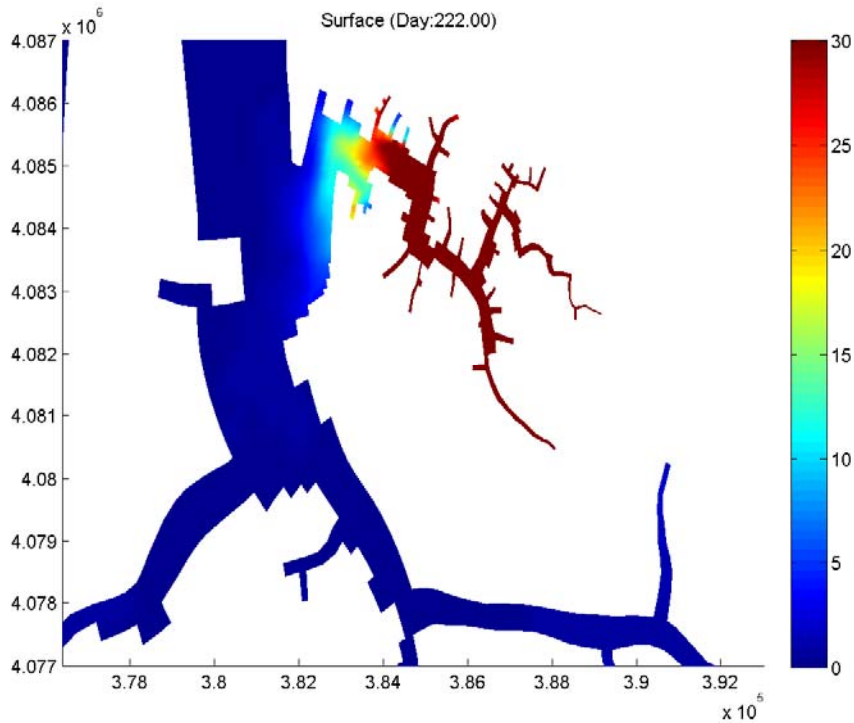


Figure A13. Larval distribution in Elizabeth River at surface layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 7.

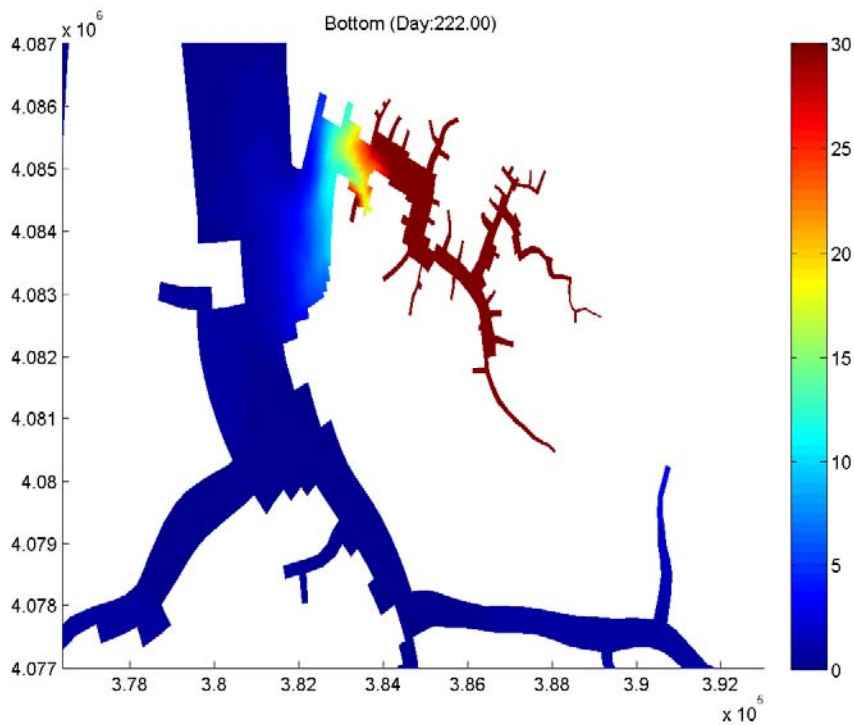


Figure A14. Larval distribution in Elizabeth River at bottom layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 7.

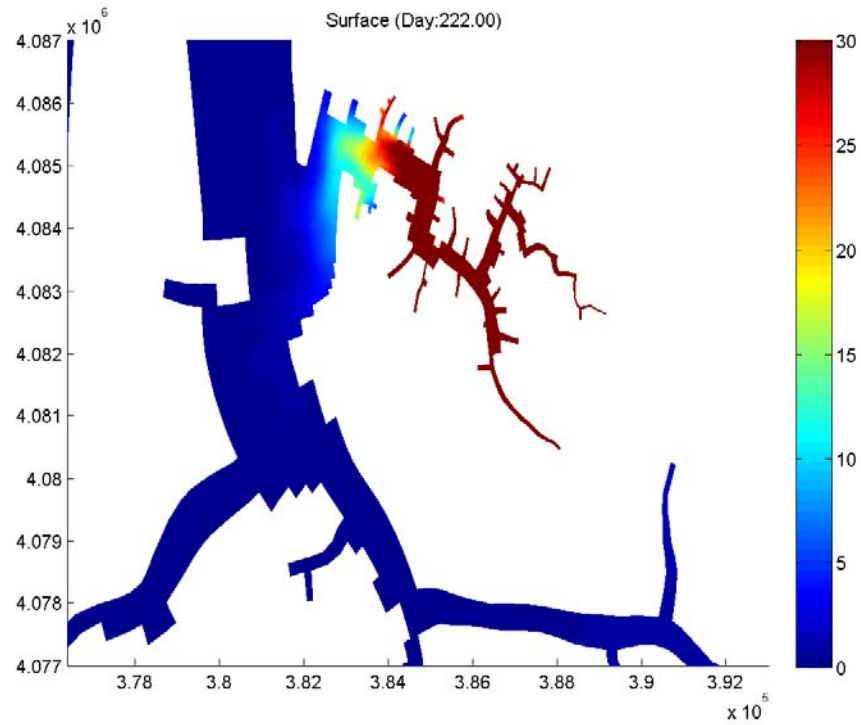


Figure A15. Larval distribution in Elizabeth River at surface layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 8.

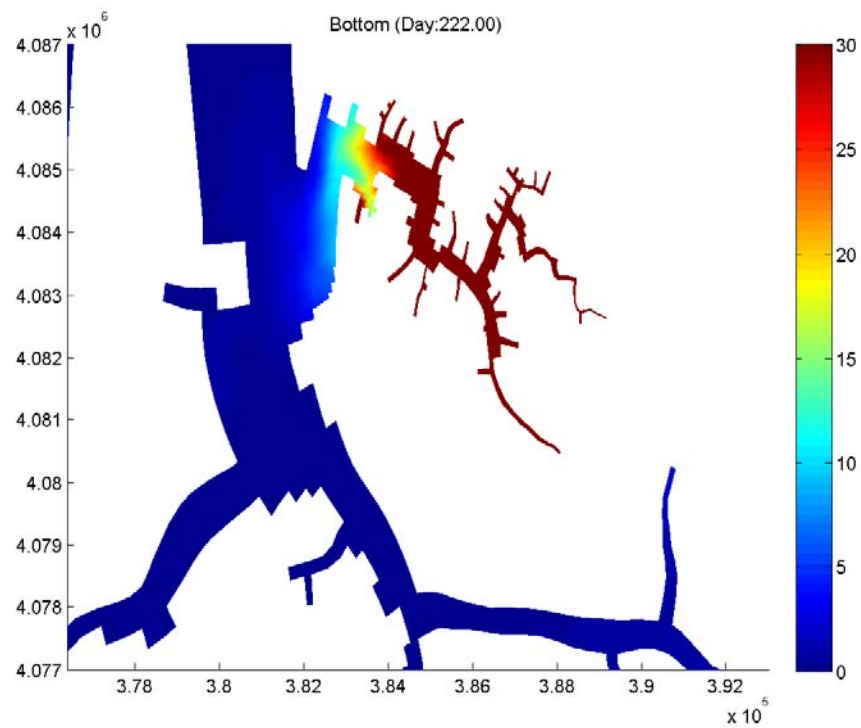


Figure A16. Larval distribution in Elizabeth River at bottom layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 8.

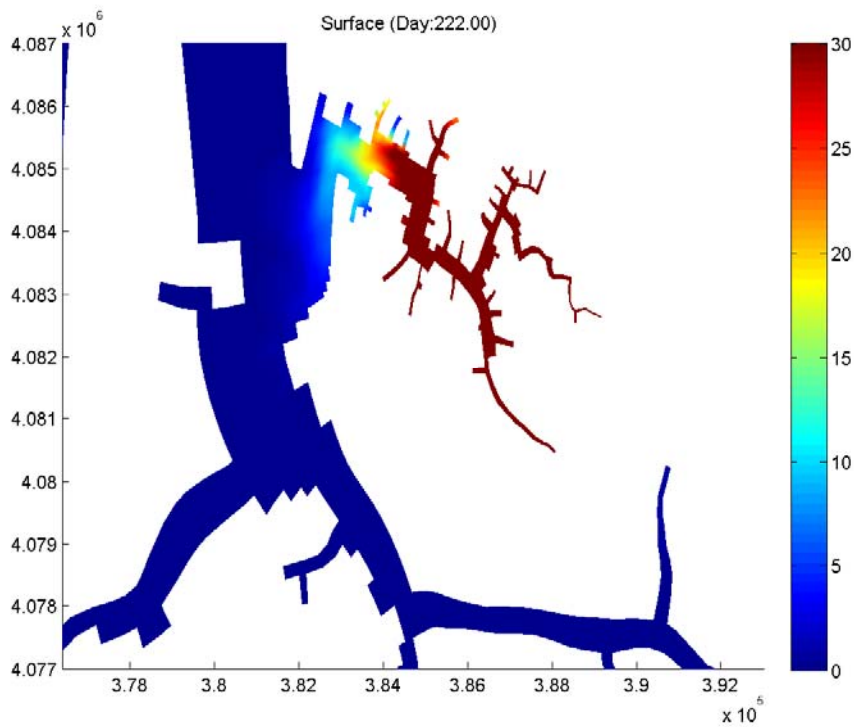


Figure A17. Larval distribution in Elizabeth River at surface layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 9.

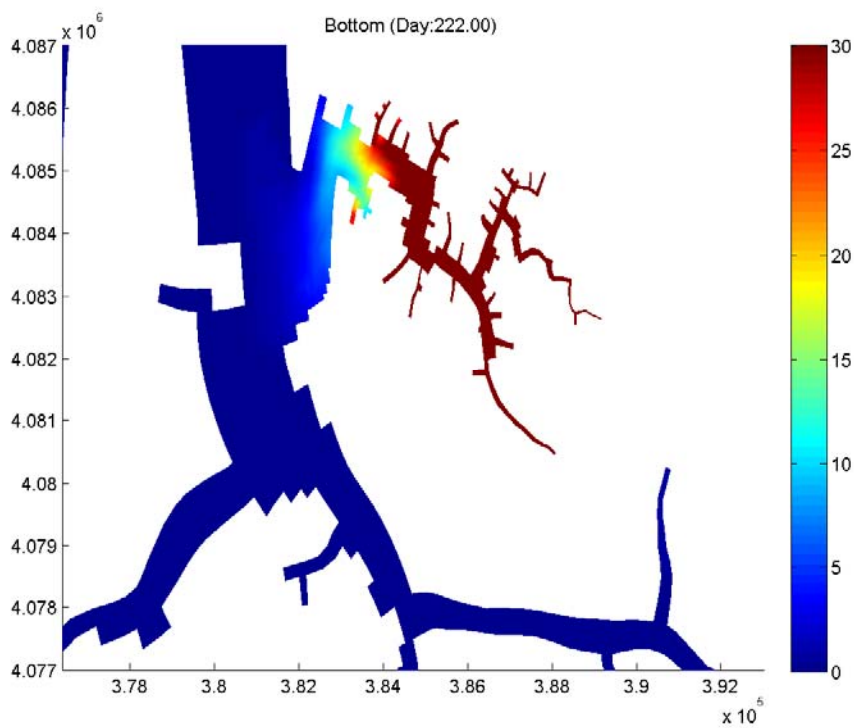


Figure A18. Larval distribution in Elizabeth River at bottom layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 9.

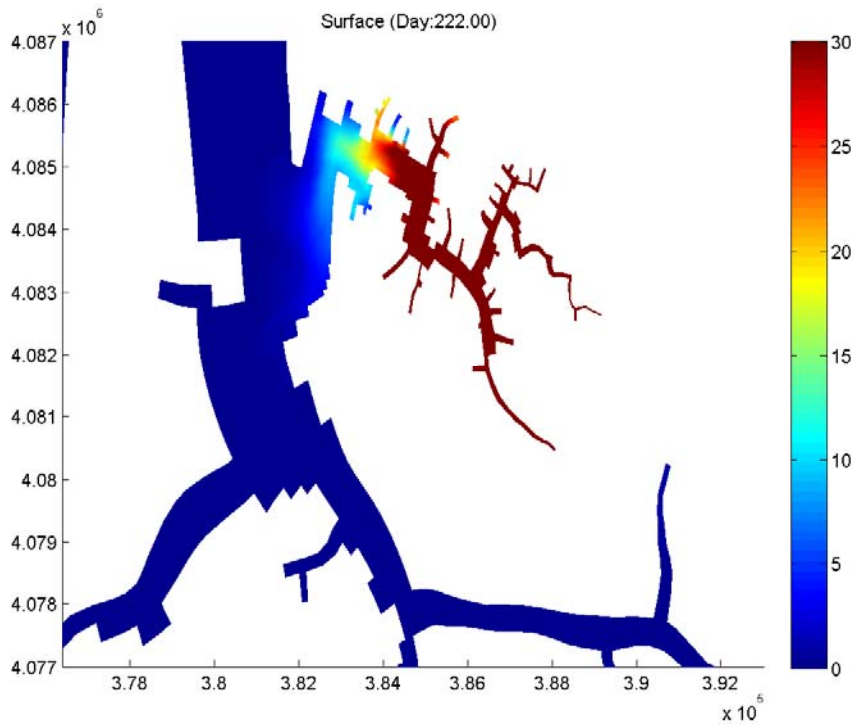


Figure A19. Larval distribution in Elizabeth River at surface layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 10.

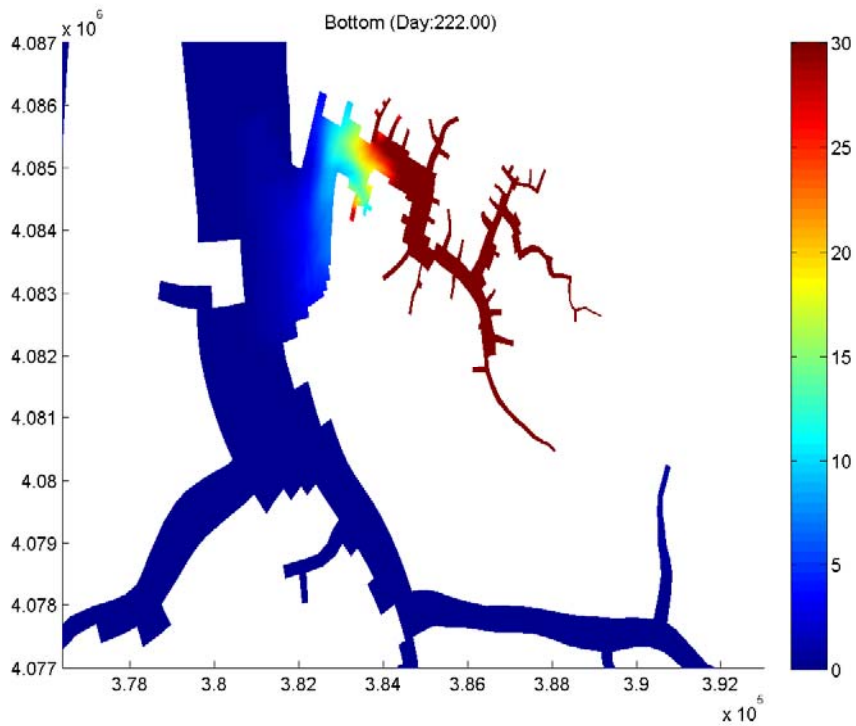


Figure A20. Larval distribution in Elizabeth River at bottom layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 10.

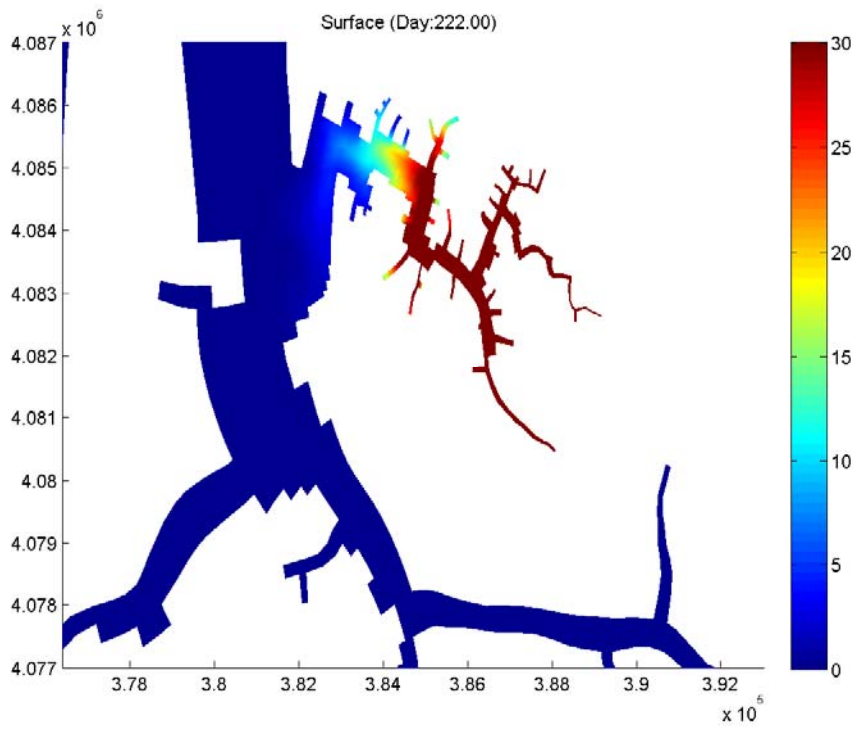


Figure A21. Larval distribution in Elizabeth River at surface layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 11.

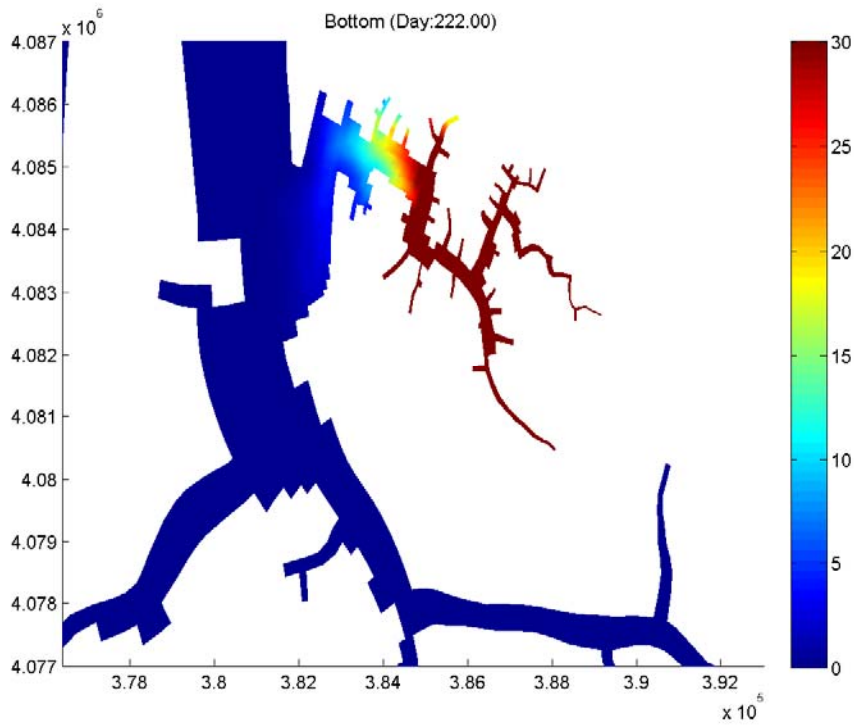


Figure A22. Larval distribution in Elizabeth River at bottom layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 11.

APPENDIX B

Spatial plots of larvae distributions 20 days after release

Hydrodynamic Simulations with local runoff

11 Release Locations in the Lafayette River (see figure on report cover)

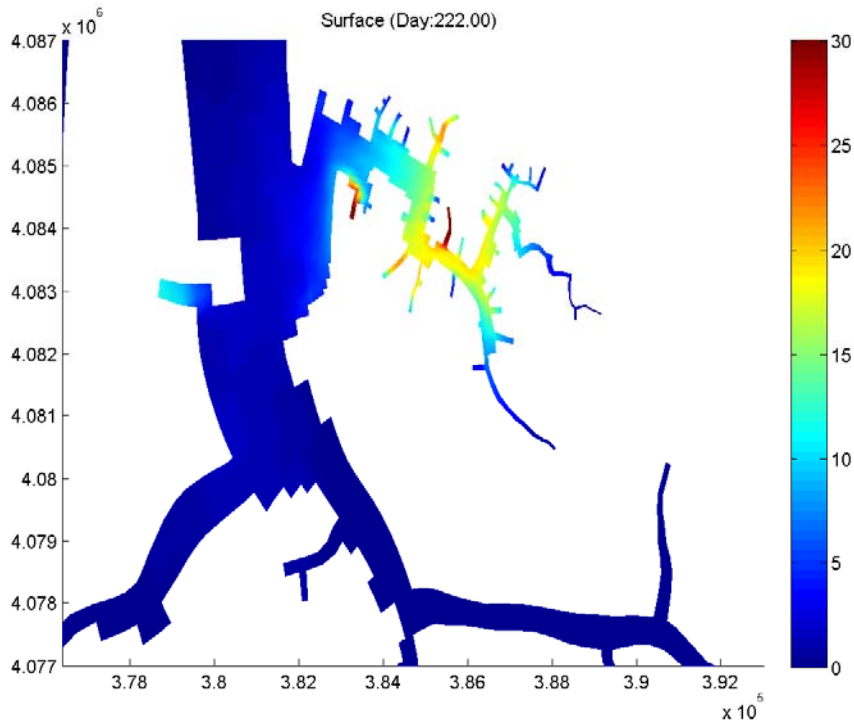


Figure B1. Larval distribution in Elizabeth River at surface layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 1.

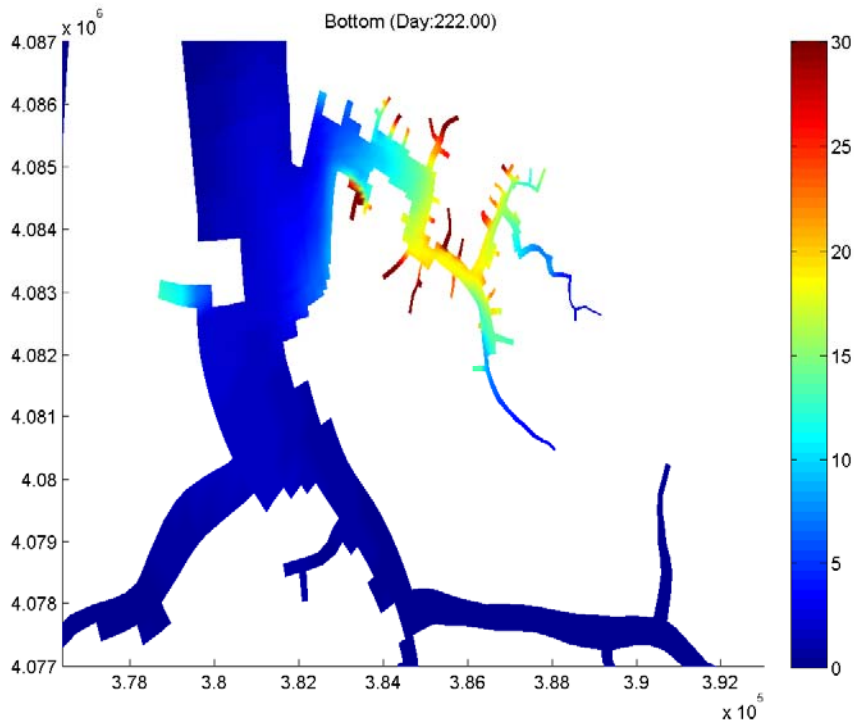


Figure B2. Larval distribution in Elizabeth River at bottom layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 1.

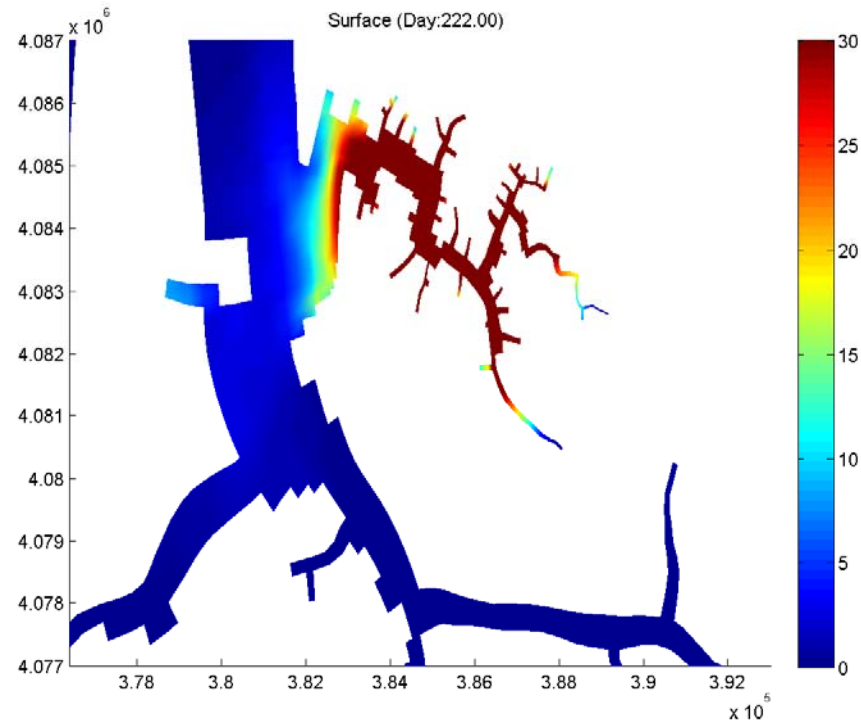


Figure B3. Larval distribution in Elizabeth River at surface layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 2.

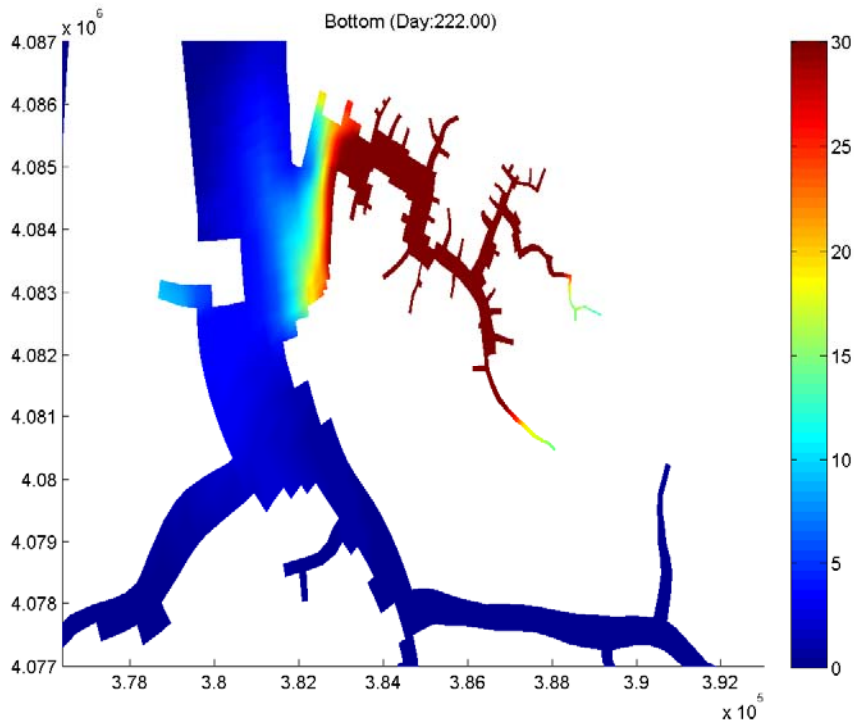


Figure B4. Larval distribution in Elizabeth River at bottom layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 2.

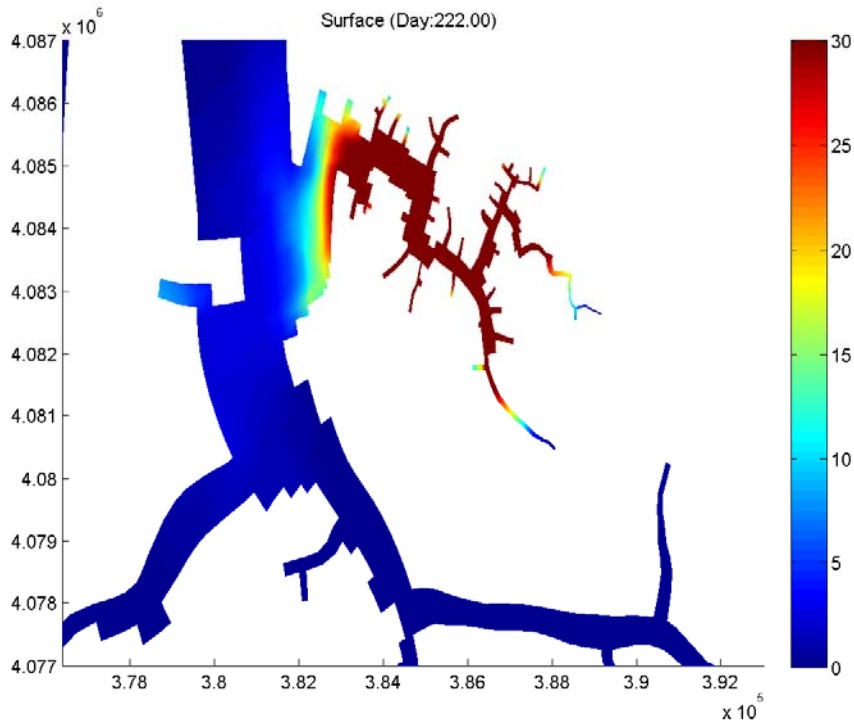


Figure B5. Larval distribution in Elizabeth River at surface layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 3.

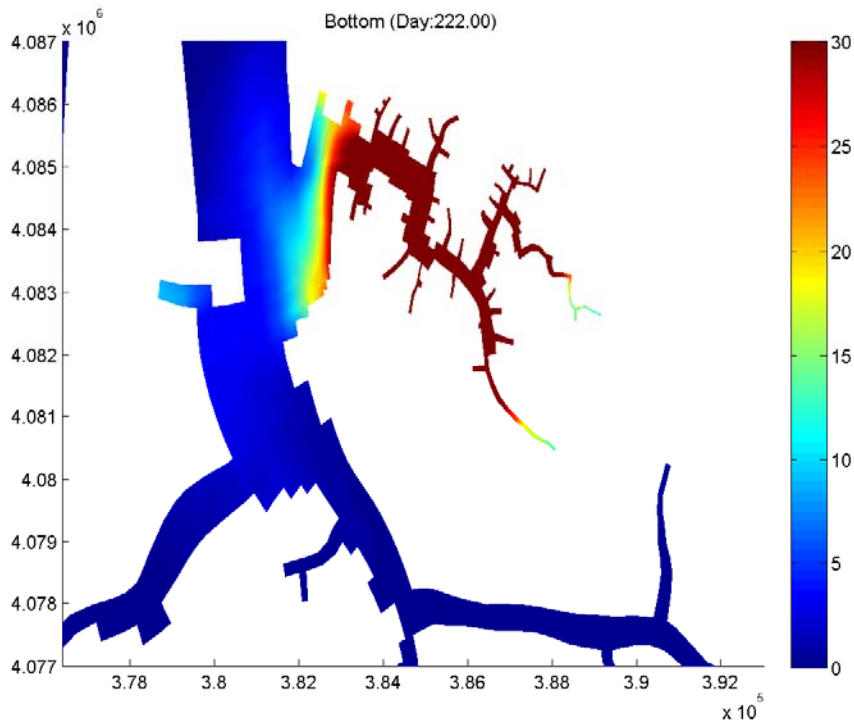


Figure B6. Larval distribution in Elizabeth River at bottom layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 3.

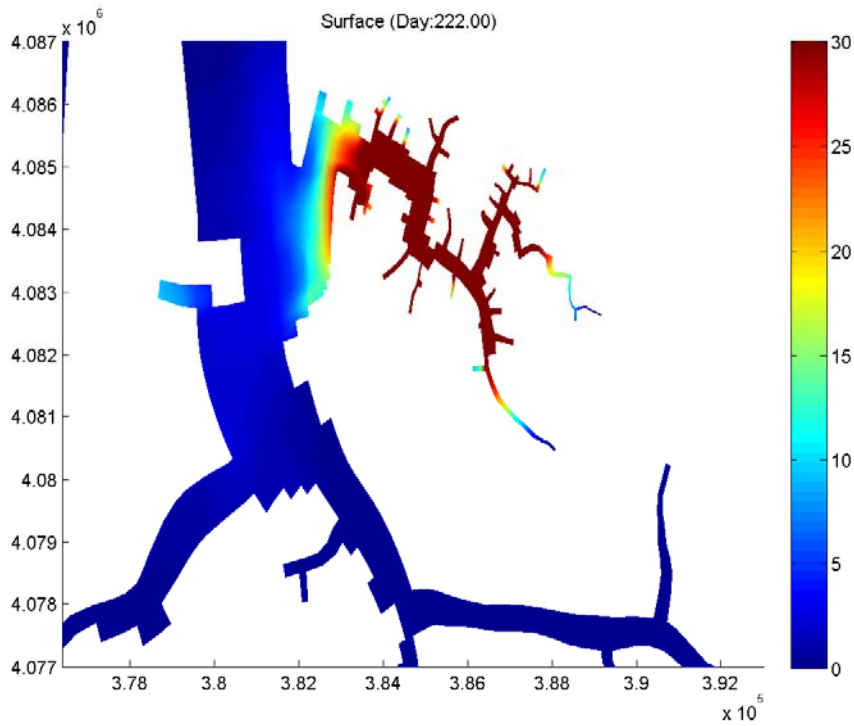


Figure B7. Larval distribution in Elizabeth River at surface layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 4.

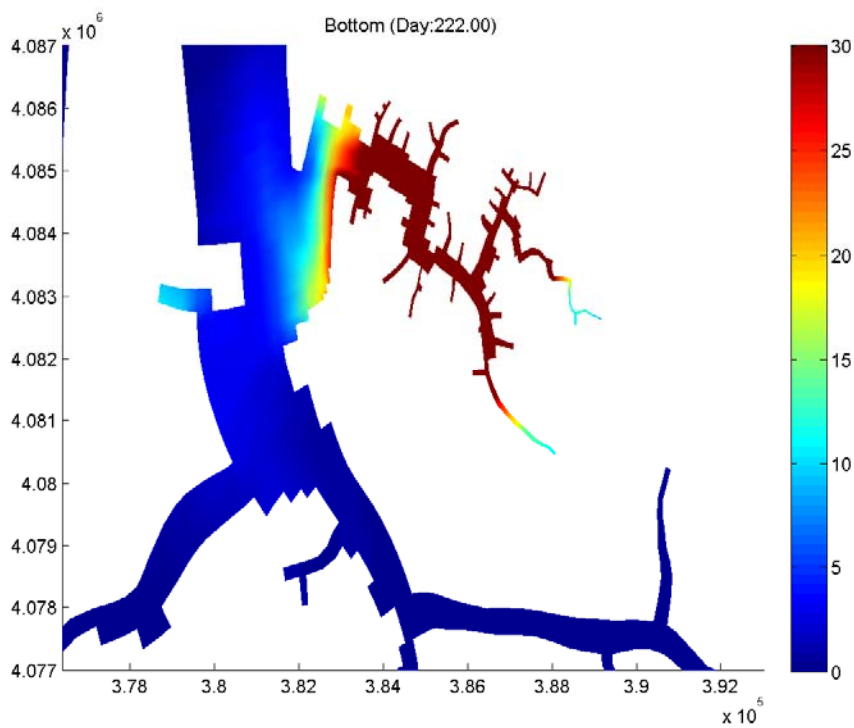


Figure B8. Larval distribution in Elizabeth River at bottom layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 4.

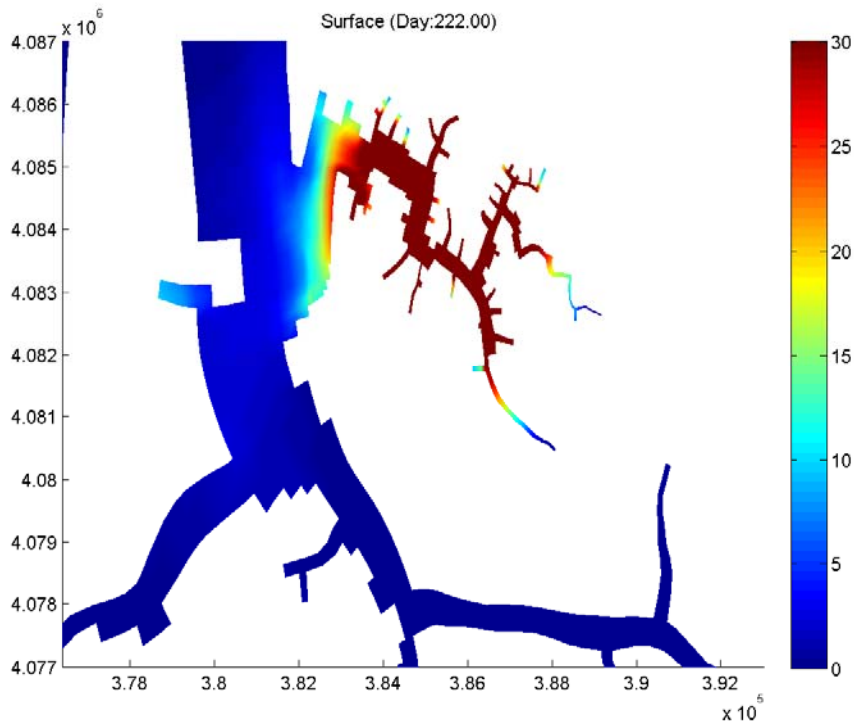


Figure B9. Larval distribution in Elizabeth River at surface layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 5.

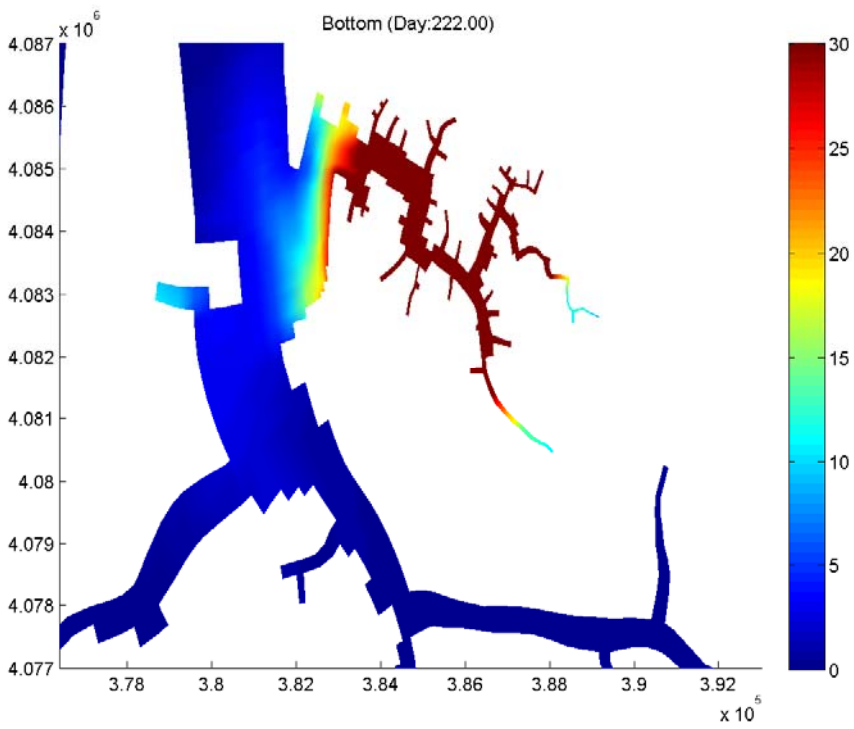


Figure B10. Larval distribution in Elizabeth River at bottom layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 5.

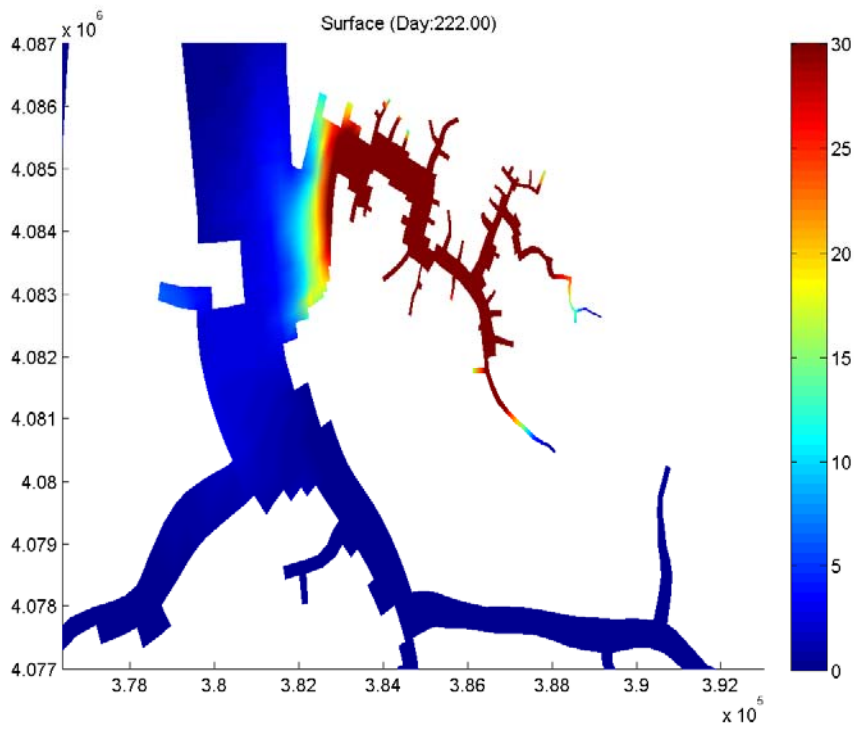


Figure B11. Larval distribution in Elizabeth River at surface layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 6.

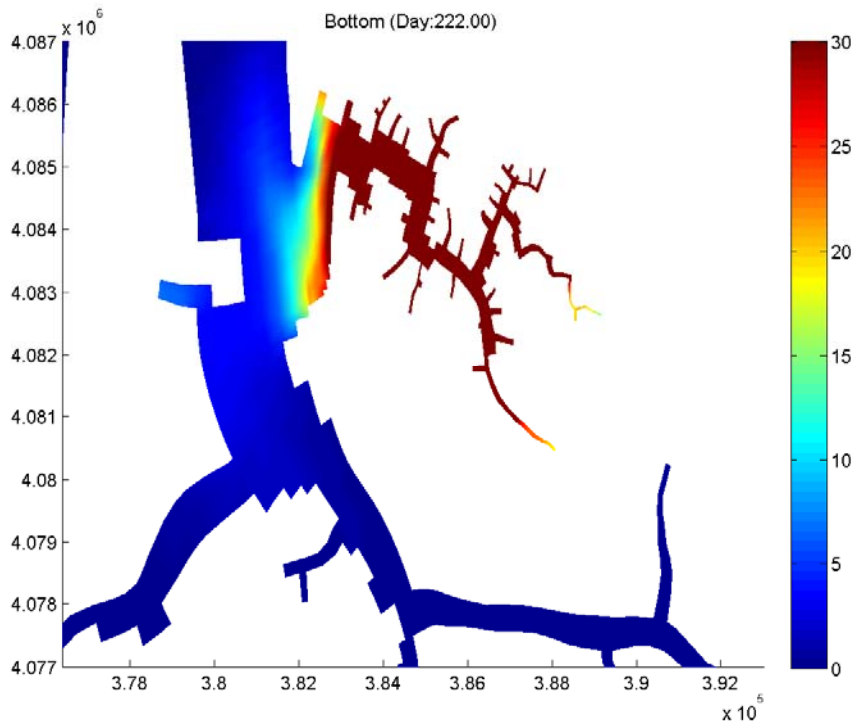


Figure B12. Larval distribution in Elizabeth River at bottom layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 6.

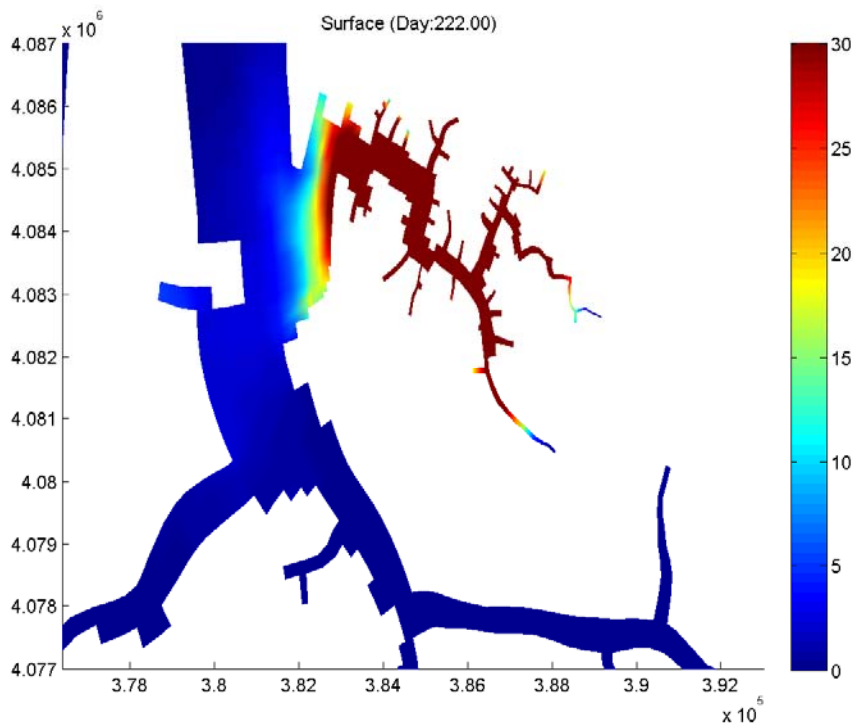


Figure B13. Larval distribution in Elizabeth River at surface layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 7.

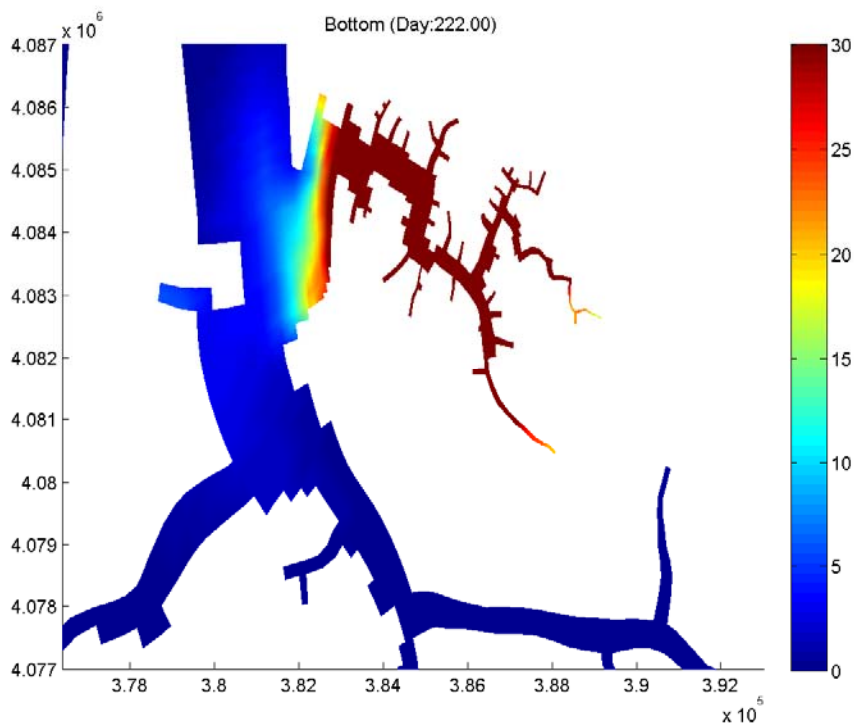


Figure B14. Larval distribution in Elizabeth River at bottom layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 7.

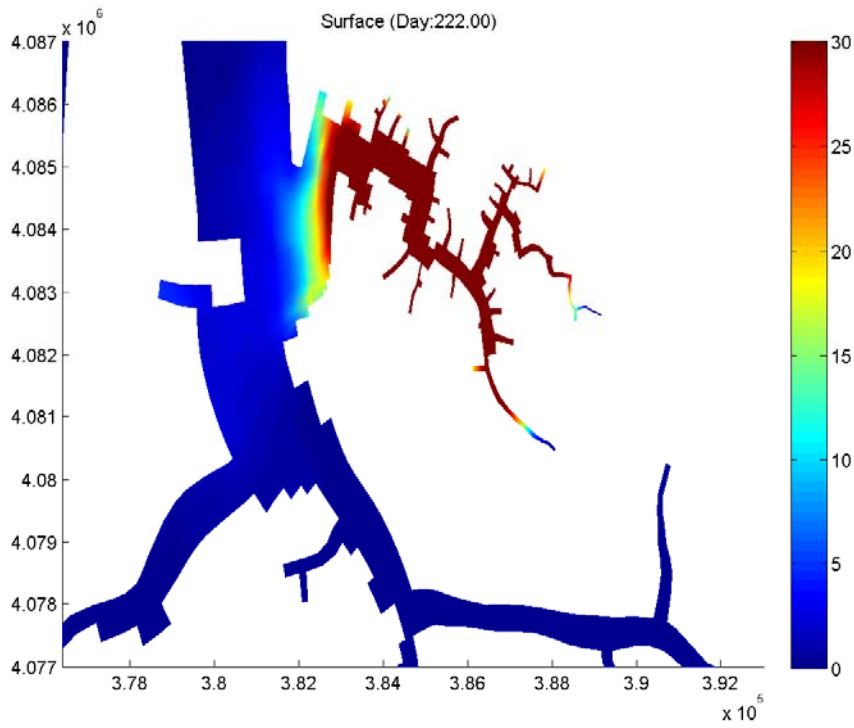


Figure B15. Larval distribution in Elizabeth River at surface layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 8.

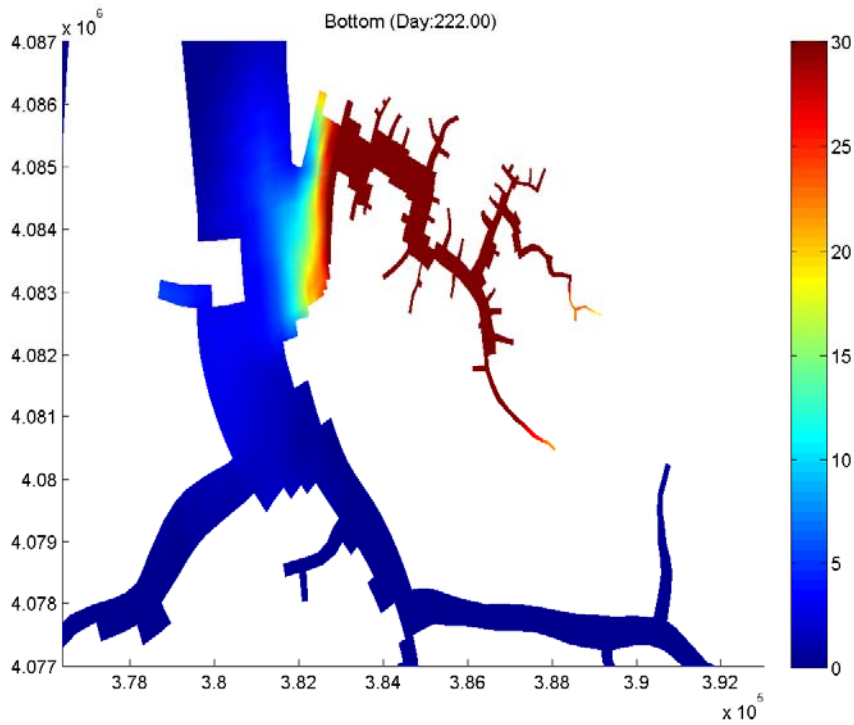


Figure B16. Larval distribution in Elizabeth River at bottom layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 8.

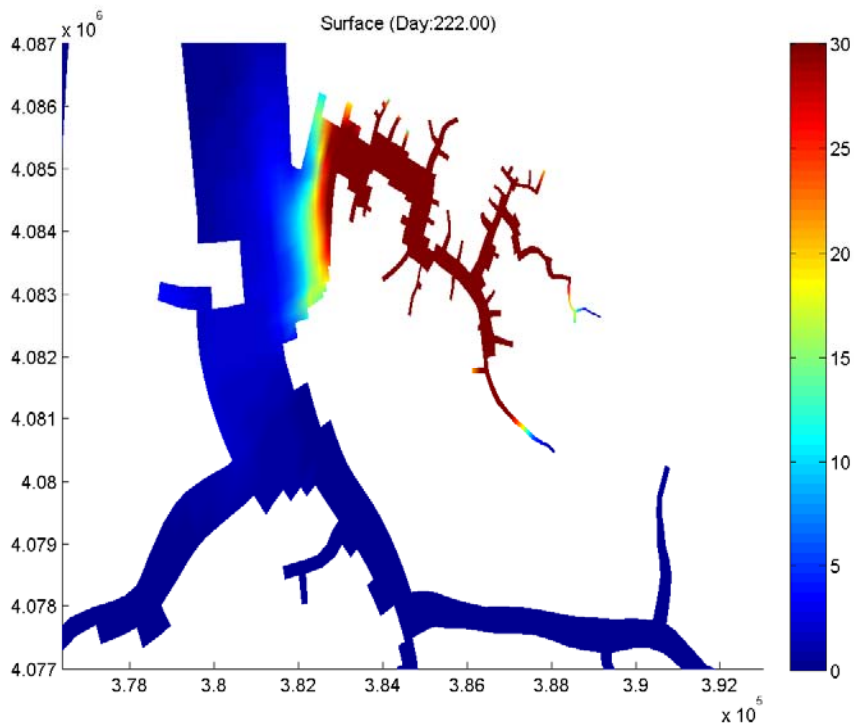


Figure B17. Larval distribution in Elizabeth River at surface layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 9.

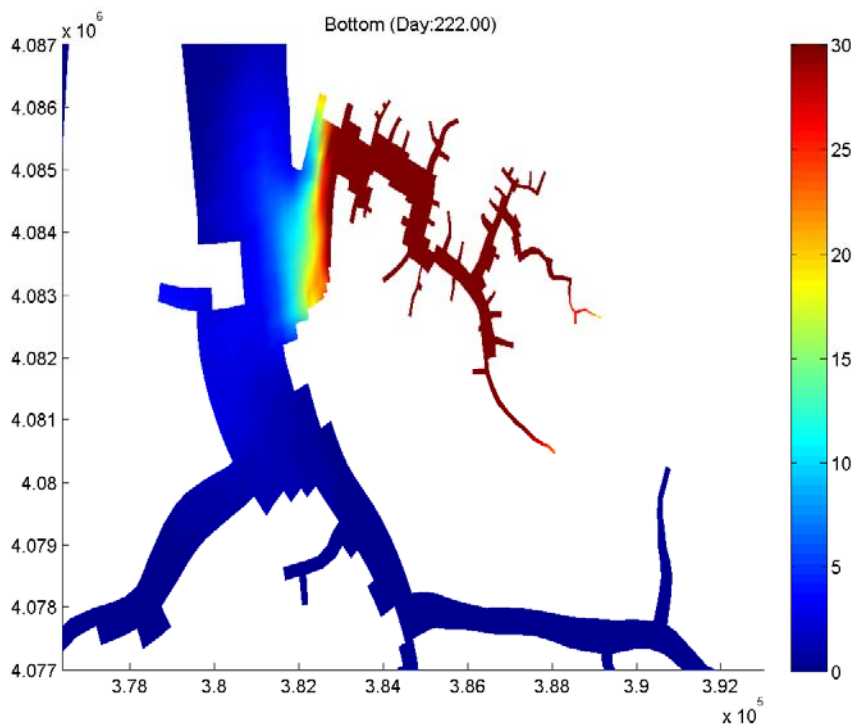


Figure B18. Larval distribution in Elizabeth River at bottom layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 9.

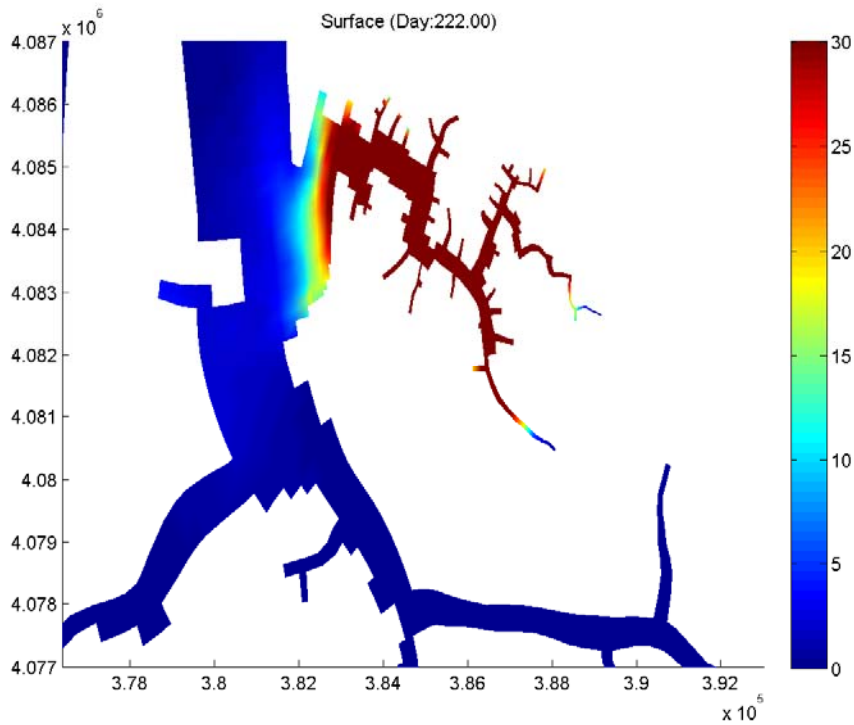


Figure B19. Larval distribution in Elizabeth River at surface layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 10.

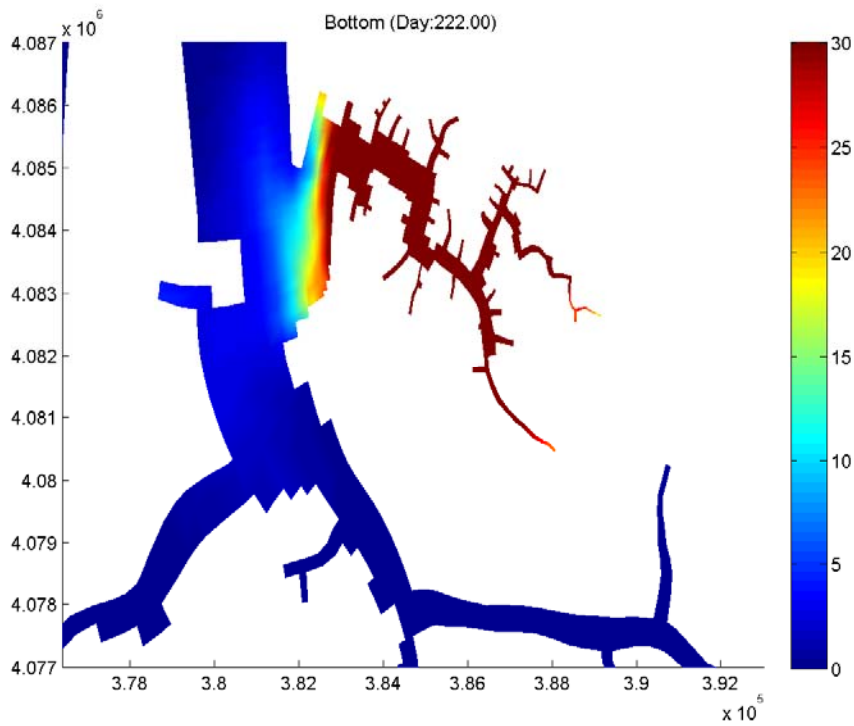


Figure B20. Larval distribution in Elizabeth River at bottom layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 10.

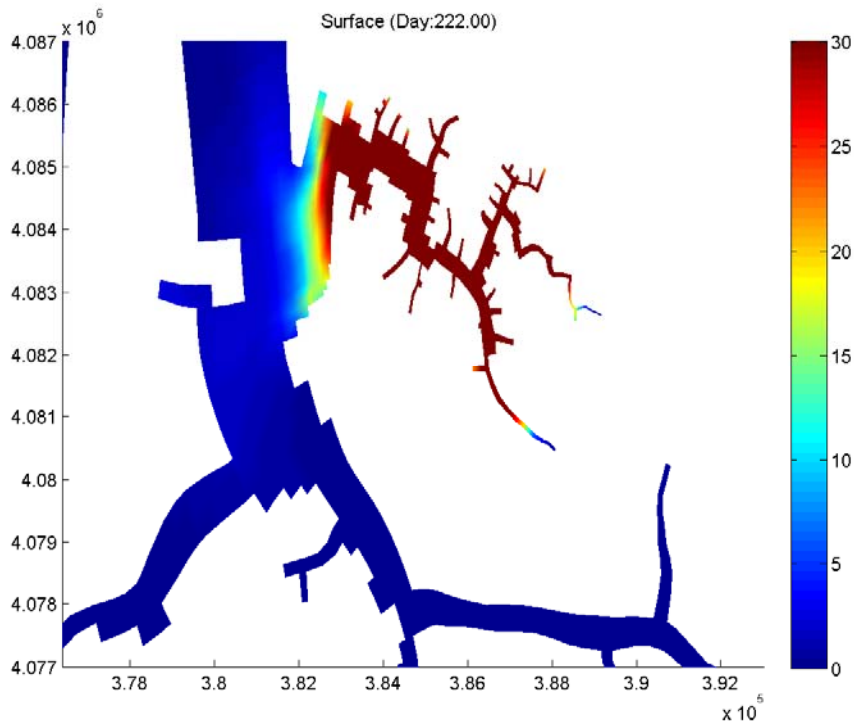


Figure B21. Larval distribution in Elizabeth River at surface layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 11.

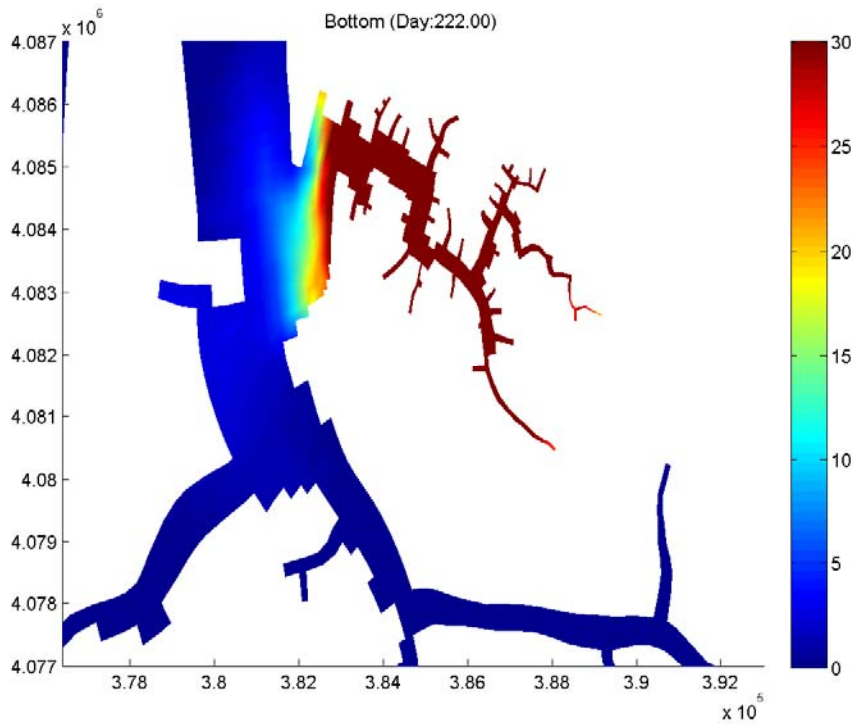


Figure B22. Larval distribution in Elizabeth River at bottom layer for Day 222, twenty days after an instantaneous release at Lafayette River Location 11.

APPENDIX C

Results of Total Larvae that Settle to Each Reef

Hydrodynamic Simulations without local runoff

11 Release Locations in the Lafayette River (see figure on report cover)

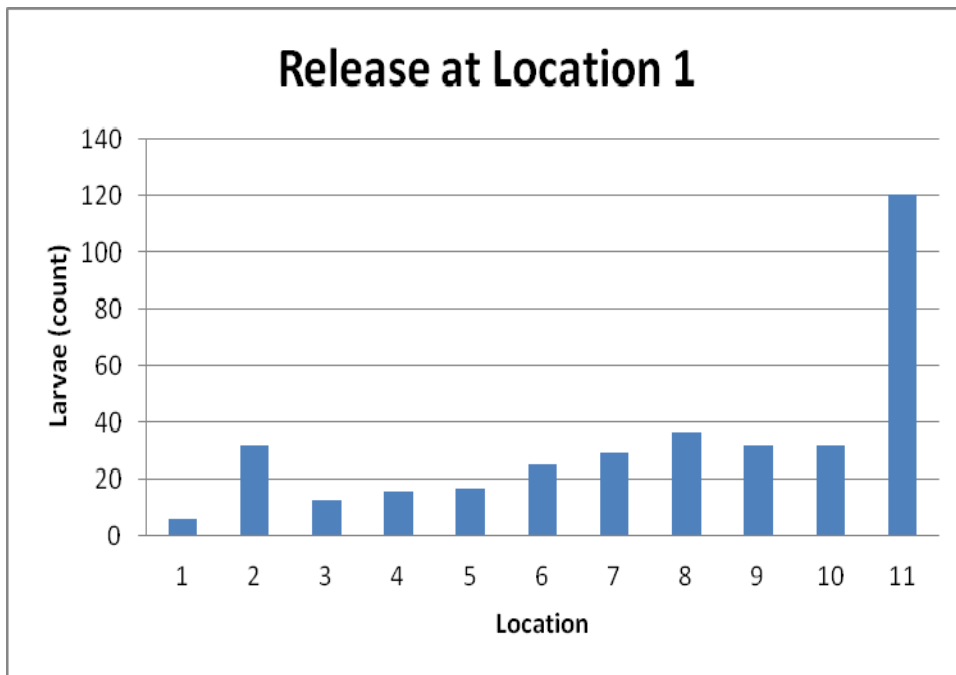


Figure C1. Results of Larvae Settlement Totals at all release points for Day 222, twenty days after an instantaneous release at Lafayette River Location 1.

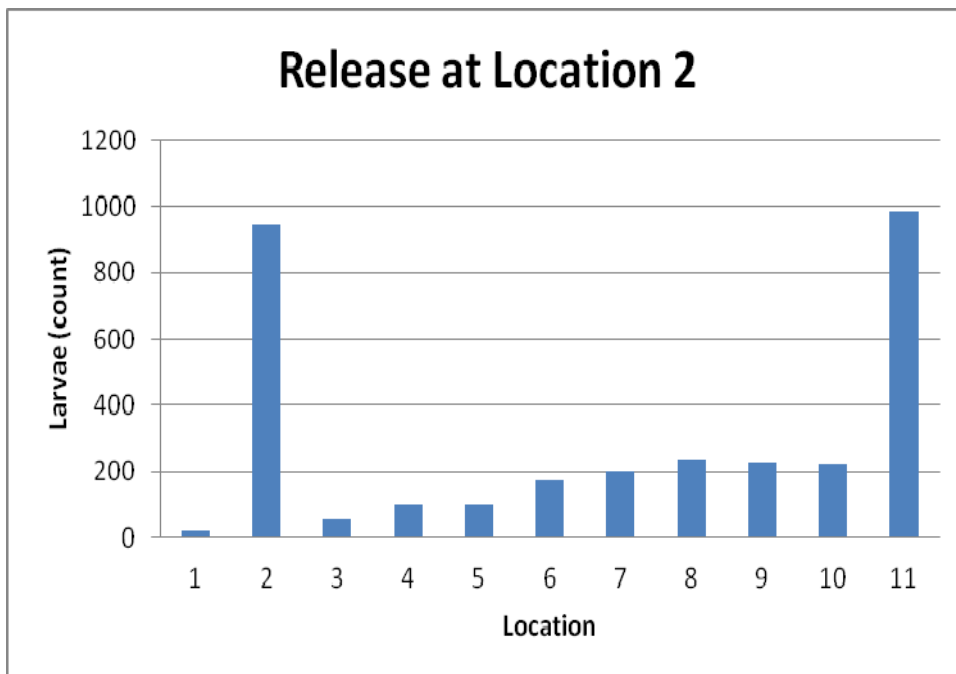


Figure C2. Results of Larvae Settlement Totals at all release points for Day 222, twenty days after an instantaneous release at Lafayette River Location 2.

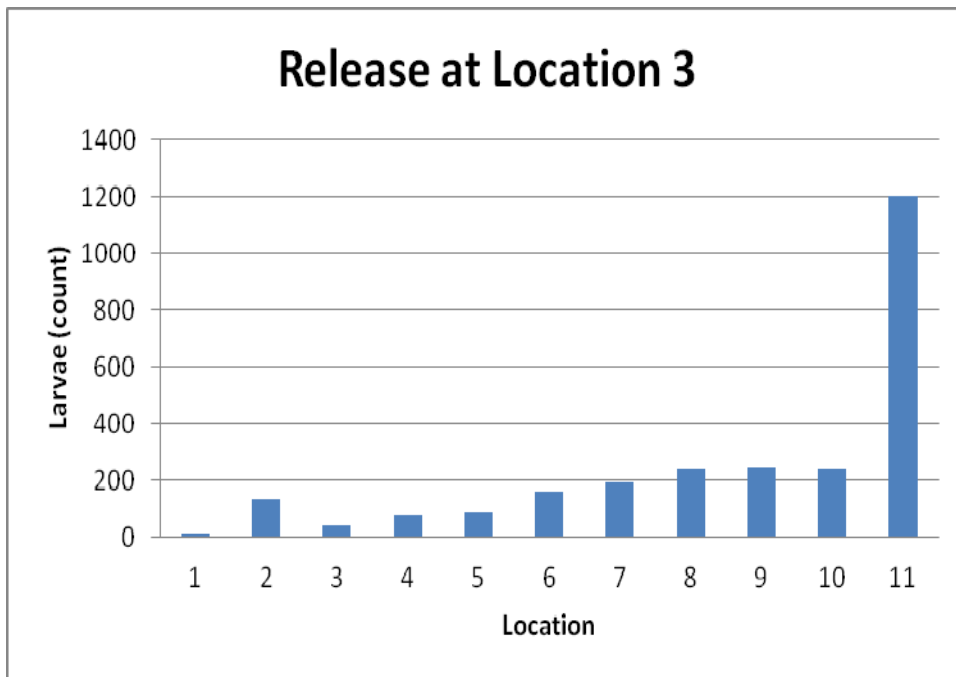


Figure C3. Results of Larvae Settlement Totals at all release points for Day 222, twenty days after an instantaneous release at Lafayette River Location 3.

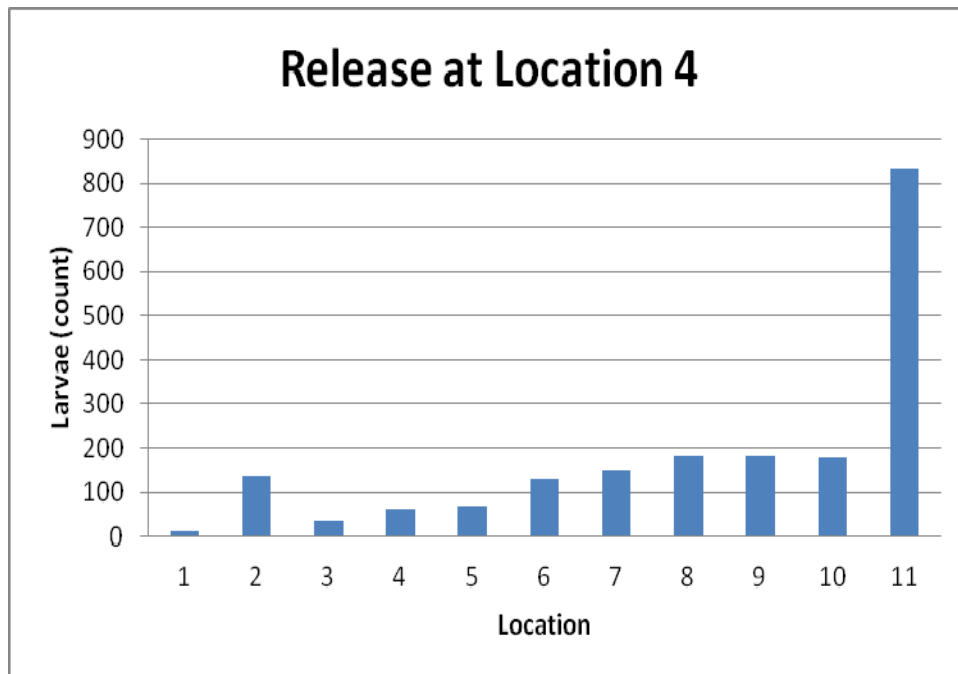


Figure C4. Results of Larvae Settlement Totals at all release points for Day 222, twenty days after an instantaneous release at Lafayette River Location 4.

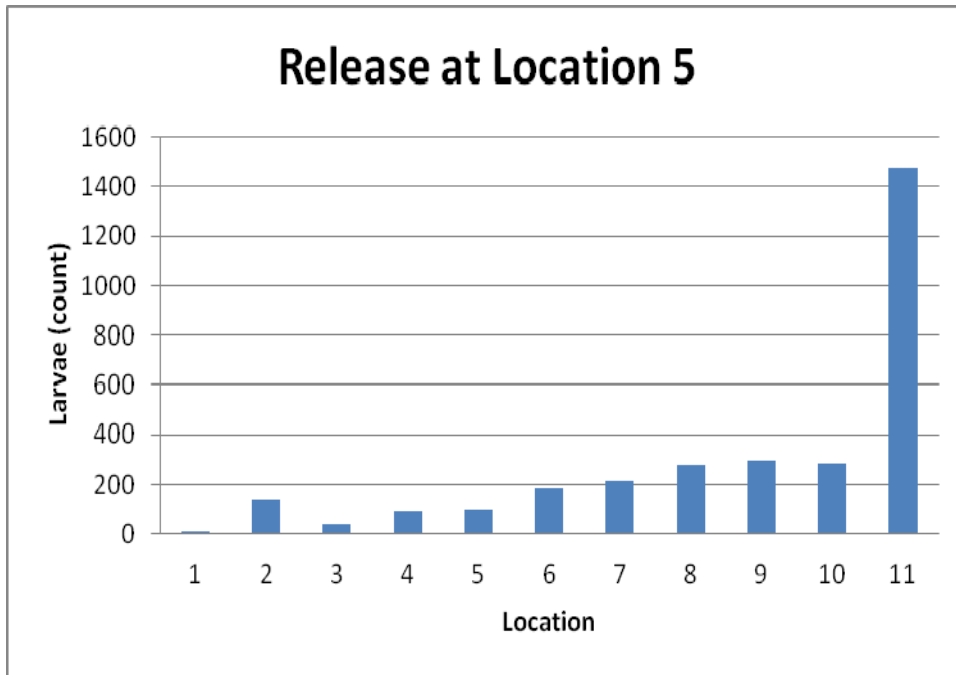


Figure C5. Results of Larvae Settlement Totals at all release points for Day 222, twenty days after an instantaneous release at Lafayette River Location 5.

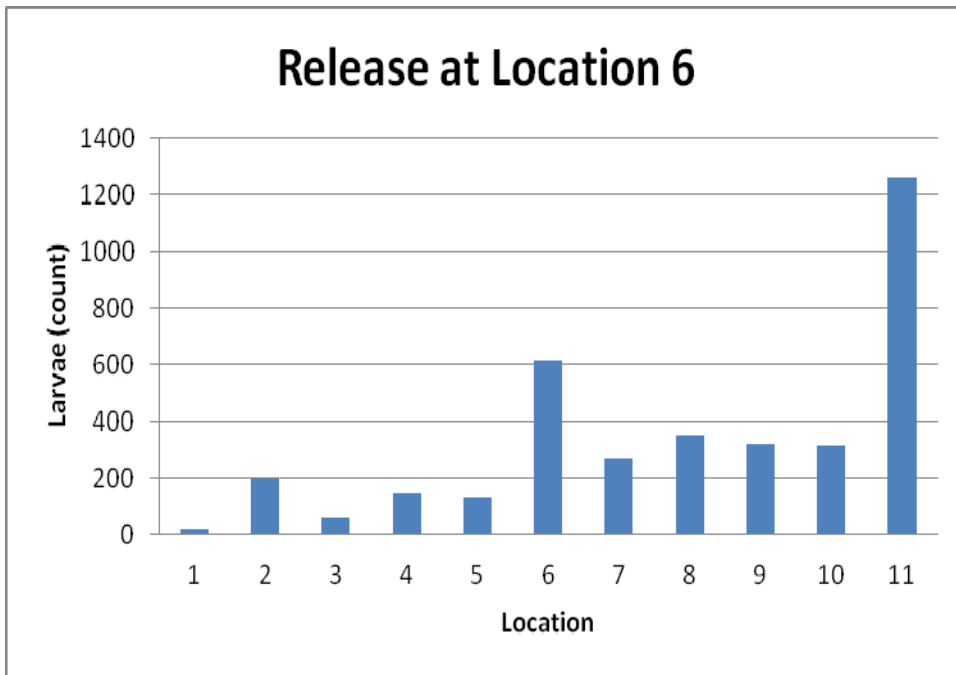


Figure C6. Results of Larvae Settlement Totals at all release points for Day 222, twenty days after an instantaneous release at Lafayette River Location 6.

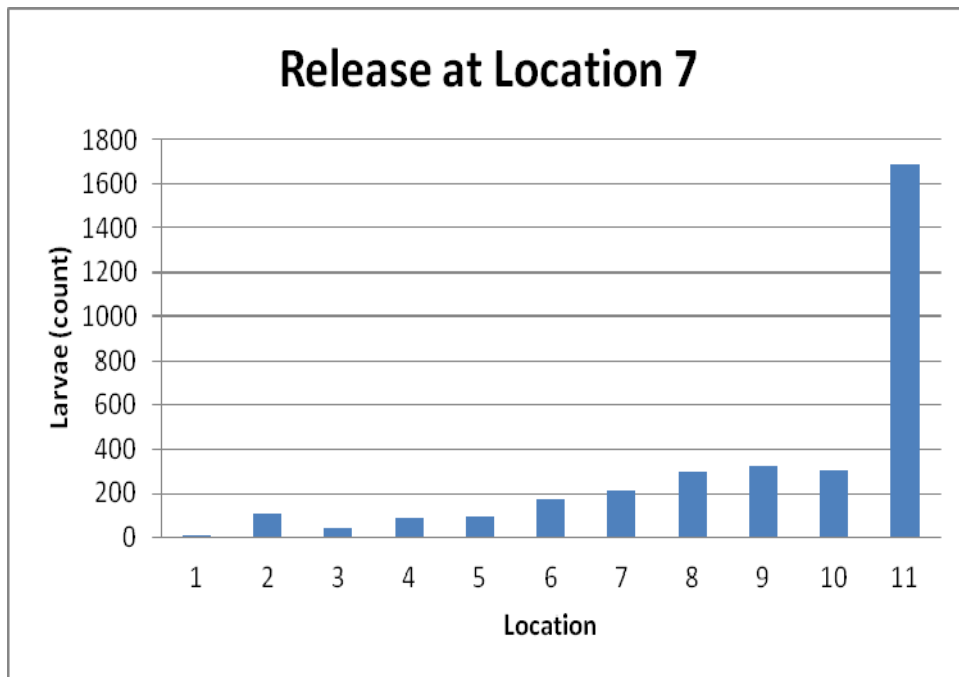


Figure C7. Results of Larvae Settlement Totals at all release points for Day 222, twenty days after an instantaneous release at Lafayette River Location 7.

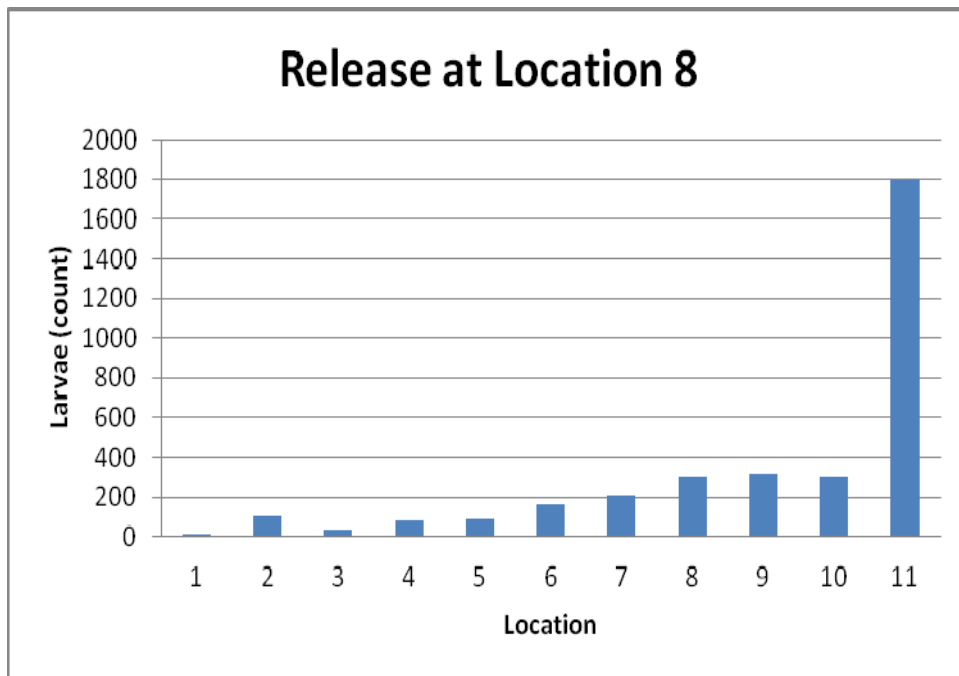


Figure C8. Results of Larvae Settlement Totals at all release points for Day 222, twenty days after an instantaneous release at Lafayette River Location 8.

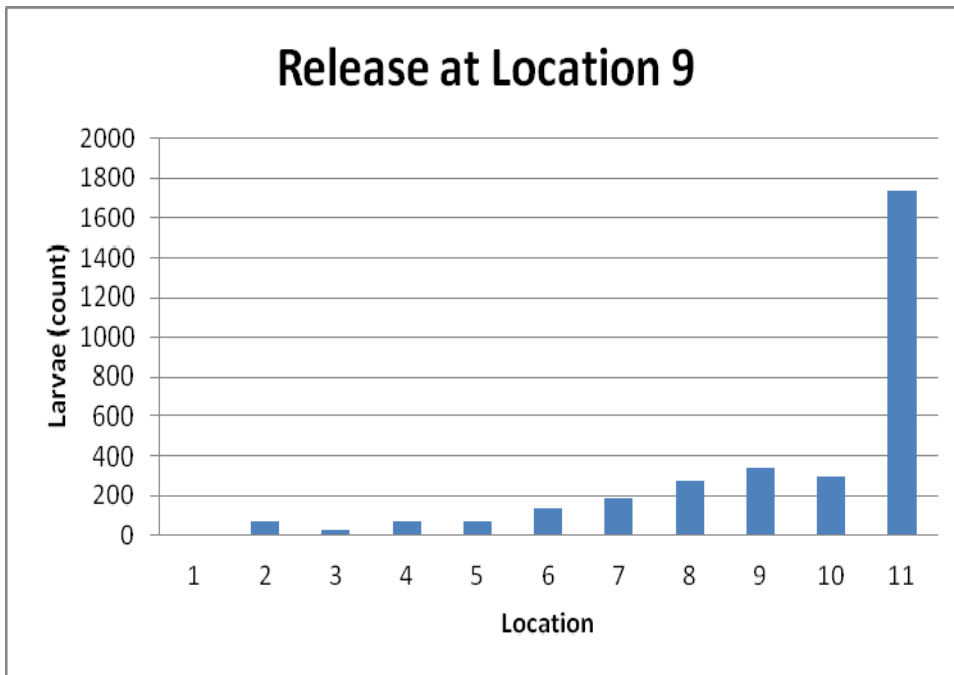


Figure C9. Results of Larvae Settlement Totals at all release points for Day 222, twenty days after an instantaneous release at Lafayette River Location 9.

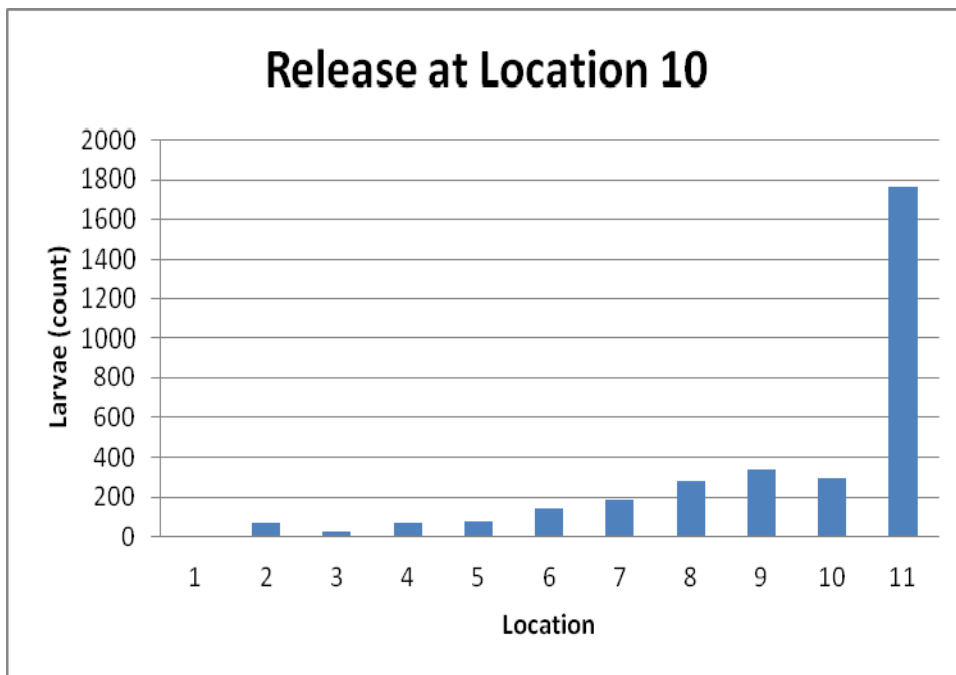


Figure C10. Results of Larvae Settlement Totals at all release points for Day 222, twenty days after an instantaneous release at Lafayette River Location 10.

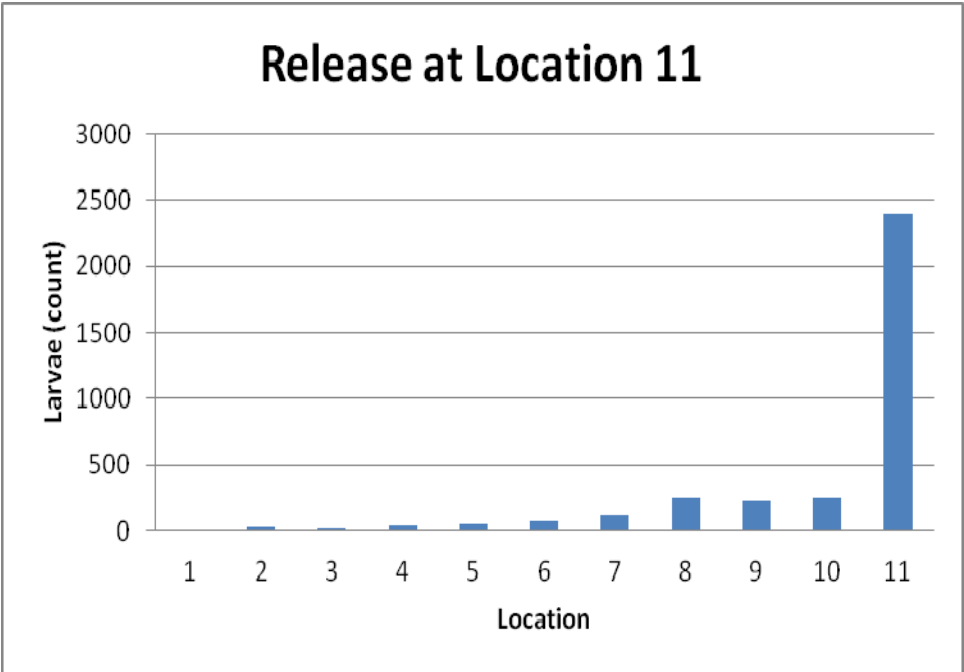


Figure C11. Results of Larvae Settlement Totals at all release points for Day 222, twenty days after an instantaneous release at Lafayette River Location 11.

APPENDIX D

Results of Total Larvae that Settle to Each Reef

Hydrodynamic Simulations with local runoff

11 Release Locations in the Lafayette River (see figure on report cover)

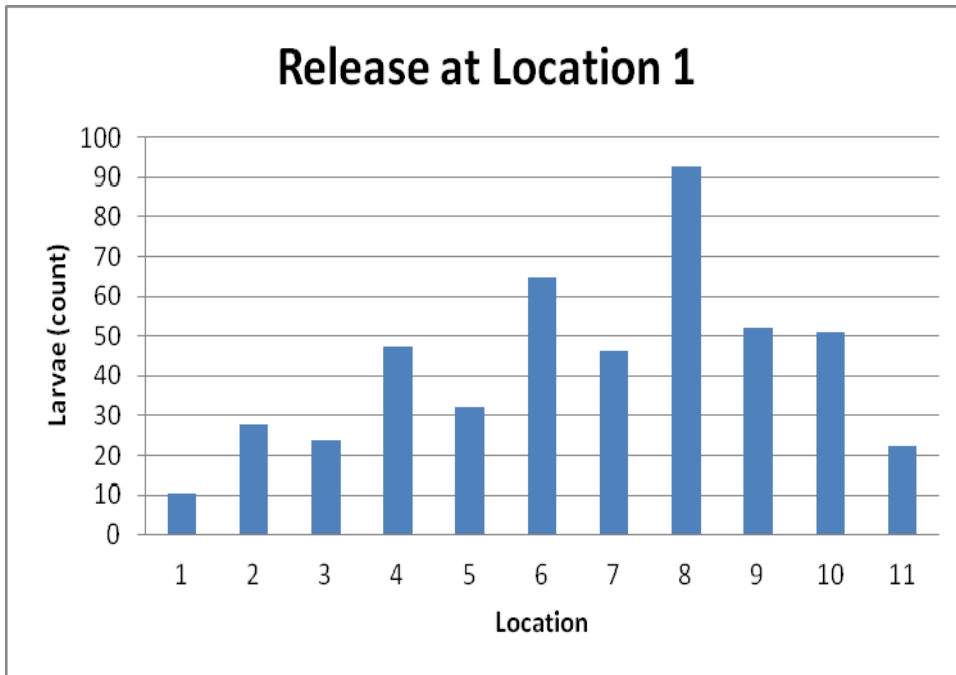


Figure D1. Results of Larvae Settlement Totals at all release points for Day 222, twenty days after an instantaneous release at Lafayette River Location 1.

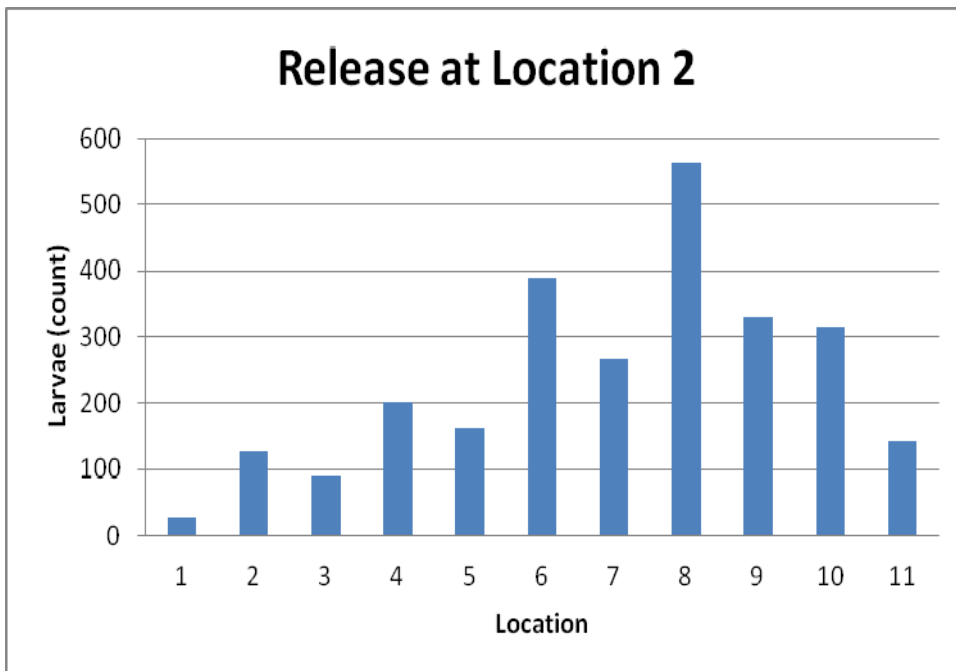


Figure D2. Results of Larvae Settlement Totals at all release points for Day 222, twenty days after an instantaneous release at Lafayette River Location 2.

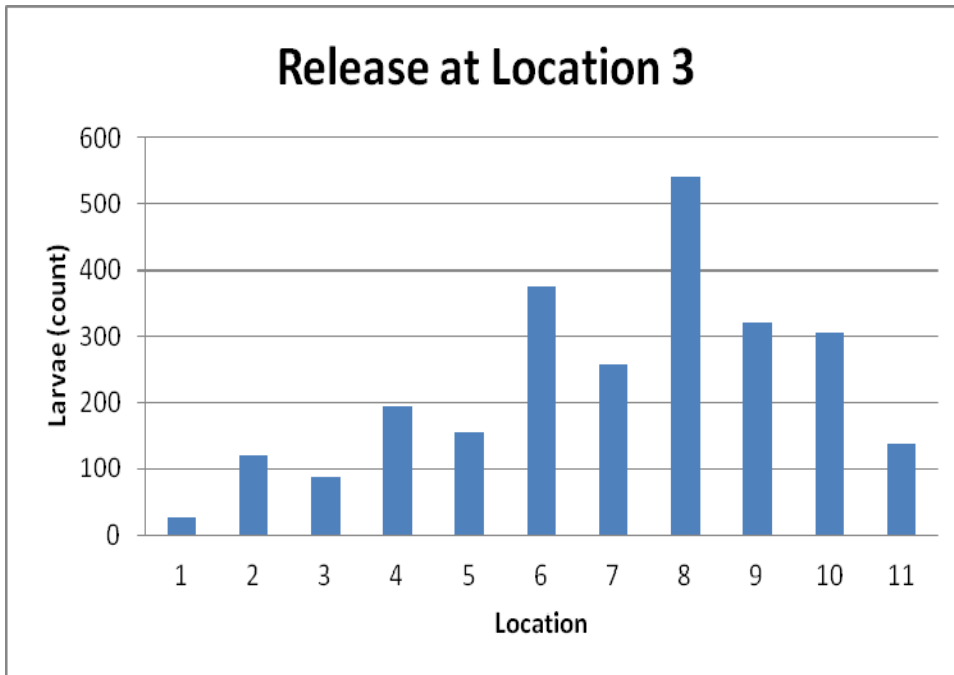


Figure D3. Results of Larvae Settlement Totals at all release points for Day 222, twenty days after an instantaneous release at Lafayette River Location 3.

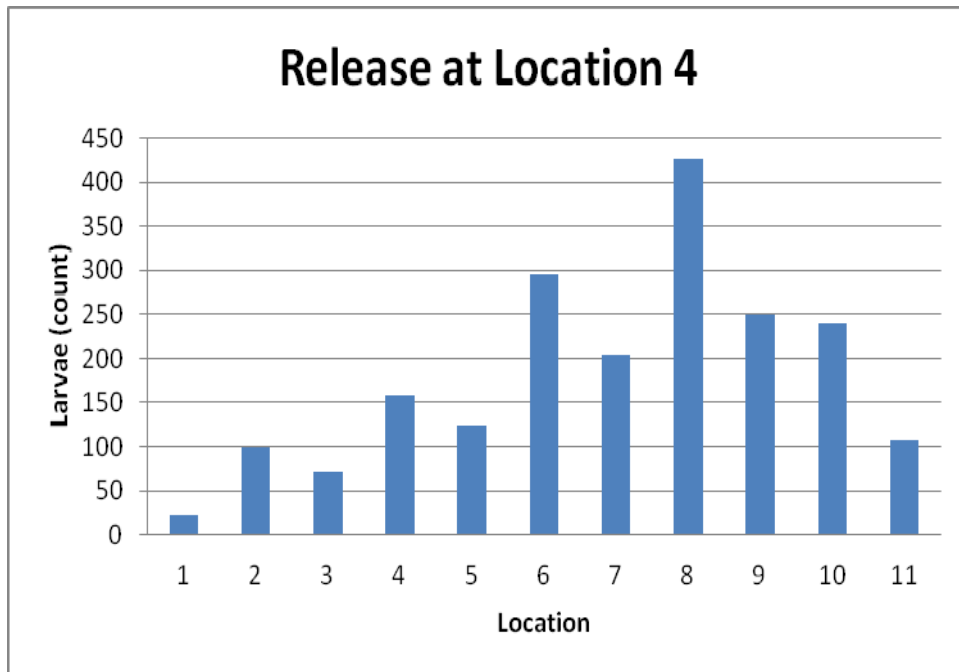


Figure D4. Results of Larvae Settlement Totals at all release points for Day 222, twenty days after an instantaneous release at Lafayette River Location 4.

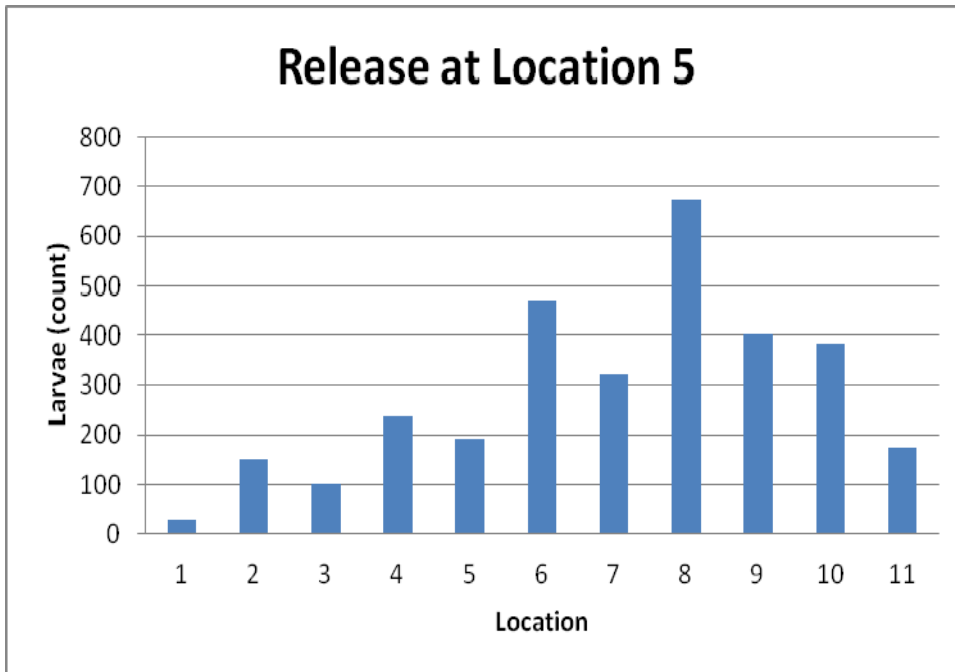


Figure D5. Results of Larvae Settlement Totals at all release points for Day 222, twenty days after an instantaneous release at Lafayette River Location 5.

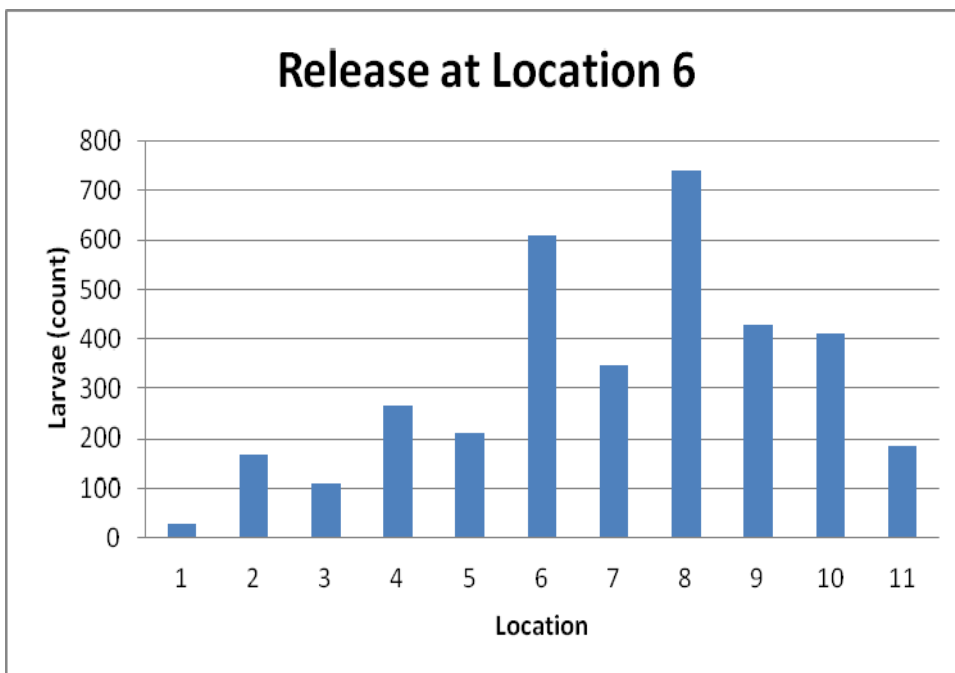


Figure D6. Results of Larvae Settlement Totals at all release points for Day 222, twenty days after an instantaneous release at Lafayette River Location 6.

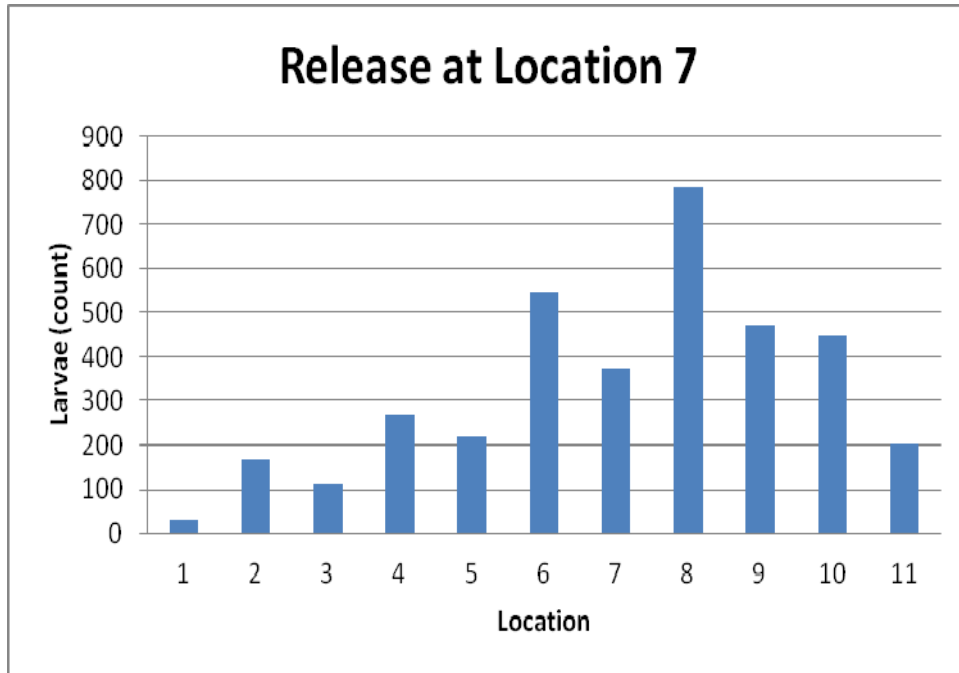


Figure D7. Results of Larvae Settlement Totals at all release points for Day 222, twenty days after an instantaneous release at Lafayette River Location 7.

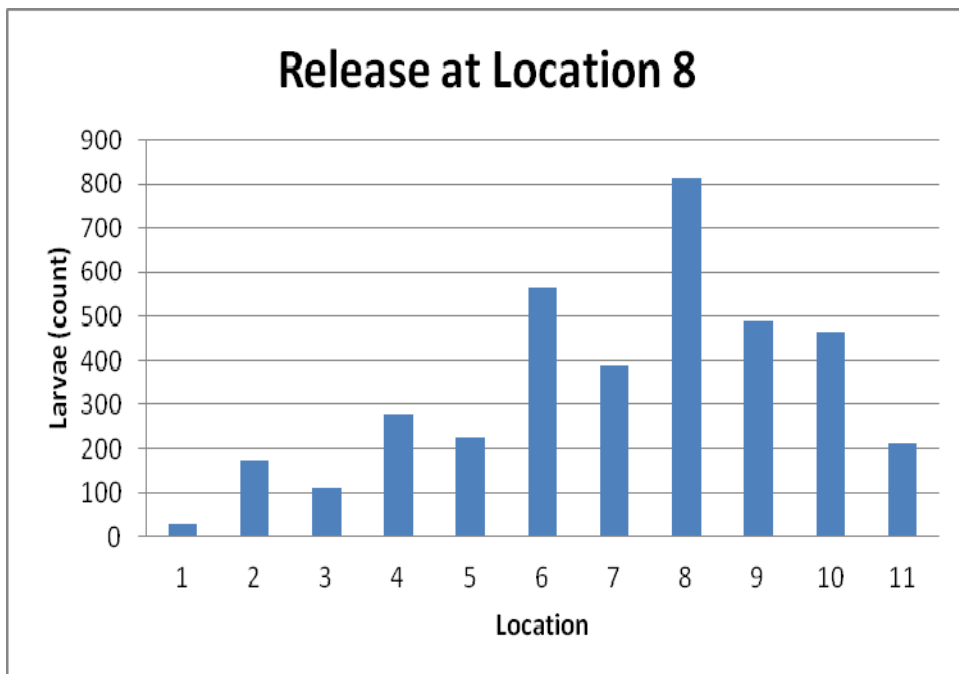


Figure D8. Results of Larvae Settlement Totals at all release points for Day 222, twenty days after an instantaneous release at Lafayette River Location 8.

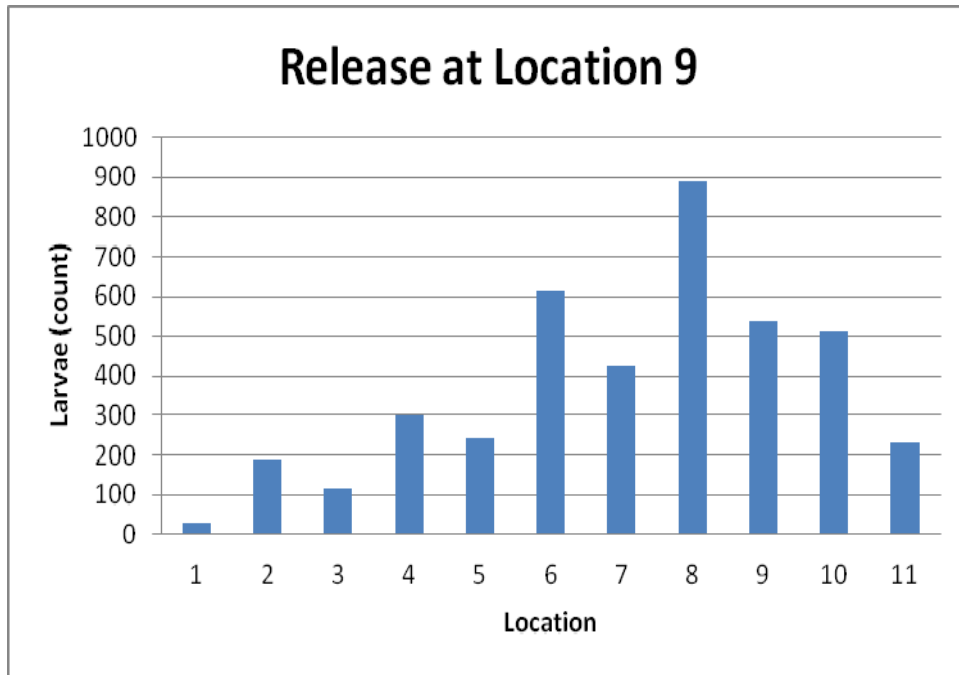


Figure D9. Results of Larvae Settlement Totals at all release points for Day 222, twenty days after an instantaneous release at Lafayette River Location 9.

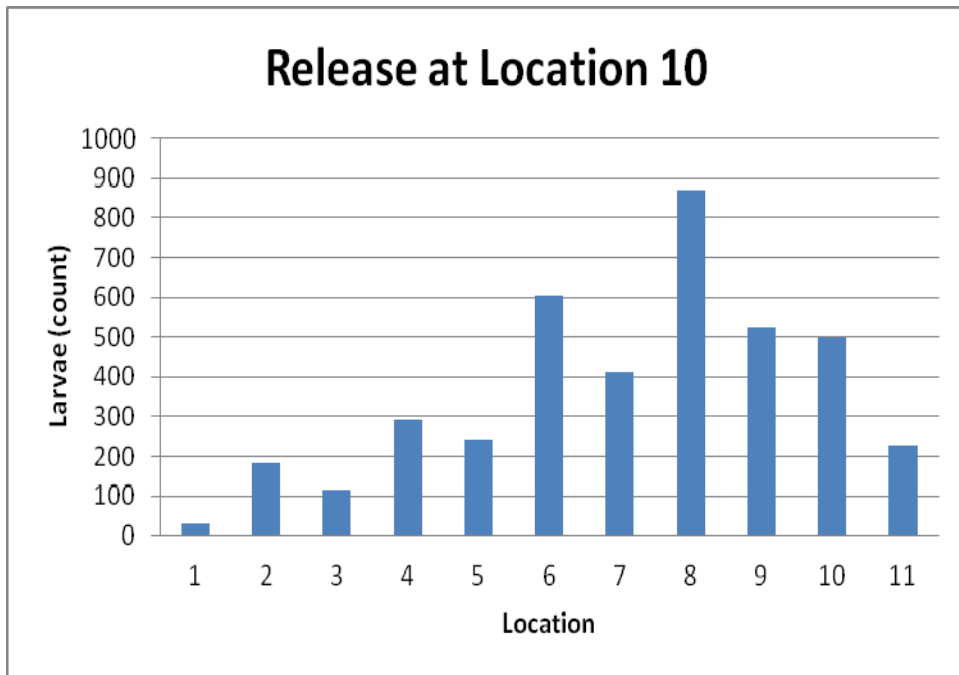


Figure D10. Results of Larvae Settlement Totals at all release points for Day 222, twenty days after an instantaneous release at Lafayette River Location 10.



Figure D11. Results of Larvae Settlement Totals at all release points for Day 222, twenty days after an instantaneous release at Lafayette River Location 11.