# Vieques Sound and Virgin Passage
# Larval Transport Assessment

NOAA Coral Reef Conservation Program
US Caribbean Coral Reef Ecosystem Connectivity:
Vieques Sound and Virgin Passage Transport Study
Project ID: 20416 – 2011
Document Version: 1.2

**OVERVIEW:**

***Vieques Sound and Virgin Passage Volume Transport***

As the primary component of the NOAA Coral Reef Conservation Program (CRCP) *US Caribbean Coral Reef Ecosystem Connectivity: Vieques Sound and Virgin Passage Transport Study*, an array of moored acoustic Doppler current profilers (ADCP) was deployed in the US Caribbean from March 3, 2010 through April 22, 2011. This array consisted of six moorings and was configured to quantify the volume transport of water across the coastal shelf at two locations. Three moorings were deployed between the Puerto Rican islands of Vieques and Culebra at the eastern end of Vieques Sound, and three moorings were deployed between the islands of Culebra, Puerto Rico and St. Thomas, United States Virgin Islands (USVI) in Virgin Passage (Fig. 1).

Hourly velocity data recorded by each moored instrument were combined to create hourly velocity sections for each passage. The Vieques Sound sections produced from these data are 15.2 km wide with cross-sectional areas of 0.38 $km^2$. These sections are oriented at a bearing of 25° from Vieques towards Culebra, approximately normal to the axis of Vieques Sound. The sections produced for Virgin Passage are 22.5 km wide with cross-sectional areas of 0.59 $km^2$. These sections are oriented along the sill of the passage, at a bearing of 77° from Culebra towards St. Thomas. The maximum depth of the Vieques Sound sections is 29 m; the maximum depth of the Virgin Passage sections is 32 m. Velocity observations were rotated to yield the component of flow crossing each section. Hourly volume transport calculations were made from the velocity sections generated where all three moorings were reporting.

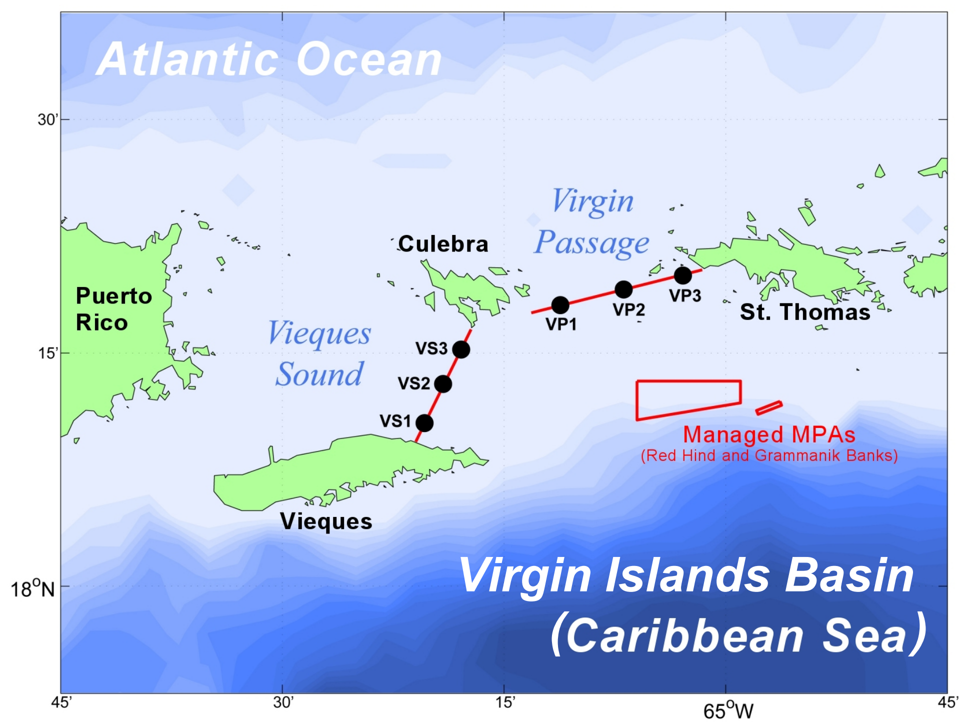



Figure 1. Vieques Sound and Virgin Passage sections and mooring locations.

Findings from the project moored ADCP array are discussed in the *Vieques Sound and Virgin Passage 2010-2011 Moored Array Transport Summary* (hereafter TRANS_SUM), archived in NOAA's Coral Reef Information System (CoRIS). This document may be directly accessed at:

*http://data.nodc.noaa.gov/coris/library/NOAA/CRCP/project/20689/Vieques_Sound_and_Virgin_Passage_Transport_Summary.pdf*

The bathymetry of each channel and the corresponding mean velocity section produced from the moored array data are shown in Figures 2 and 3 (reproduced from TRANS_SUM). The locations of the moored ADCPs are indicated with yellow markers. All contours are plotted in cm $s^{-1}$ and represent the mean flow normal (perpendicular) to the section (red lines shown in Figure 1). For Vieques Sound, positive values represent flow moving from the Virgin Islands Basin (VIB) into the sound. For Virgin Passage, positive values indicate flow moving from the VIB, through the passage into the Atlantic Ocean.

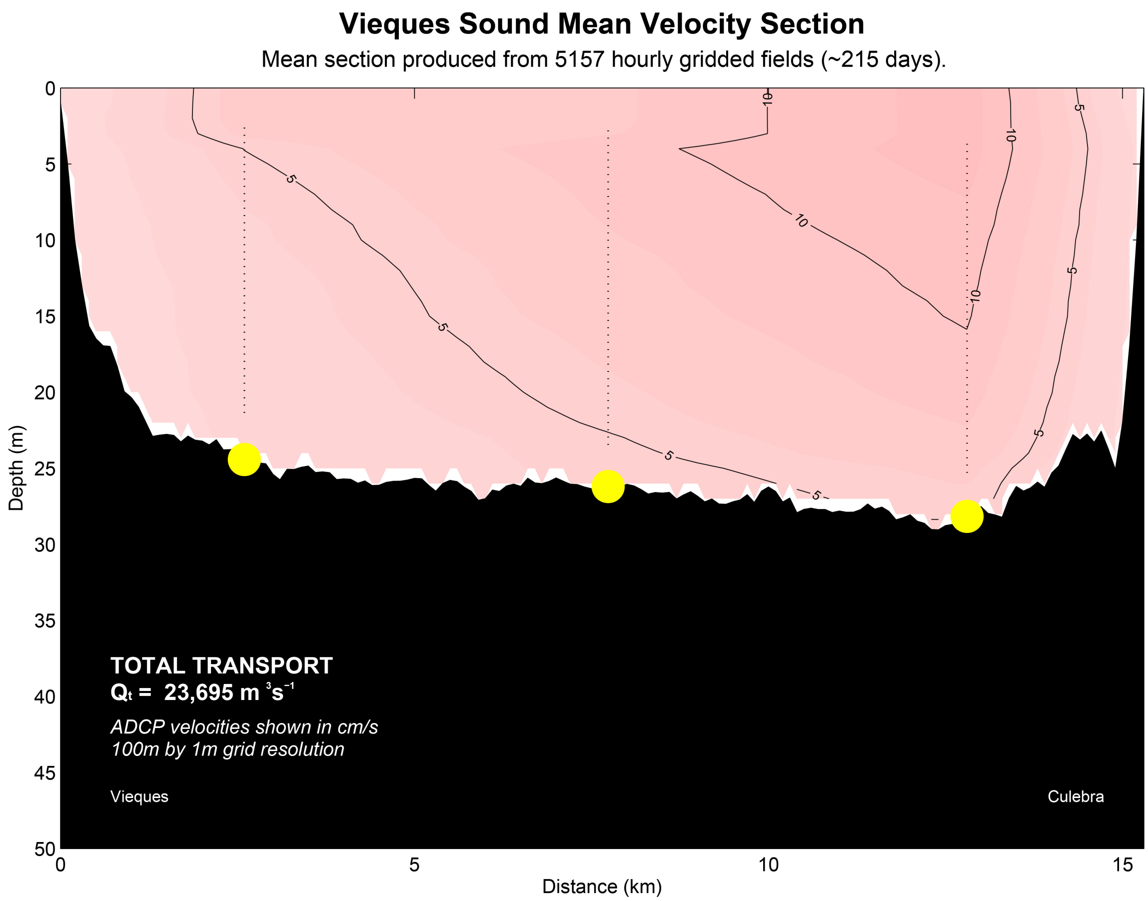



Figure 2. The Vieques Sound 215-day mean velocity section is shown above. ADCP mooring locations are indicated with yellow markers. Velocities shoreward of the moorings have been extrapolated (see TRANS_SUM for further details). The mean transport for the period of the moored array deployment was found to be 23,695 $m^3s^{-1}$.

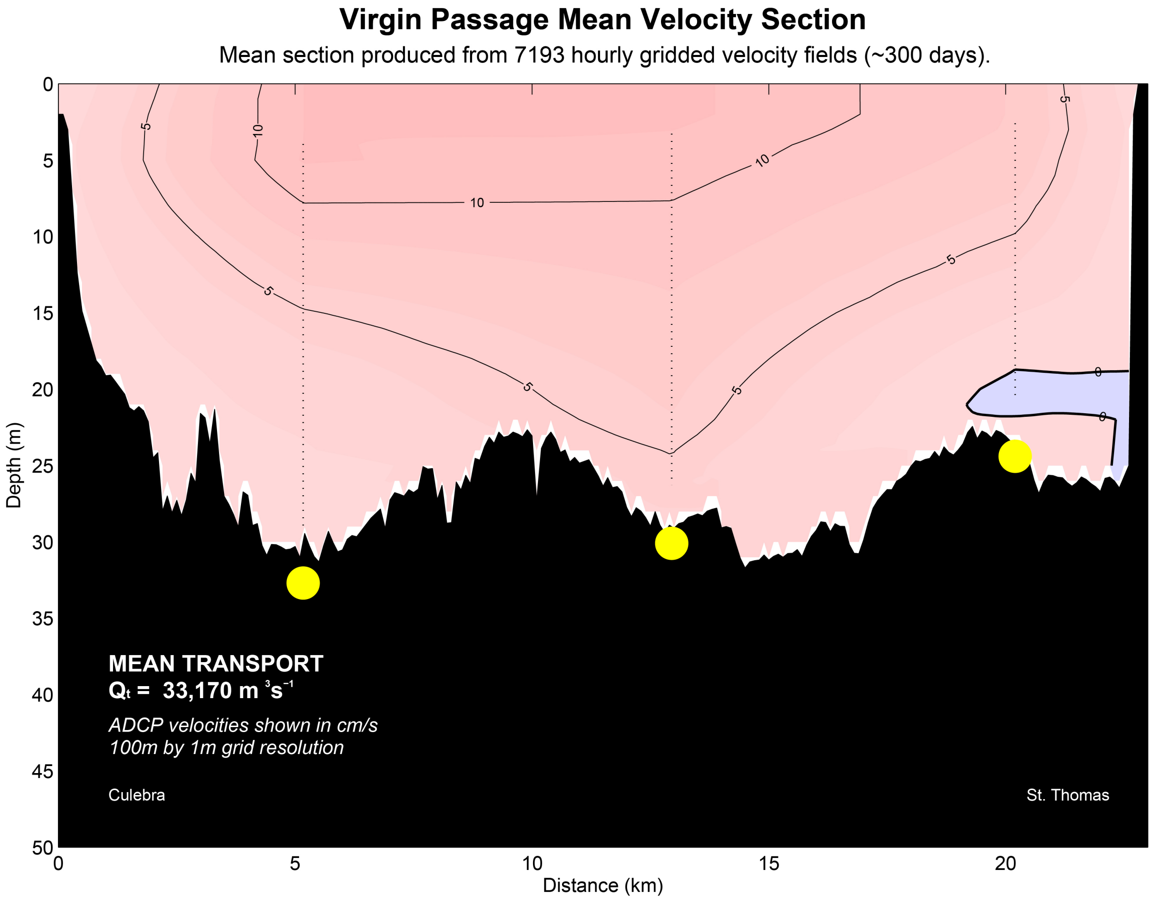
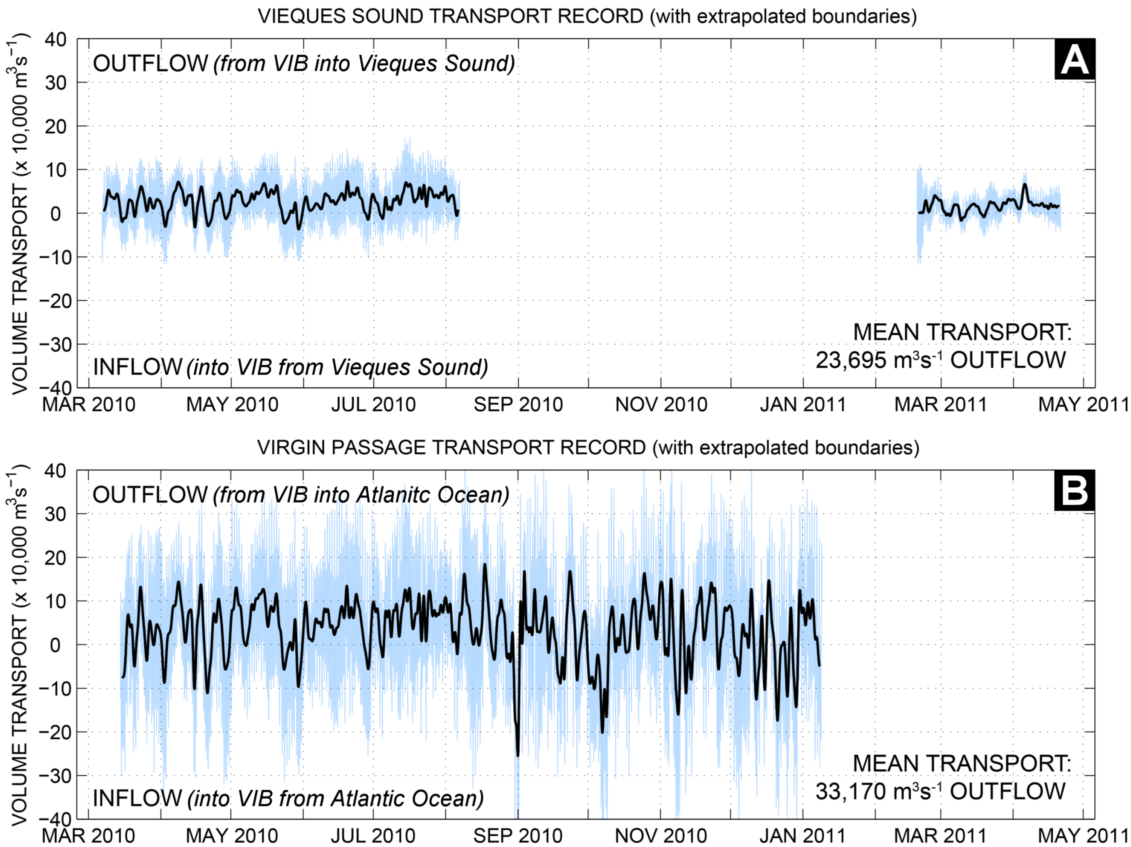



Figure 3. The Virgin Passage 300-day mean velocity section is shown above. ADCP mooring locations are indicated with yellow markers. Velocities shoreward of the moorings have been extrapolated (see TRANS_SUM for further details). The mean transport for the period of the moored array deployment was found to be 31,170 $m^3s^{-1}$.

Volume transport time-series for the Vieques Sound and Virgin Passage sections are shown in Figures 4a and 4b respectively (also reprinted from TRANS_SUM). Each time-series represents the hourly section transport over the duration of the moored array deployment. The raw hourly volume transports for these plots are shown in light blue and can give one a sense of the transport magnitude associated with the tidal component of the flow. Despite a net transport outflow from the VIB through both of these sections, each section typically experiences an inflow period during the course of a tidal cycle. The raw hourly velocity magnitudes for Virgin Passage are much greater than for the Vieques Sound Section (light blue lines). However, when the tidal signals are filtered with a 40-hour low-pass filer (40HLP) the signal is greatly reduced (black lines). These filtered time-series are what we will use for the larval transport calculations later in this document as they represent the subtidal transport rather than the flow that is simply moving back and forth across the section with each tidal cycle. When averaged over the entire record, these time-series yield the mean volume transport for each transect.




Figures 4a and 4b. Vieques Sound (a) and Virgin Passage (b) volume transport time-series are shown above. Light blue lines indicate raw hourly transport values for each section. Black lines indicate 40HLP values (see TRANS_SUM for further details).

***Vieques Sound and Virgin Passage Ichthyoplankton Transport***

In an effort to gain a better understanding of how larval reef fish move across the Virgin Islands bank ecosystem, larval fish data gathered during annual cruises conducted aboard the NOAA Ship *Nancy Foster* from 2007 through 2009 were analyzed in conjunction with the moored ADCP data collected as part of this project.

This document will serve to provide reasonable estimates for concentrations of reef fish larvae moving across the Vieques Sound and Virgin Passage transects (Fig. 1). While the project's moored ADCP data are not concurrent with the larval reef fish data, the ~year-long record of volume transport for each section produced from the moored array data provides a time-series which may be typical of flows across each transect (and is the only data set of its kind for the region). Additionally, the ichthyoplankton densities, calculated from the larval fish collections made during the cruises across the Virgin Island banks, may not be representative of densities prevalent over the course of the entire year in which they were collected. However, these ichthyoplankton densities represent the only data with regional coverage available. With these caveats, we apply selected larval densities to the project volume transport time-series to produce theoretical larval transports for each section. Results may be relevant to regional connectivity of reef fish populations in the US Caribbean.

The ichthyoplankton families selected for analysis are:

| | |
|---|---|
| Apogonidae | (cardinalfish) |
| Gobiidae | (goby) |
| Labridae | (wrasse) |
| Lutjanidae | (snapper) |
| Scaridae | (parrotfish) |
| Serranidae | (grouper) |

**METHODS:**

For years 2007, 2008, and 2009, ichthyoplankton larvae were collected at discrete stations, shown in Figures 5-25. For the purpose of this analysis we will assume a uniform larval density with depth in the upper 50 meters (the banks of the Virgin Islands are typically shallower than 50 meters). Larvae were collected from the NOAA Ship *Nancy Foster* using either bongo nets, towed for 10 minutes at the sea surface (505 micron mesh) or nets 4 and 5 from a Multiple Opening/Closing Net and Environmental Sensing System (MOCNESS). In the case of MOCNESS tows, net 4 (50 to 25 meters depth, 505 micron mesh) and net 5 (25 to 0 meters depth, 505 micron mesh) were each towed for 10 minutes and analyzed together yielding a sample valid from 50 meters depth to the surface. Both net configurations used flow meters to monitor flow rates through the nets, and all larval densities shown here are represented as larvae per cubic meter.

For each family and each year, discrete larval densities were plotted using *Surfer 10* (Golden Software). From these distributions, density fields were contoured using the Surfer 10 kriging interpolation method. The density fields were then averaged to produce a mean density for each family in each of the three years. For comparison, a second set of mean densities was also calculated by averaging only the discrete data points at each station location. For each section, the 40HLP volume transport time-series was then multiplied by the mean larval density yielding a larval transport for each family in each of the three years.

**FINDINGS:**

Larval density plots of the six selected families are shown below for years 2007-2009.

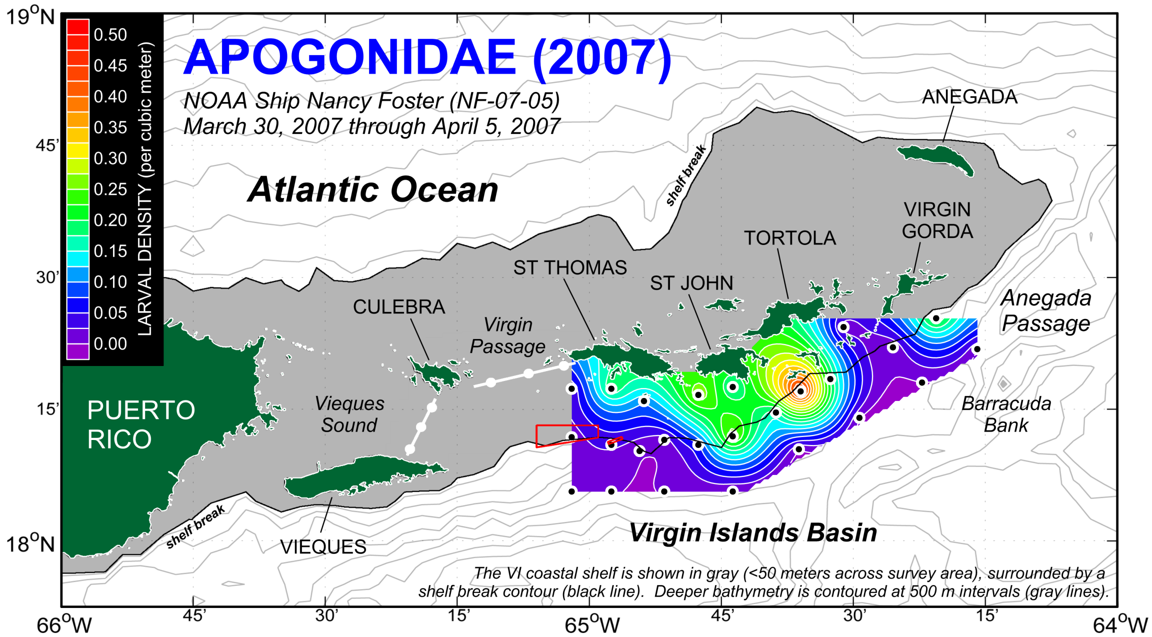



Figure 5. Apogonidae (cardinalfish) gridded larval density for the 2007 survey.

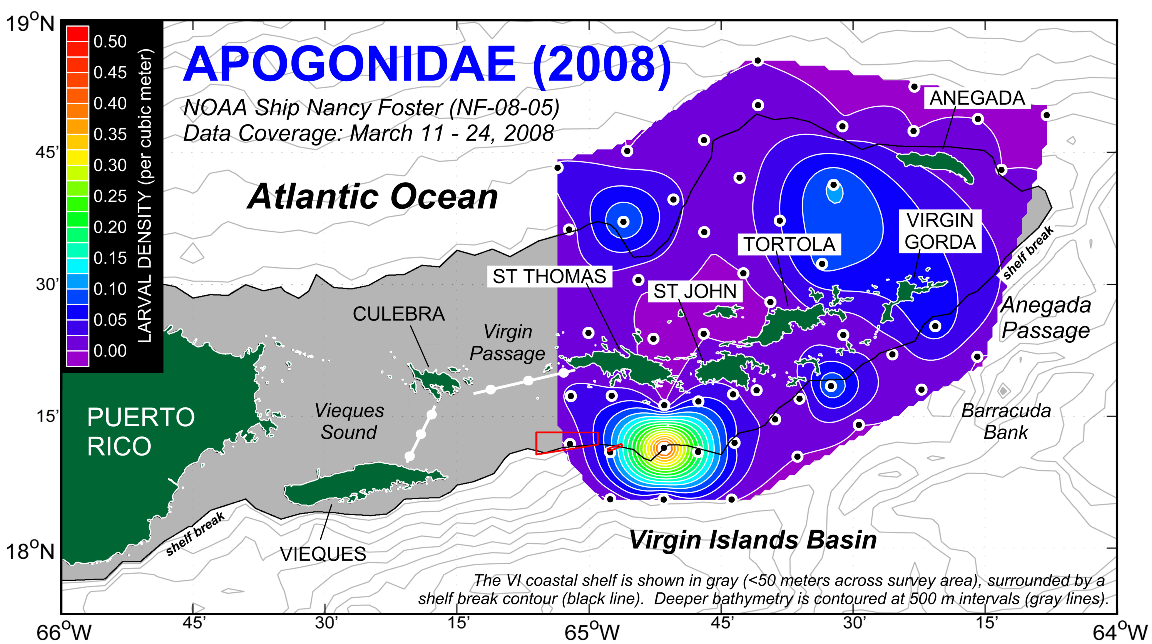



Figure 6. Apogonidae (cardinalfish) gridded larval density for the 2008 survey.

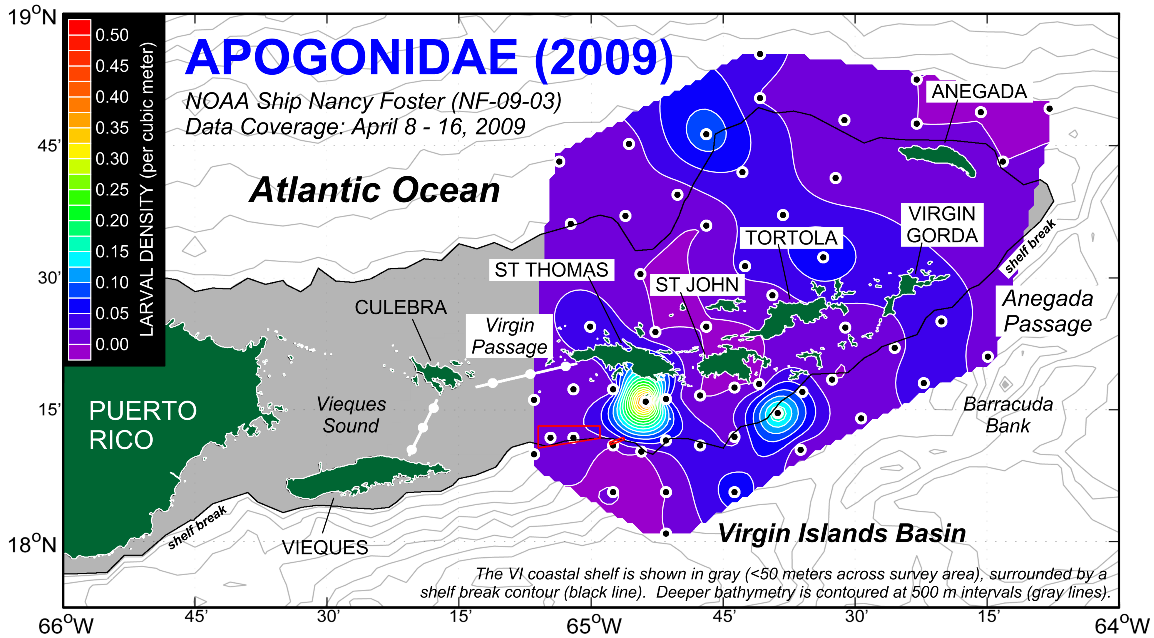



Figure 7. Apogonidae (cardinalfish) gridded larval density for the 2009 survey.

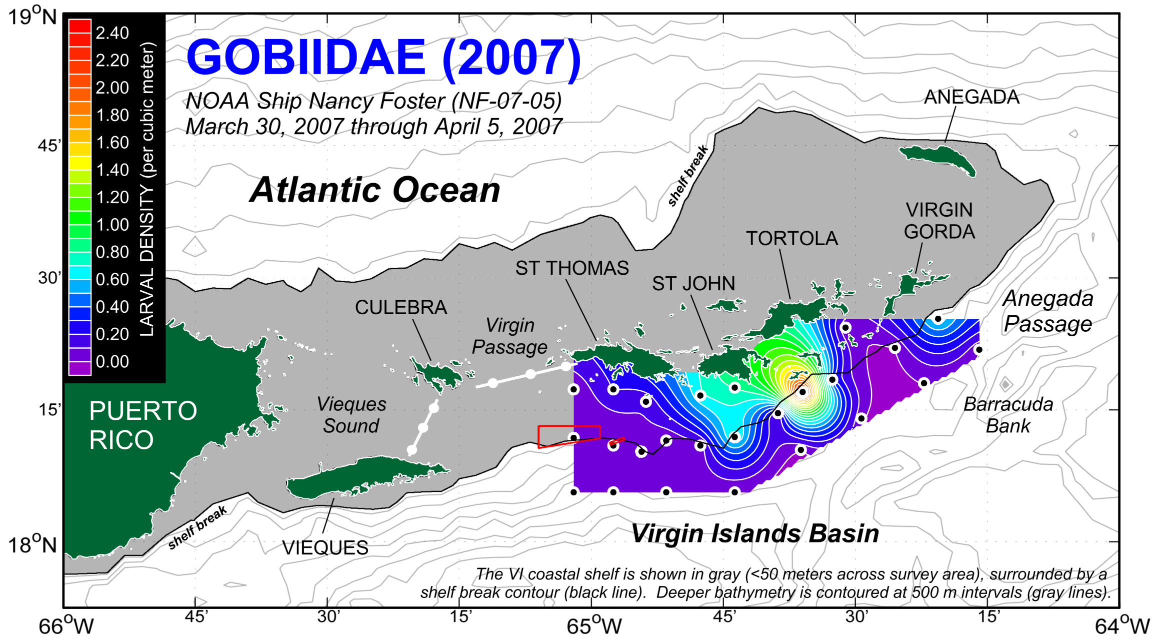



Figure 8. Gobiidae (goby) gridded larval density for the 2007 survey.

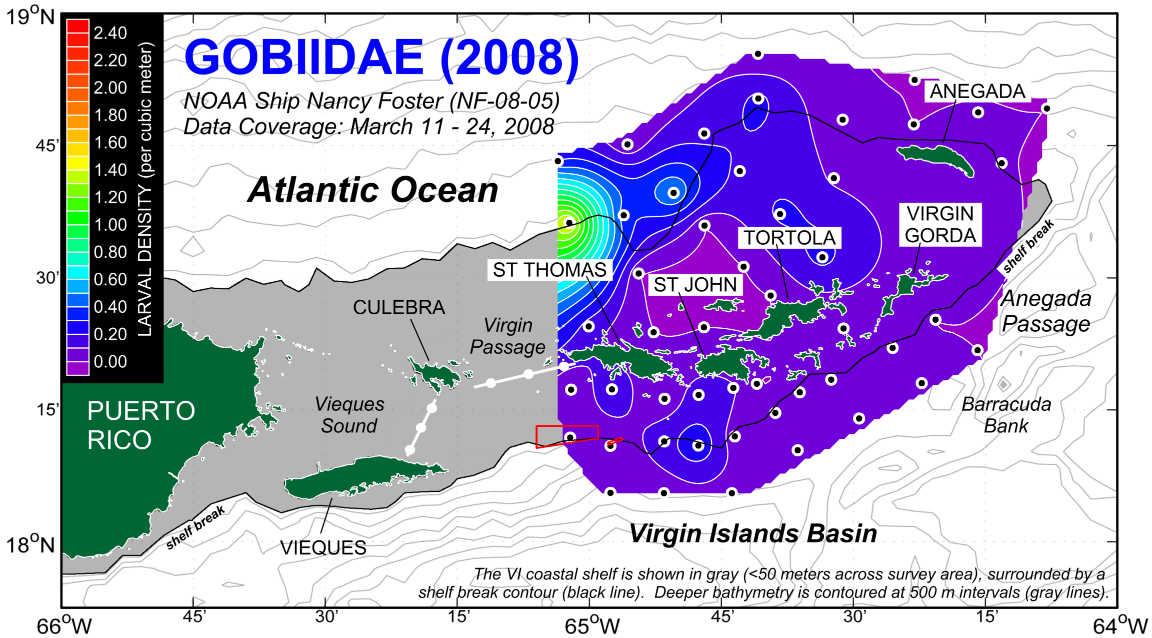



Figure 9. Gobiidae (goby) gridded larval density for the 2008 survey.

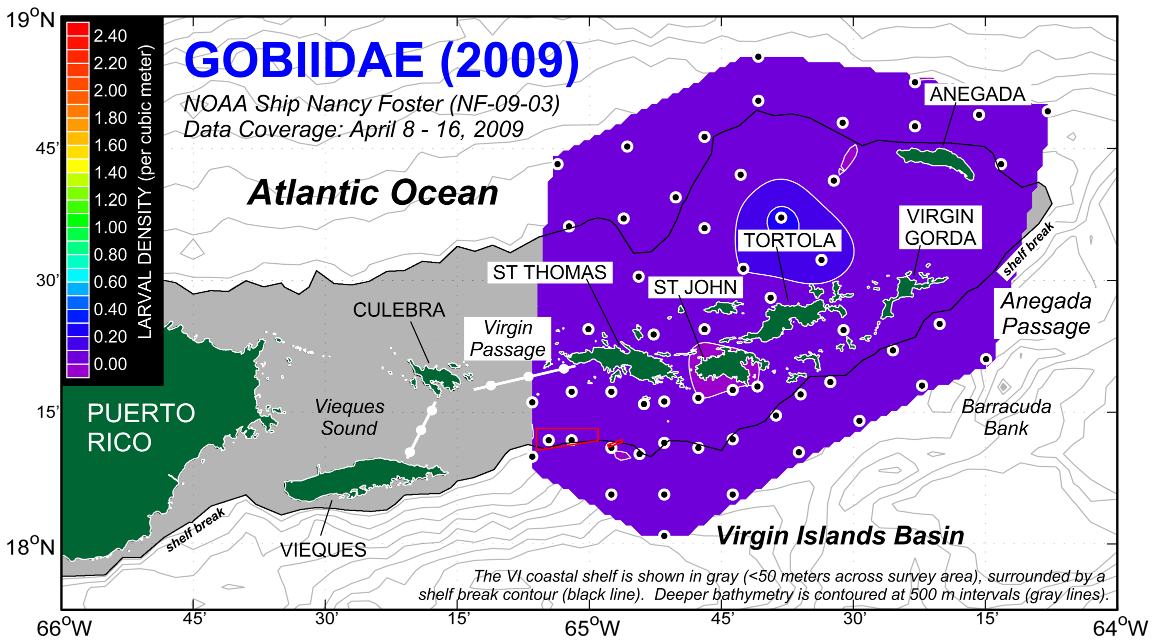



Figure 10. Gobiidae (goby) gridded larval density for the 2009 survey.

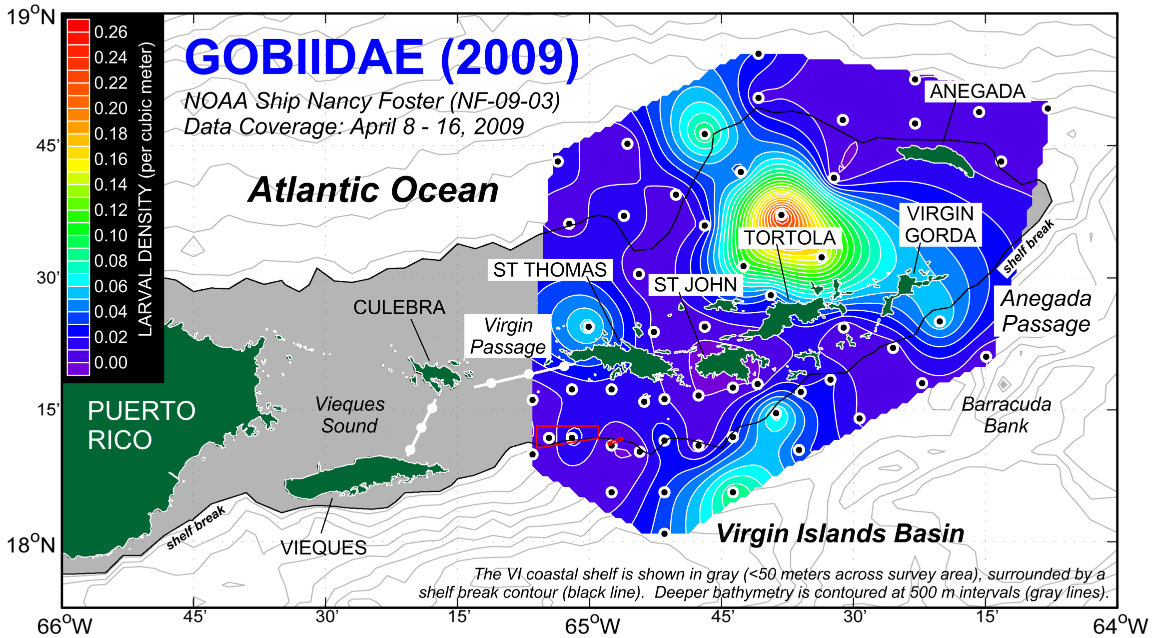



Figure 11. Gobiidae (goby) gridded larval density for the 2009 survey (modified color scale).

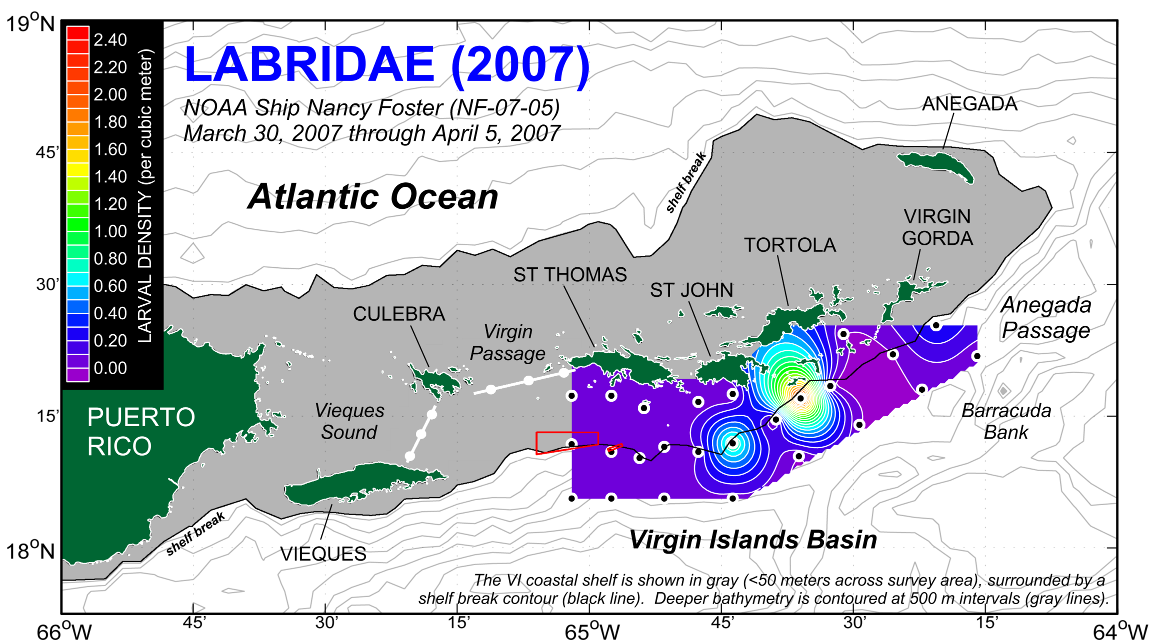



Figure 12. Labridae (wrasse) gridded larval density for the 2007 survey.

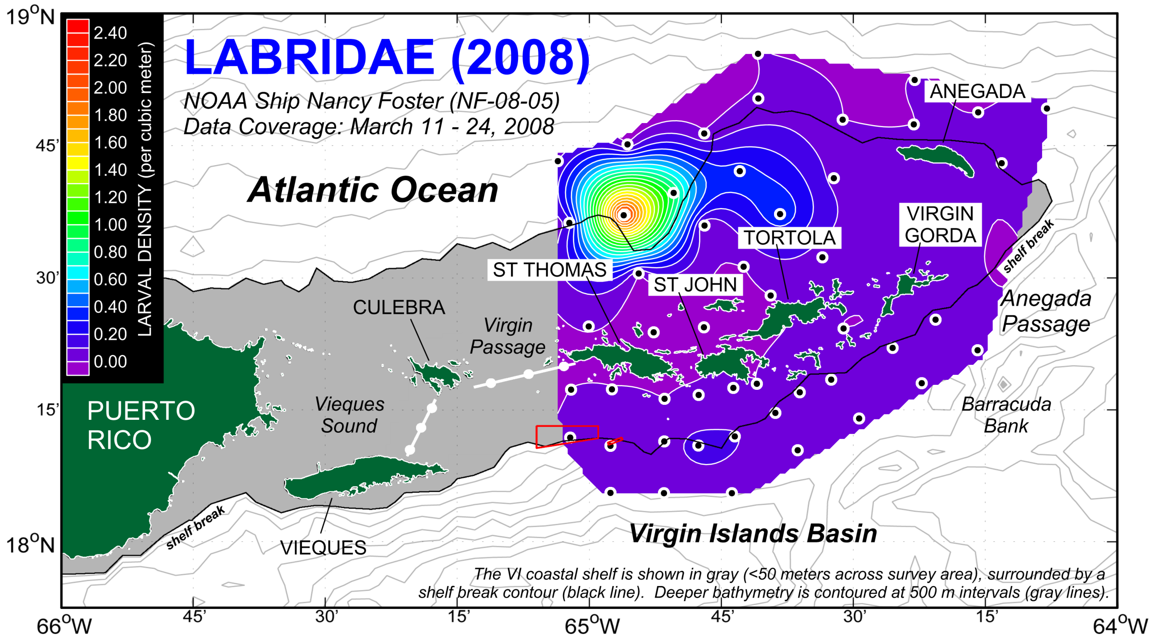



Figure 13. Labridae (wrasse) gridded larval density for the 2008 survey.

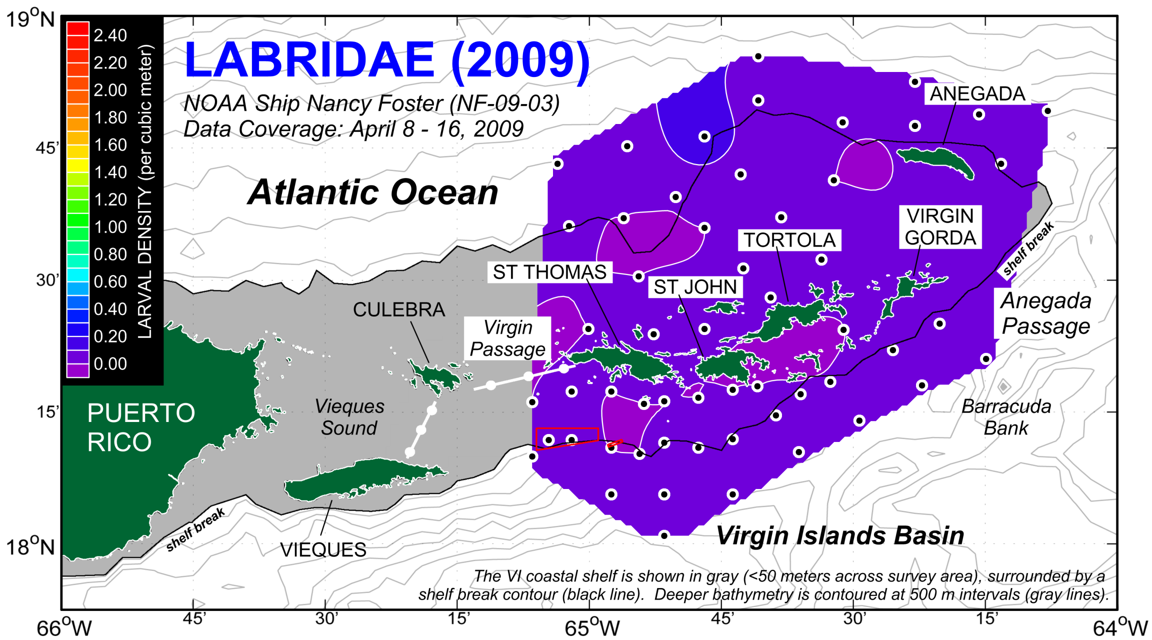



Figure 14. Labridae (wrasse) gridded larval density for the 2009 survey.

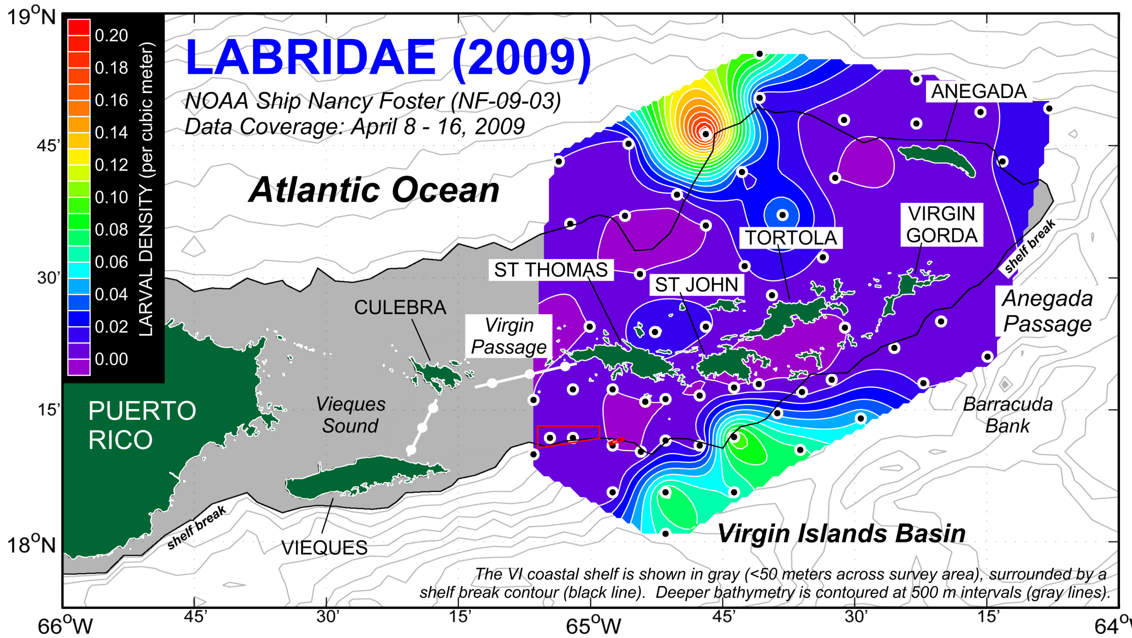



Figure 15. Labridae (wrasse) gridded larval density for the 2009 survey (modified color scale).

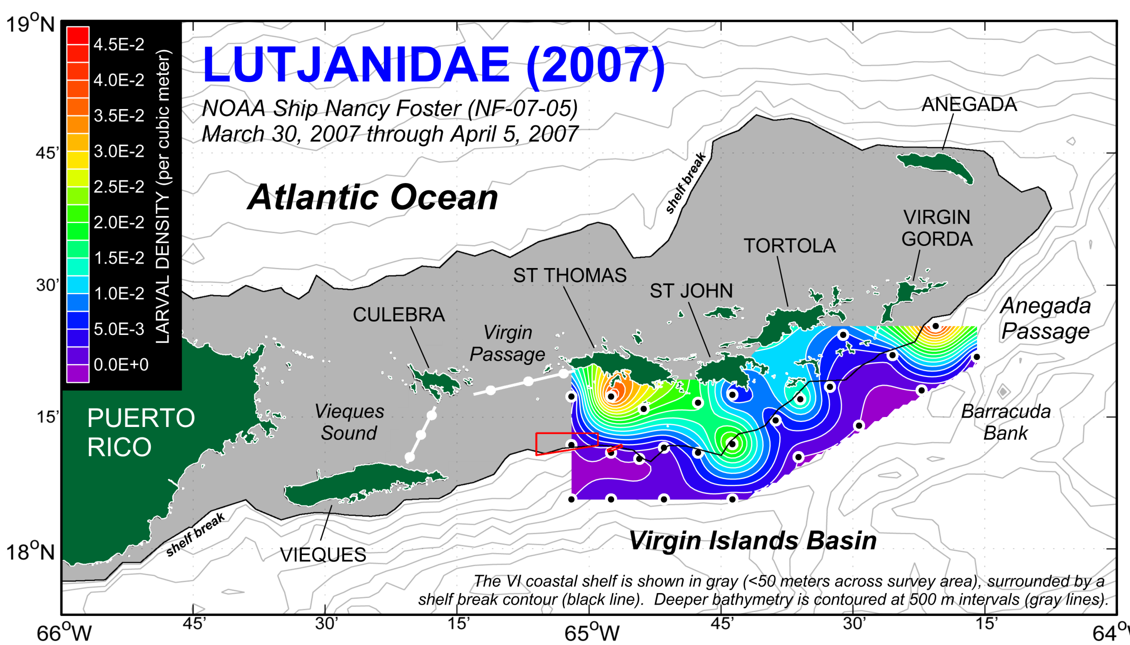



Figure 16. Lutjanidae (snapper) gridded larval density for the 2007 survey (modified color scale).

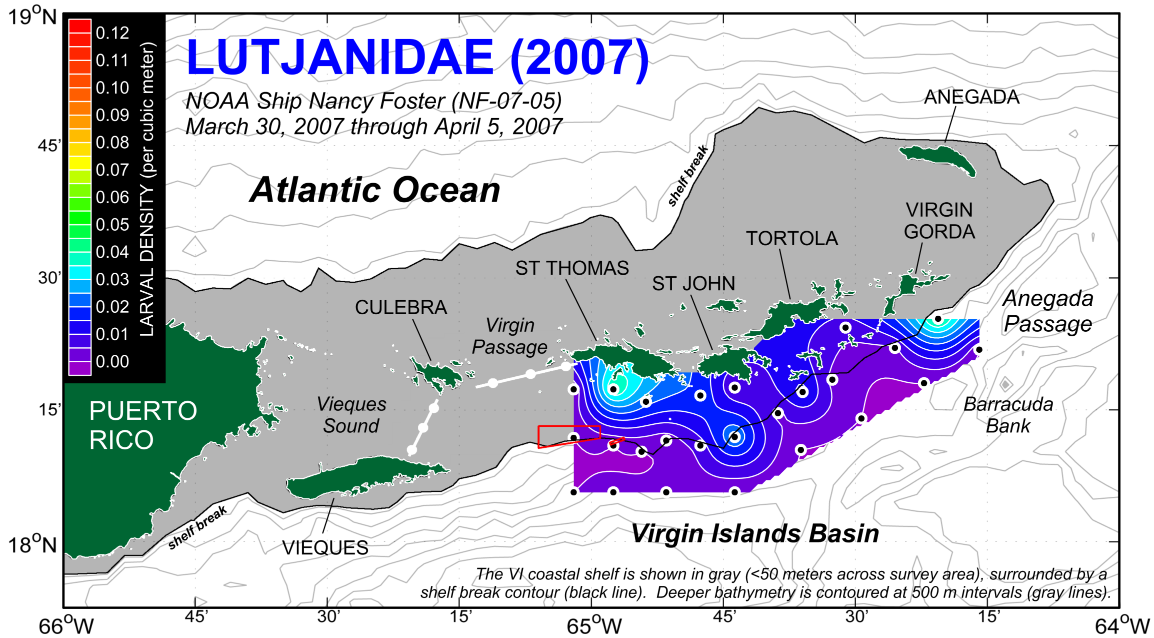



Figure 17. Lutjanidae (snapper) gridded larval density for the 2007 survey.

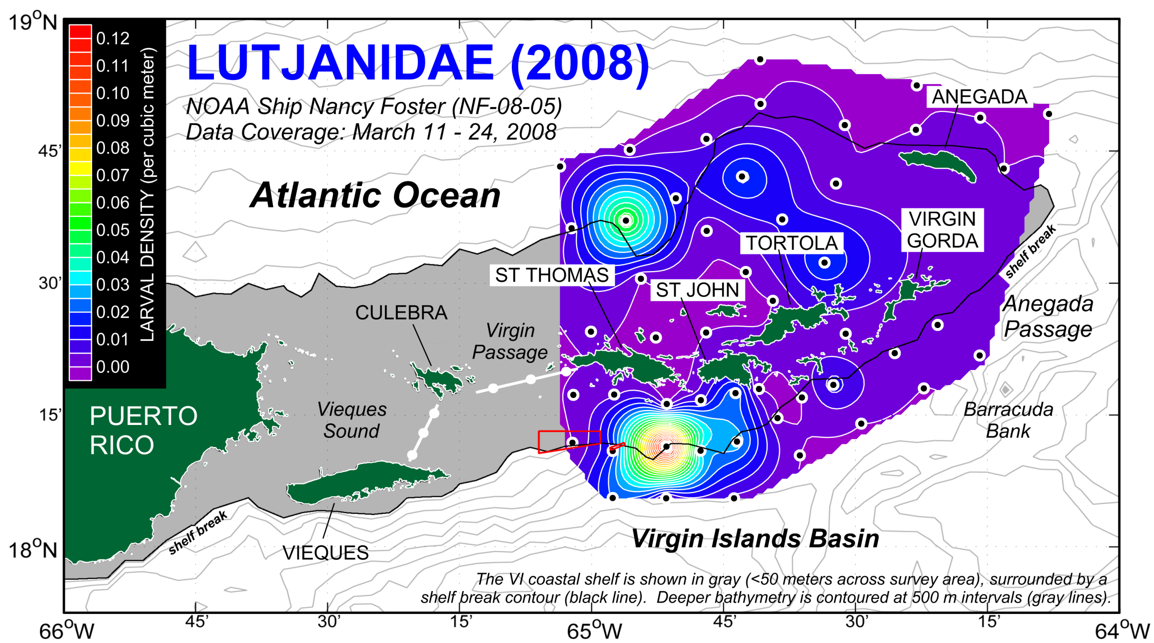



Figure 18. Lutjanidae (snapper) gridded larval density for the 2008 survey.

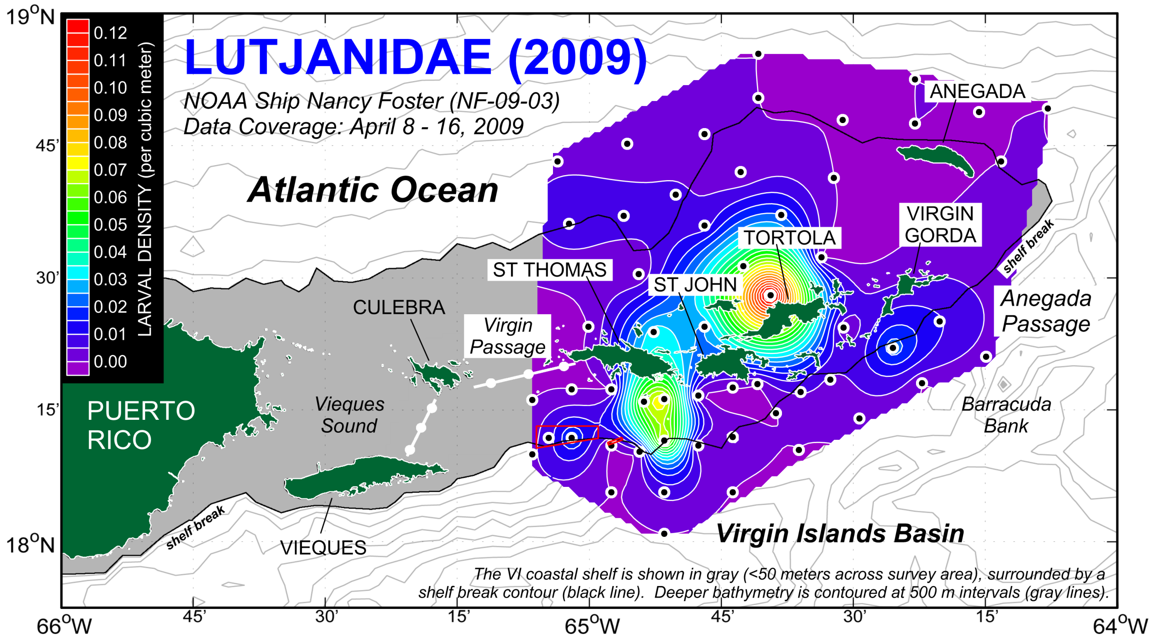



Figure 19. Lutjanidae (snapper) gridded larval density for the 2009 survey.

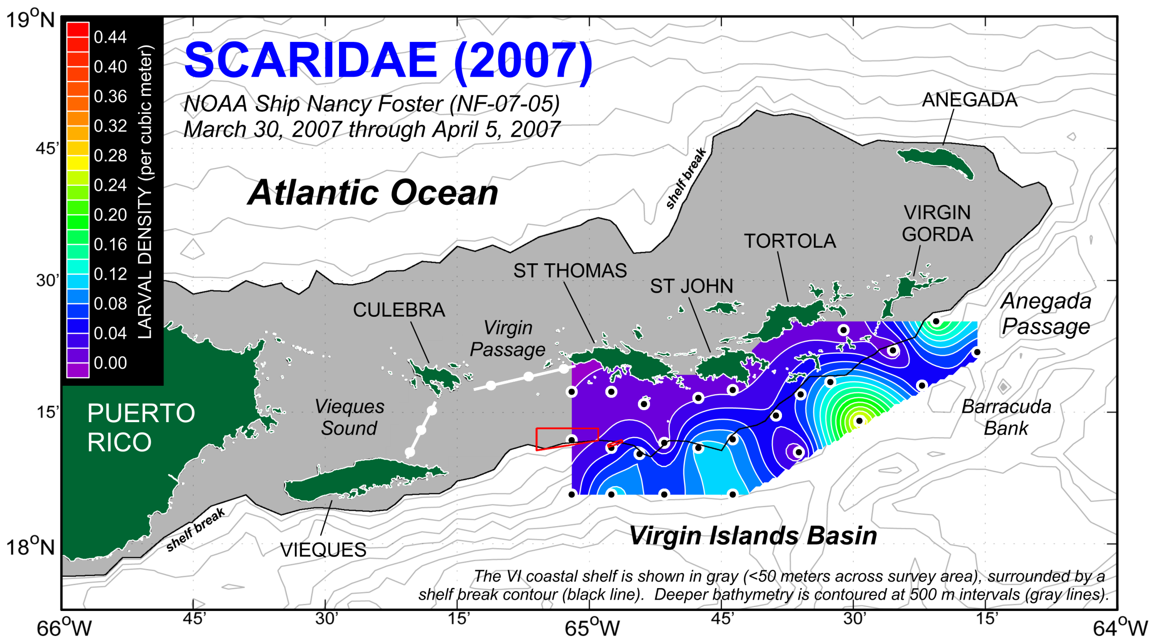



Figure 20. Scaridae (parrotfish) gridded larval density for the 2007.

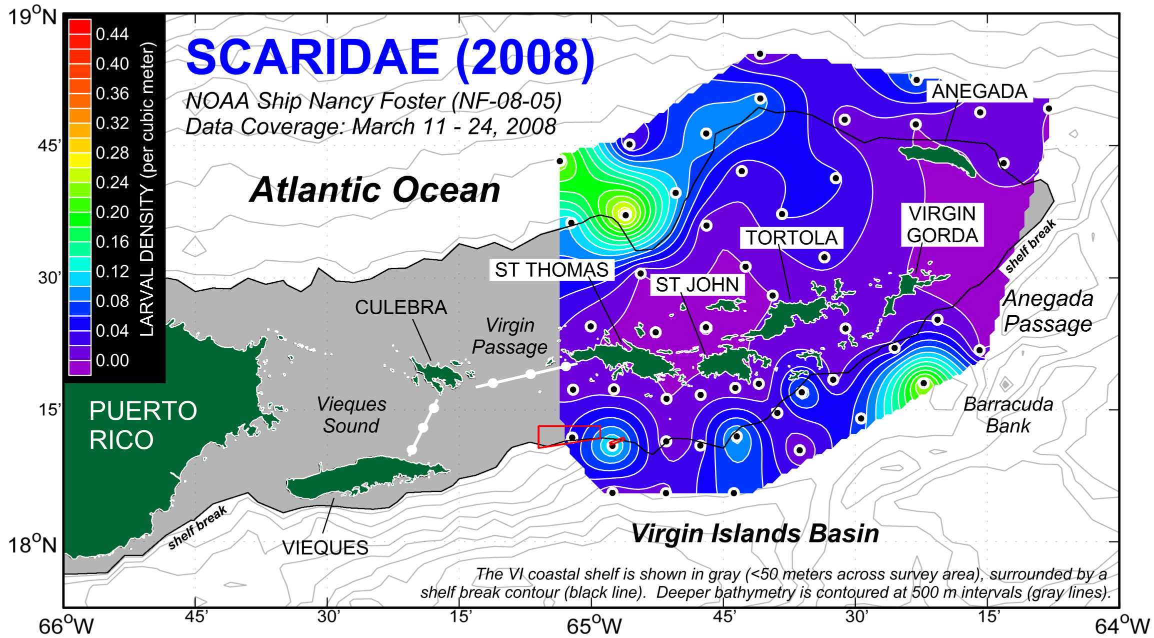



Figure 21. Scaridae (parrotfish) gridded larval density for the 2008 survey.

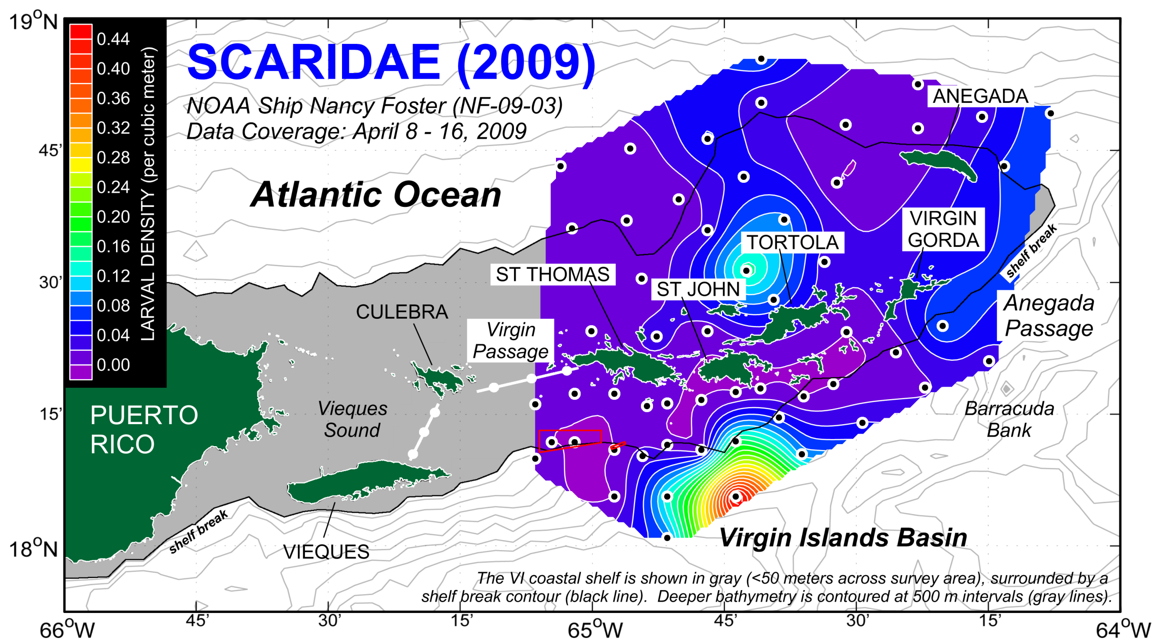



Figure 22. Scaridae (parrotfish) gridded larval density for the 2009 survey.

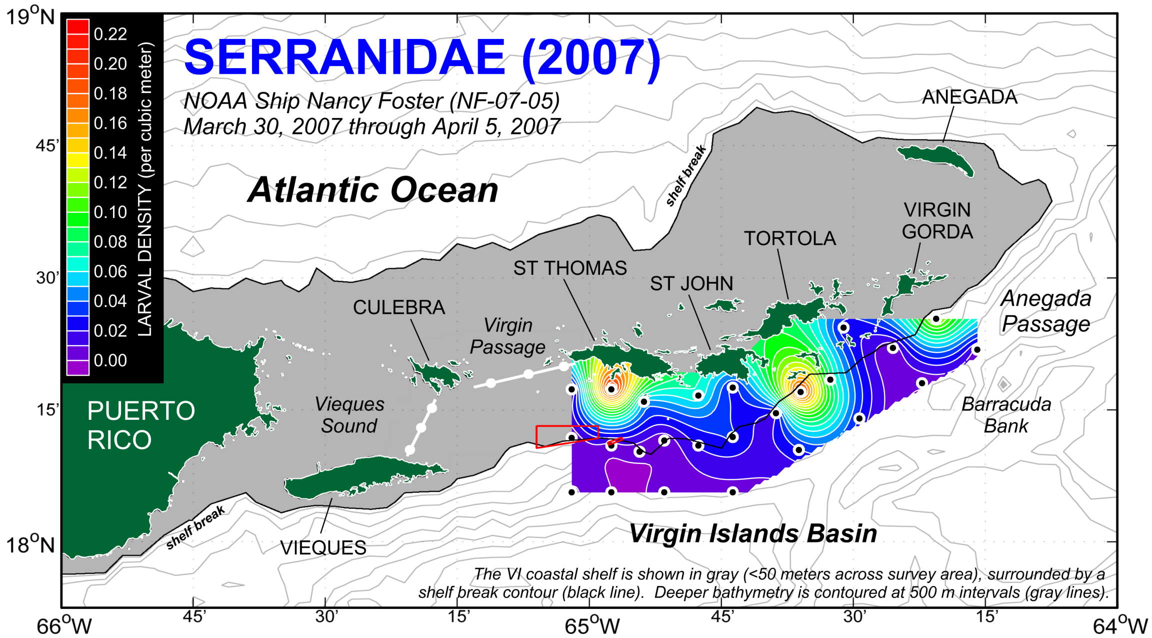



Figure 23. Serranidae (grouper) gridded larval density for the 2007 survey.

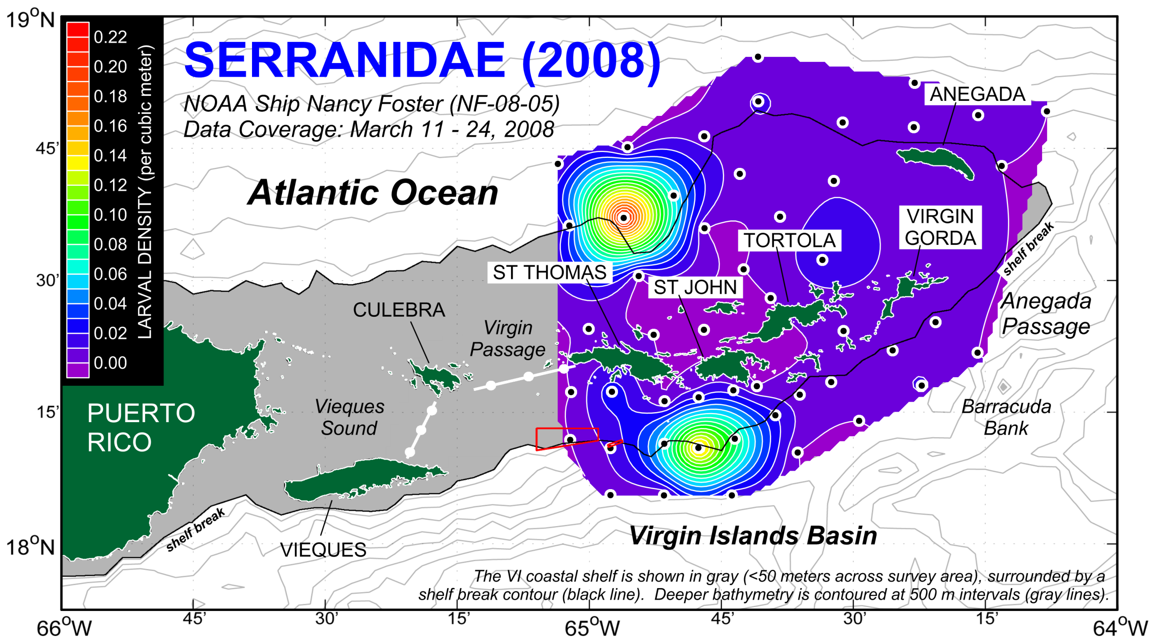



Figure 24. Serranidae (grouper) gridded larval density for the 2008 survey.

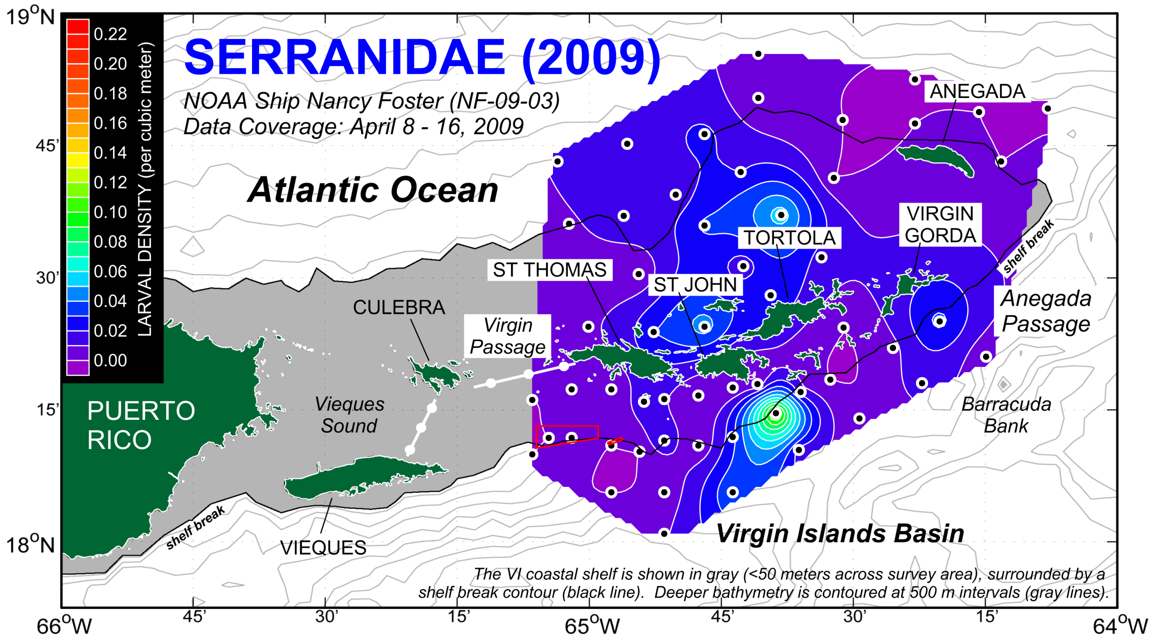
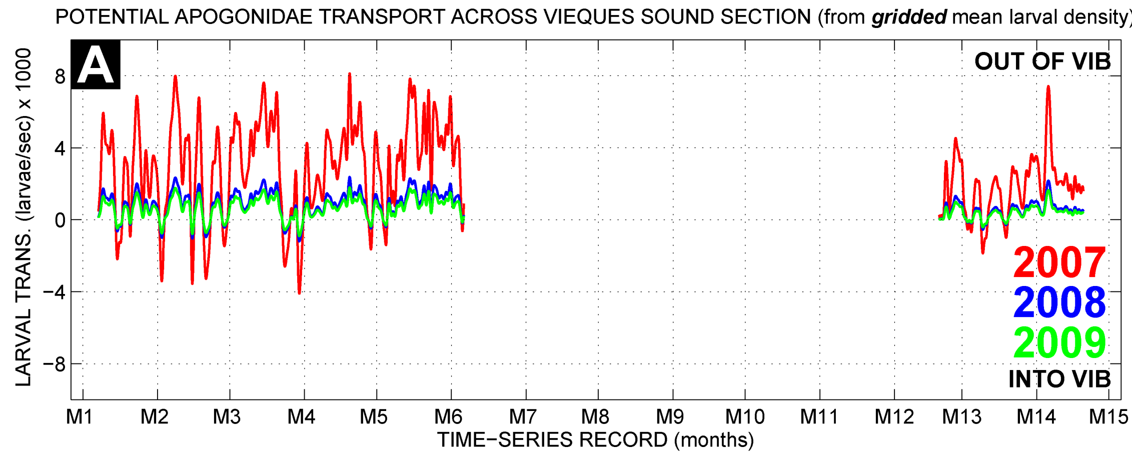



Figure 25. Serranidae (grouper) gridded larval density for the 2009 survey.

Time-series of potential larval transport across Vieques Sound and Virgin Passage transects are shown below for each of the six selected families. Larval data from 2007 are shown in red, larval data from 2008 are shown in blue, and larval data from 2009 are shown in green. Positive values indicate flow out of the Virgin Islands Basin (VIB, Fig. 1) into either Vieques Sound or the Atlantic Ocean.



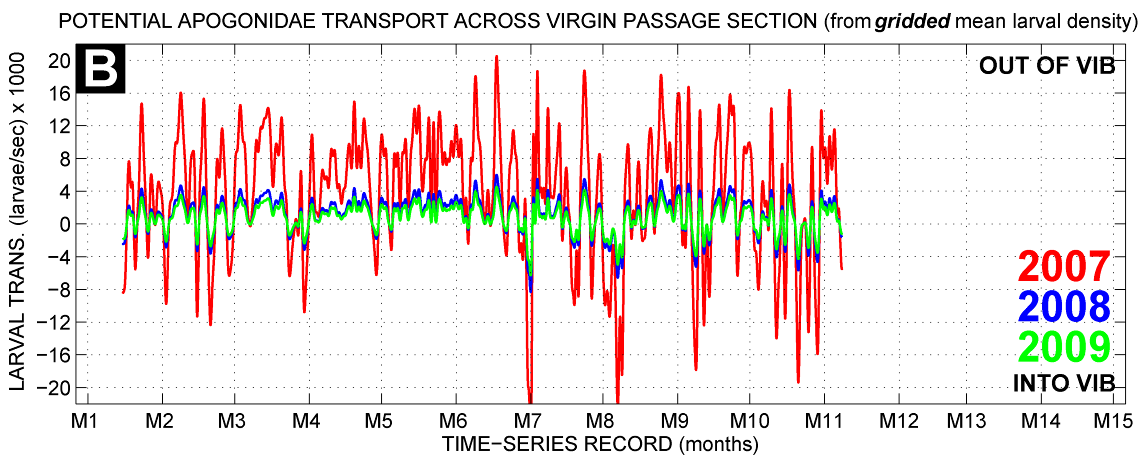
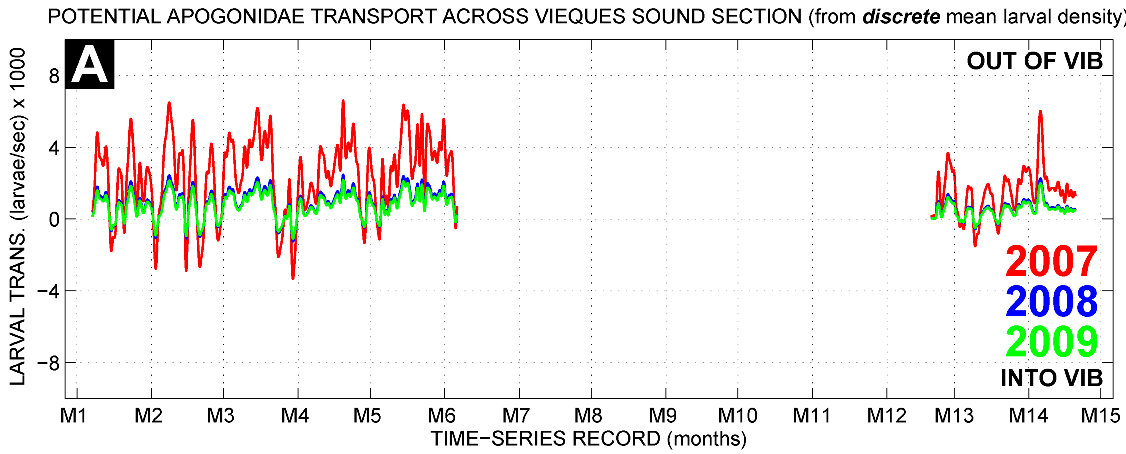




Figure 26. Potential apogonidae (cardinalfish) larval transport (larvae per second) across Vieques Sound (a) and Virgin Passage (b) sections as computed from a gridded mean larval density.

Gridded mean larval densities (larvae per cubic meter):

| | |
|---|---|
| 2007 | 0.111416 |
| 2008 | 0.032580 |
| 2009 | 0.024586 |



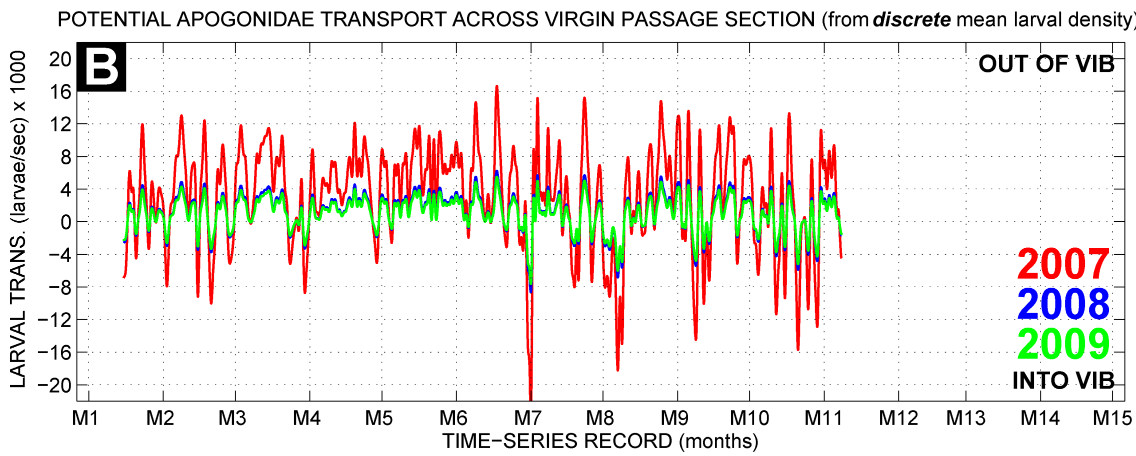




Figure 27. Potential apogonidae (cardinalfish) larval transport (larvae per second) across Vieques Sound (a) and Virgin Passage (b) sections as computed from a discrete mean larval density.

Discrete mean larval densities (larvae per cubic meter):

| | |
|---|---|
| 2007 | 0.090378 |
| 2008 | 0.033830 |
| 2009 | 0.029825 |

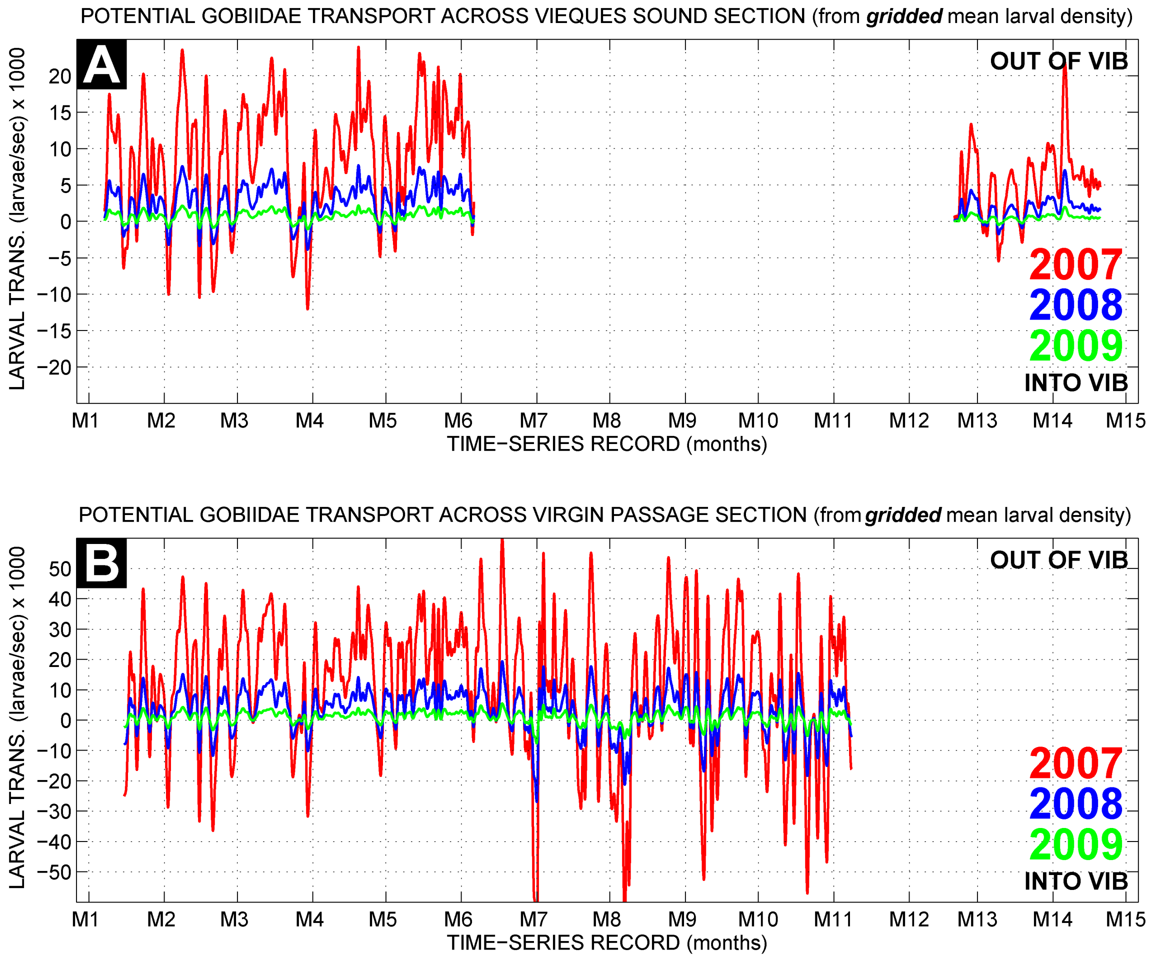



Figure 28. Potential gobiidae (goby) larval transport (larvae per second) across Vieques Sound (a) and Virgin Passage (b) sections as computed from a gridded mean larval density.

Gridded mean larval densities (larvae per cubic meter):

| | |
|---|---|
| 2007 | 0.328341 |
| 2008 | 0.105374 |
| 2009 | 0.029827 |

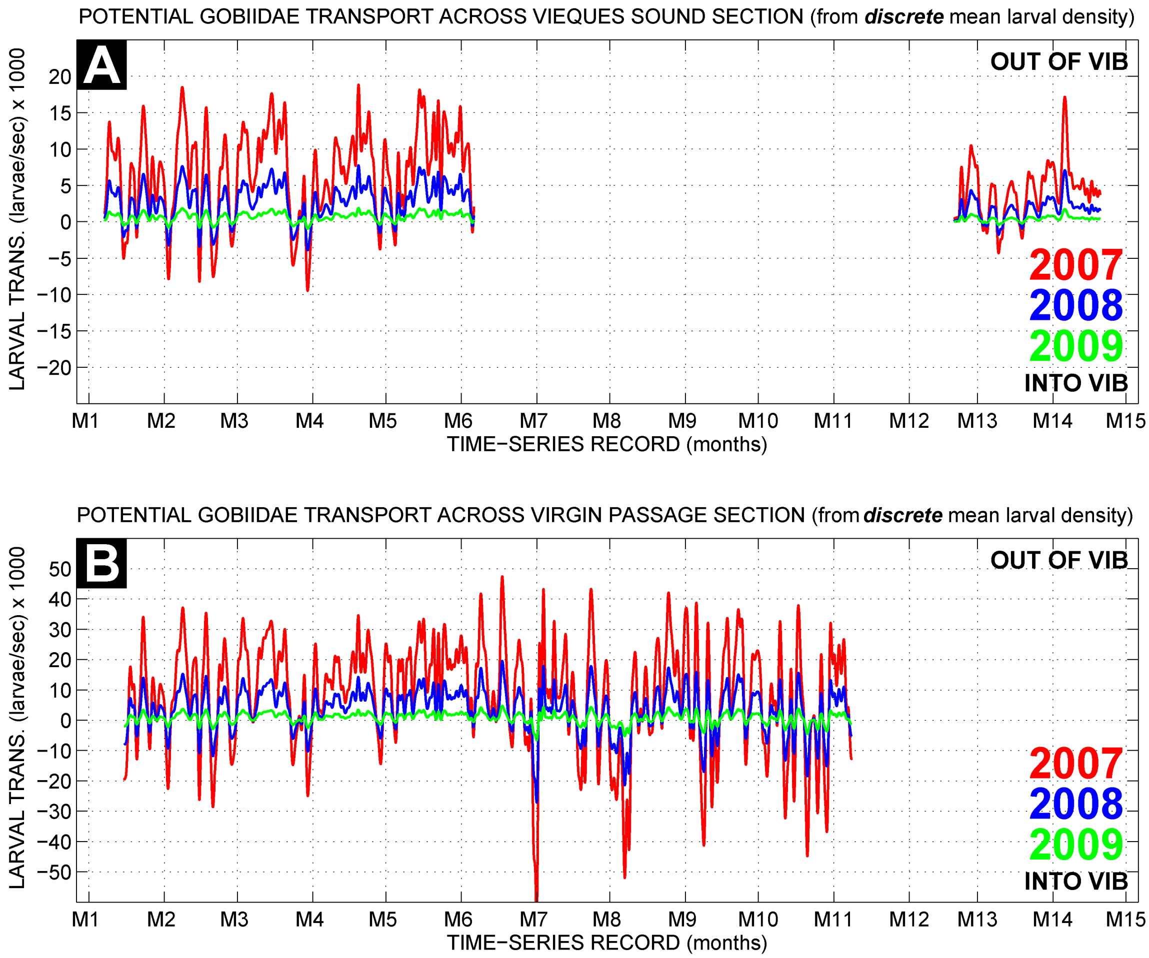



Figure 29. Potential gobiidae (goby) larval transport (larvae per second) across Vieques Sound (a) and Virgin Passage (b) sections as computed from a discrete mean larval density.

Discrete mean larval densities (larvae per cubic meter):

| | |
|---|---|
| 2007 | 0.257701 |
| 2008 | 0.106113 |
| 2009 | 0.025746 |

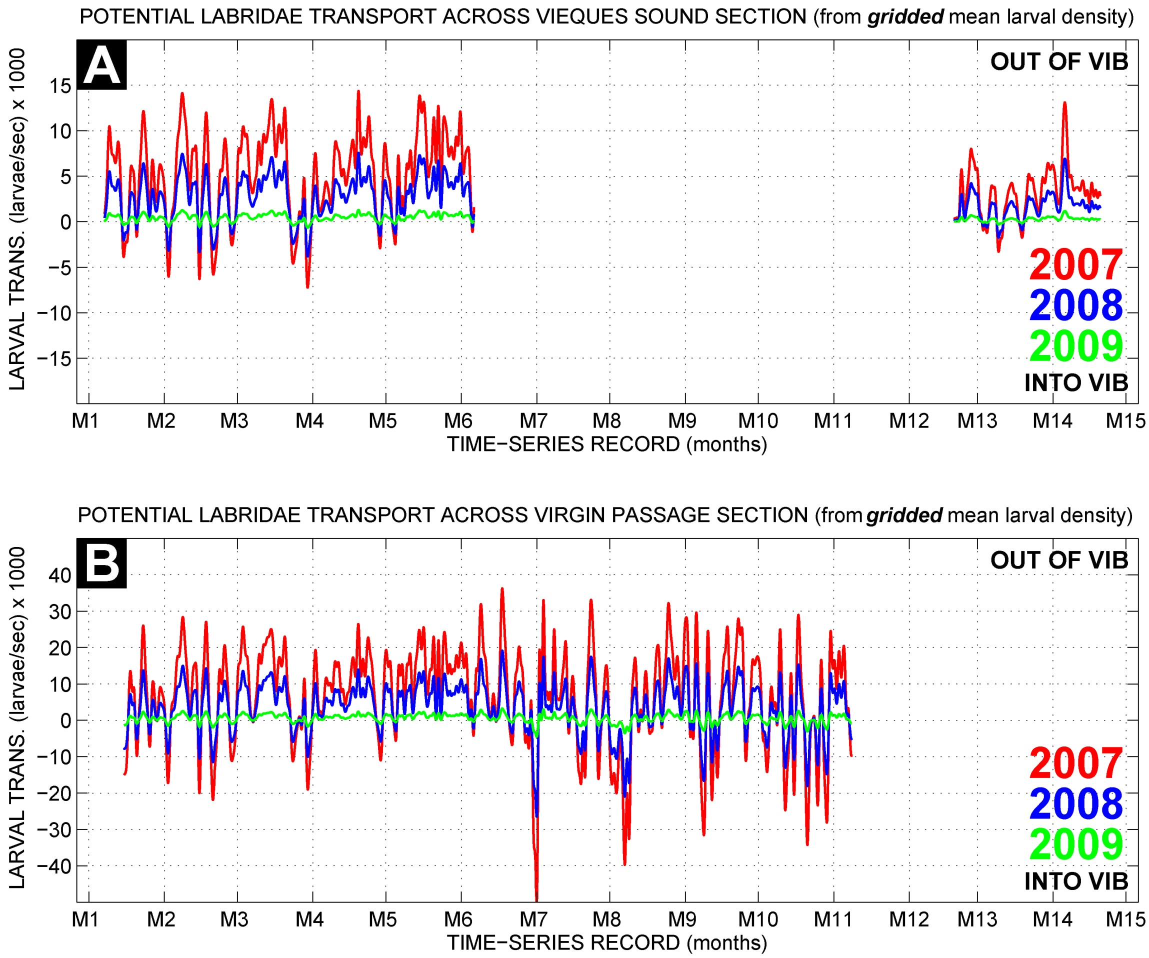



Figure 30. Potential labridae (wrasse) larval transport (larvae per second) across Vieques Sound (a) and Virgin Passage (b) sections as computed from a gridded mean larval density.

Gridded mean larval densities (larvae per cubic meter):

| | |
|---|---|
| 2007 | 0.196915 |
| 2008 | 0.103869 |
| 2009 | 0.017605 |

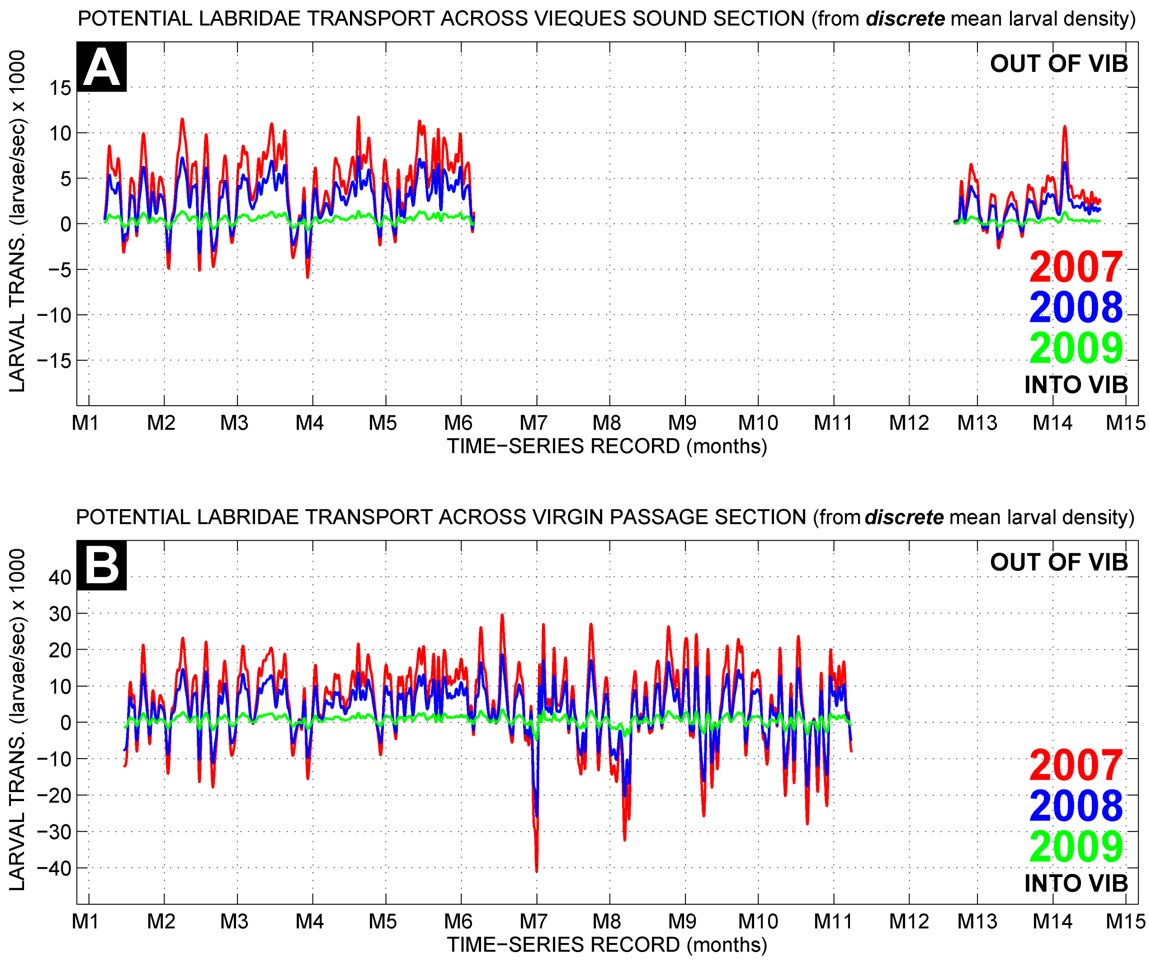



Figure 31. Potential labridae (wrasse) larval transport (larvae per second) across Vieques Sound (a) and Virgin Passage (b) sections as computed from a discrete mean larval density.

Discrete mean larval densities (larvae per cubic meter):

| | |
|---|---|
| 2007 | 0.160902 |
| 2008 | 0.101182 |
| 2009 | 0.018964 |

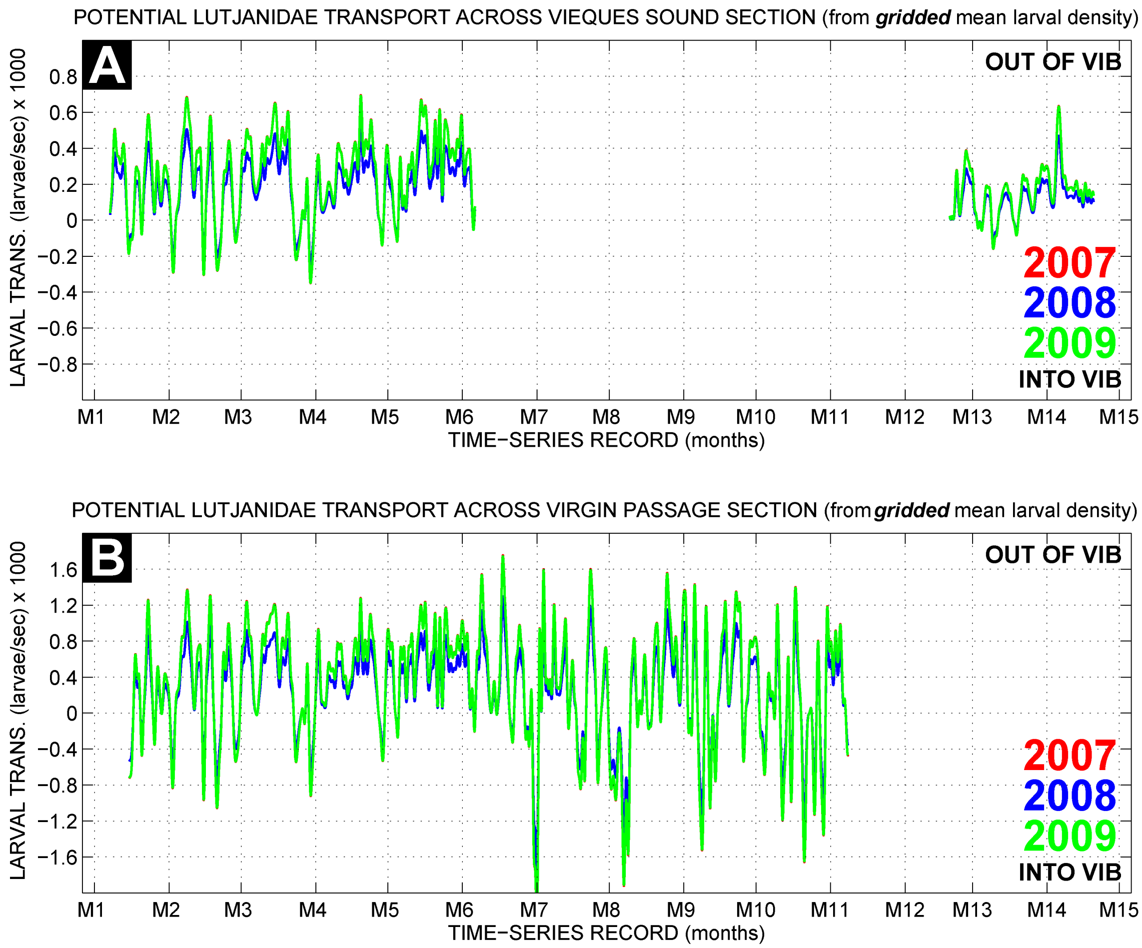



Figure 32. Potential lutjanidae (snapper) larval transport (larvae per second) across Vieques Sound (a) and Virgin Passage (b) sections as computed from a gridded mean larval density. Note, due to similar means for 2007 and 2009, the green line obscures the red line.

Gridded mean larval densities (larvae per cubic meter):

| | |
|---|---|
| 2007 | 0.009525 |
| 2008 | 0.007040 |
| 2009 | 0.009470 |

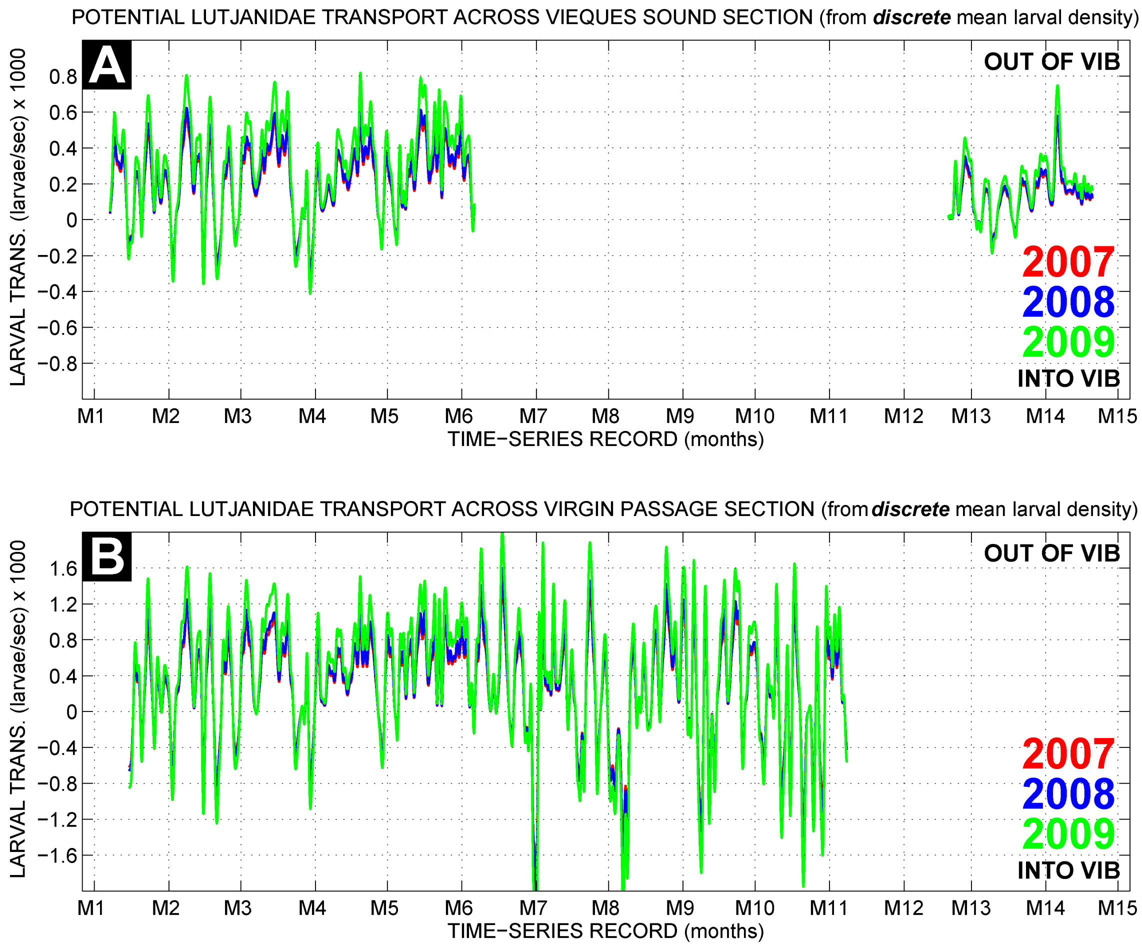



Figure 33. Potential lutjanidae (snapper) larval transport (larvae per second) across Vieques Sound (a) and Virgin Passage (b) sections as computed from a discrete mean larval density.

Discrete mean larval densities (larvae per cubic meter):

| | |
|---|---|
| 2007 | 0.008137 |
| 2008 | 0.008673 |
| 2009 | 0.011219 |

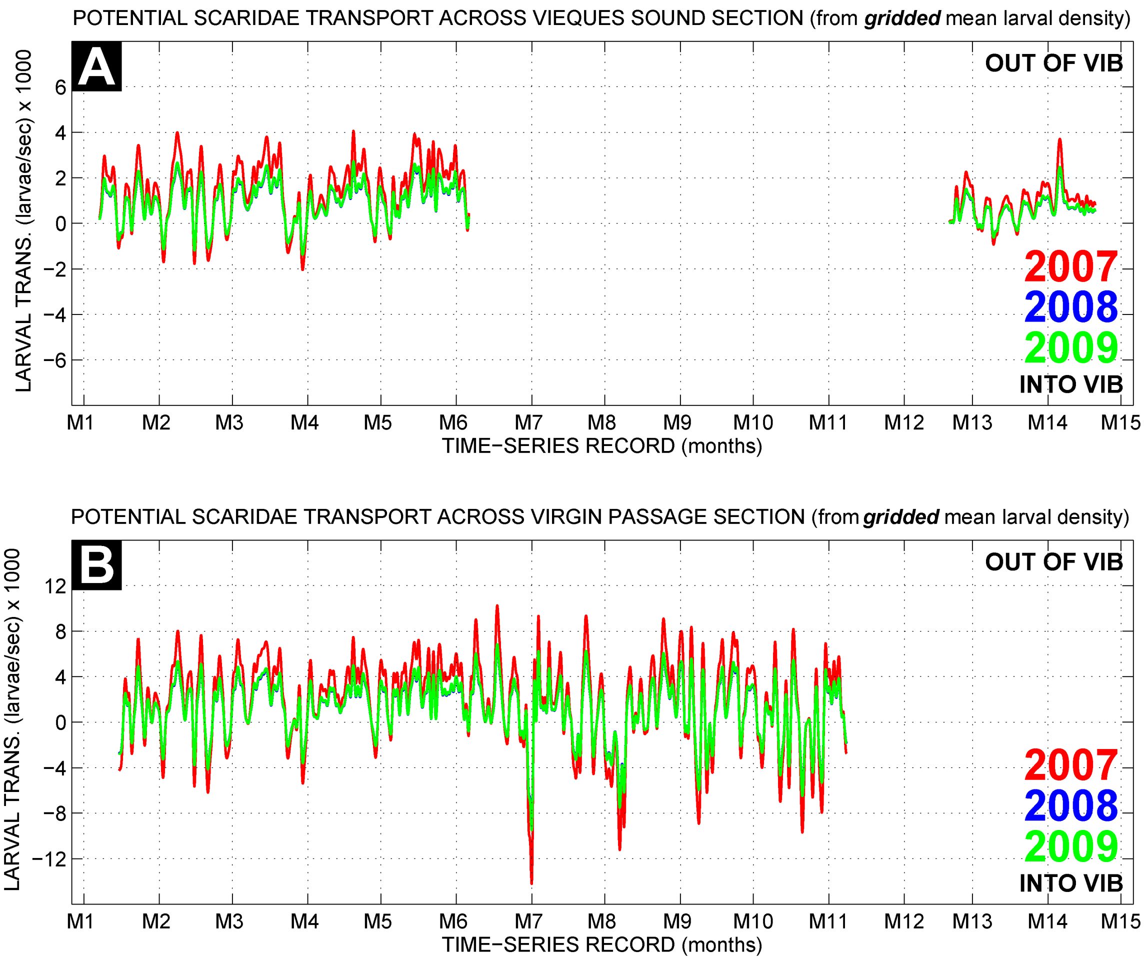



Figure 34. Potential scaridae (parrotfish) larval transport (larvae per second) across Vieques Sound (a) and Virgin Passage (b) sections as computed from a gridded mean larval density. Note, due to similar means for 2008 and 2009, the green line obscures the blue line.

Gridded mean larval densities (larvae per cubic meter):

| | |
|---|---|
| 2007 | 0.055689 |
| 2008 | 0.036051 |
| 2009 | 0.037217 |

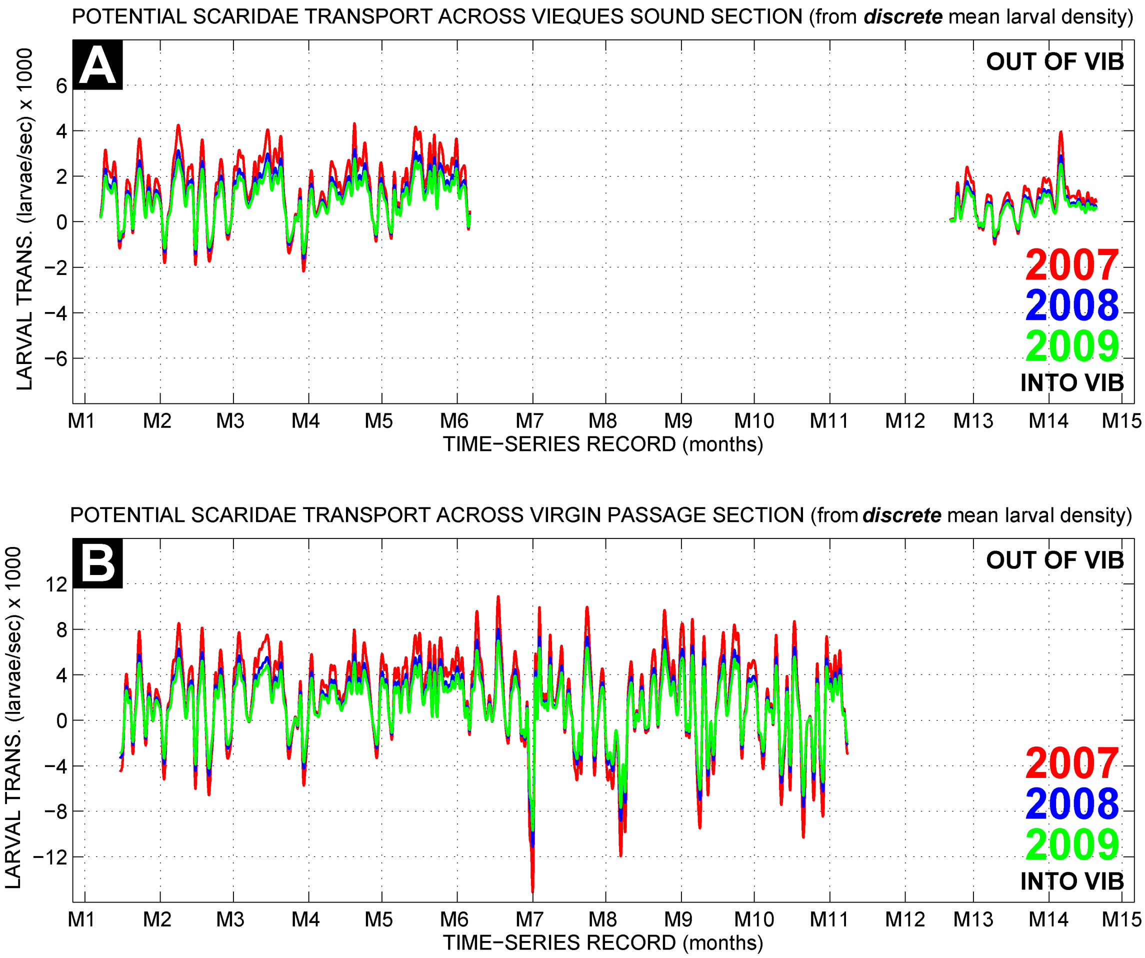



Figure 35. Potential scaridae (parrotfish) larval transport (larvae per second) across Vieques Sound (a) and Virgin Passage (b) sections as computed from a discrete mean larval density.

Discrete mean larval densities (larvae per cubic meter):

| | |
|---|---|
| 2007 | 0.059247 |
| 2008 | 0.043682 |
| 2009 | 0.038027 |

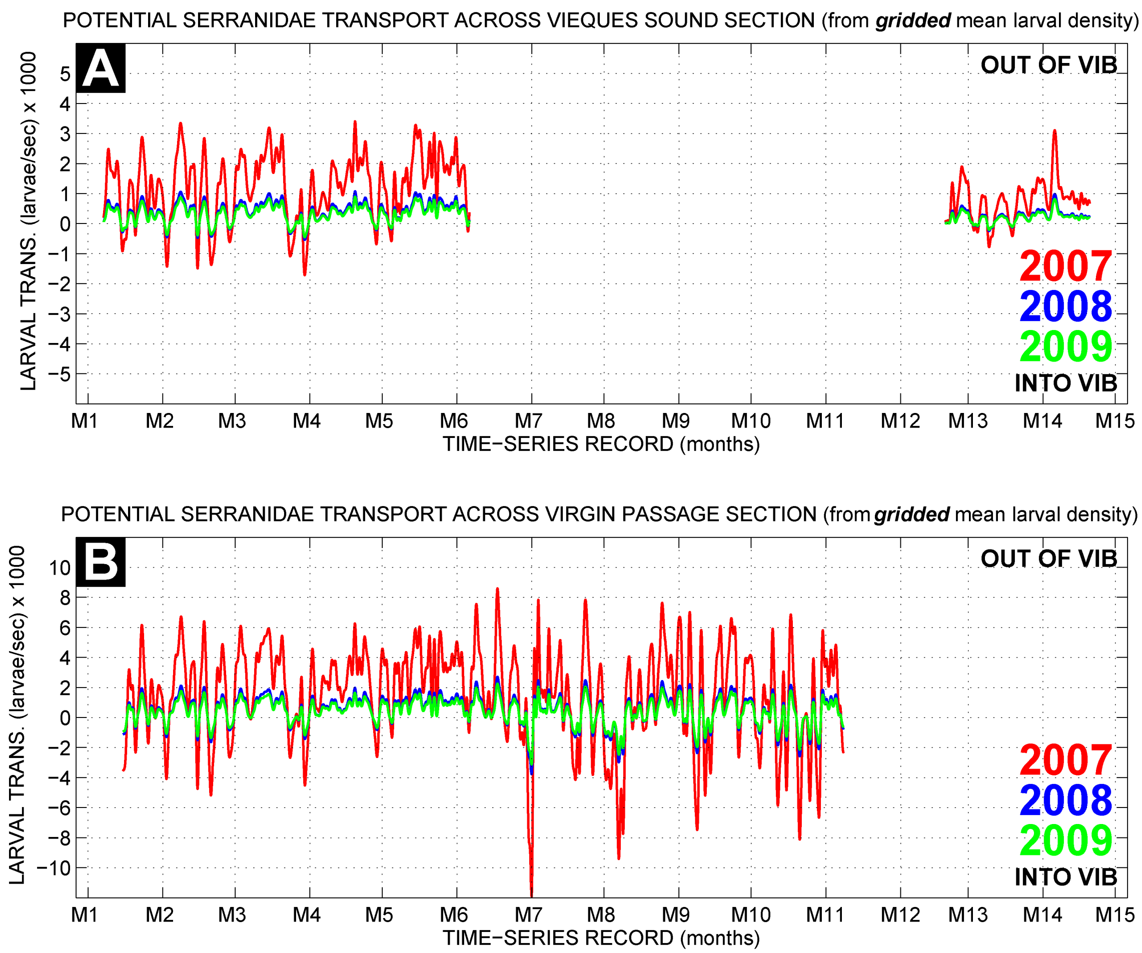



Figure 36. Potential serranidae (grouper) larval transport (larvae per second) across Vieques Sound (a) and Virgin Passage (b) sections as computed from a gridded mean larval density.

Gridded mean larval densities (larvae per cubic meter):

| | |
|---|---|
| 2007 | 0.046666 |
| 2008 | 0.014741 |
| 2009 | 0.012216 |

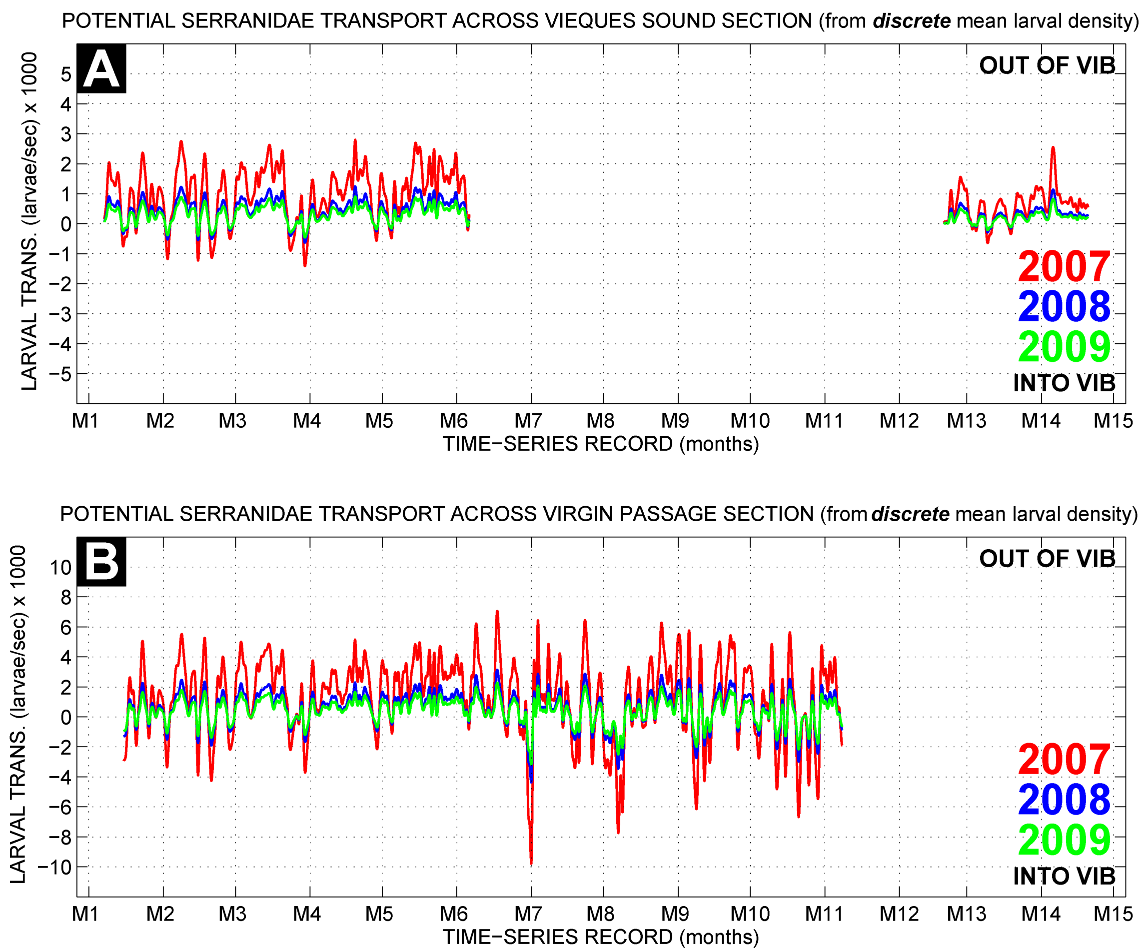



Figure 37. Potential serranidae (grouper) larval transport (larvae per second) across Vieques Sound (a) and Virgin Passage (b) sections as computed from a discrete mean larval density.

Discrete mean larval densities (larvae per cubic meter):

| | |
|---|---|
| 2007 | 0.038351 |
| 2008 | 0.017096 |
| 2009 | 0.012402 |

Due to the net flux of water out of the Virgin Islands Basin (VIB) during the period of the moored array time-series, for all cases, the net transport of larvae may similarly move from the VIB into Vieques Sound and the Atlantic Ocean. With a much greater component of this flow observed to be moving through Virgin Passage, this may support a biophysical connectivity pathway between protected habitat areas south of St. Thomas and banks to the north of the Virgin Islands. However, as is clearly indicated in Figures 5-25, during the three surveys, areas of high larval concentration for the various families were observed to be sporadic in location. Therefore, such linkages may not be easily confirmed without additional in situ measurements.

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