Annual Report for Period: 03/2011 - 02/2012
Submitted on: 03/15/2012
Principal Investigator: Pierson, James J.
Award ID: 0961942
Organization: U of MD Ctr Environ Scs
Submitted By:
Pierson, James - Principal Investigator
Title:
Collaborative Research: Hypoxia in Marine Ecosystems: Implications for Neritic Copepods

Project Participants

Senior Personnel

Name: Pierson, James
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Houde, Edward
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Roman, Michael
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Stoecker, Diane
Worked for more than 160 Hours: Yes
Contribution to Project:

Post-doc

Name: Elliott, David
Worked for more than 160 Hours: Yes
Contribution to Project:
Numerical modeling of copepod life histories, copepod development time experiments, vital staining of copepods.

Graduate Student

Name: Barba, Ali
Worked for more than 160 Hours: Yes
Contribution to Project:
Collection and analysis of zooplankton samples, presented results at national conference.

Name: Liu, Katherine
Worked for more than 160 Hours: Yes
Contribution to Project:
Collection and analysis of gelatinous zooplankton samples.

Undergraduate Student

Name: Fisher, Aidan
Worked for more than 160 Hours: Yes
Contribution to Project:

Sample collection and analysis.

Name: Yeager, Daniel

Worked for more than 160 Hours: Yes

Contribution to Project:

Part of the COSEE Coastal Trends supported Scientist-Educator team that developed education modules based on this project (http://www.teachoceanscience.net)

Name: Goggins, Lenise

Worked for more than 160 Hours: Yes

Contribution to Project:

Part of the COSEE Coastal Trends supported Scientist-Educator team that developed education modules based on this project (http://www.teachoceanscience.net)

Technician, Programmer

Name: Jahn, Ginger

Worked for more than 160 Hours: Yes

Contribution to Project:

Sample collection and analysis

Name: Weigel, Alison

Worked for more than 160 Hours: Yes

Contribution to Project:

Shipboard and laboratory technician

Name: Guitterez, Robert

Worked for more than 160 Hours: Yes

Contribution to Project:

Shipboard and laboratory technician

Name: Seuberling, James

Worked for more than 160 Hours: Yes

Contribution to Project:

Shipboard and laboratory technician

Other Participant

Research Experience for Undergraduates

Organizational Partners

Chesapeake Bay Program Office

Chesapeake Bay Program Office deploys profiling moorings, and has invited the PIs from this project to participate in determining sites for those moorings, and to facilitate stronger direct ties between our complementary programs.

Other Collaborators or Contacts

We are coordinating field sampling and data analysis of our project with the NSF funded 'Life in the Deadzone' (LiDZ) project (OCE 0961920), which has similar research initiatives for other components of the Chesapeake Bay Ecosystem. In 2010 and 2011 two of our investigators participated in the LiDZ cruises aboard the Hugh R. Sharp to collect zooplankton data in conjunction with the microbial and chemical analyses undertaken by that project.

Activities and Findings

Research and Education Activities: (See PDF version submitted by PI at the end of the report)

In 2011 we conducted three cruises to the Chesapeake Bay to carry out the goals of this program. Those cruises were all highly successful despite a few equipment problems with the shipboard and our own scientific equipment. Analysis of the samples and data that we collected is ongoing.

Two graduate students (Ali Barba and Katherine Liu) are employed for this project, and their work is ongoing. Ali Barba is studying the vertical distribution of the target copepod species, Acartia tonsa, in relation to hypoxic conditions and other environmental factors encountered. Katherine Liu is examining the gut contents and distribution of two gelatinous zooplankton species, ctenophore, Mnemiopsis leidyi, and scyphomedusan, Chrysaora quinquecirrha, in relation to the copepod and hypoxic distributions.

One postdoctoral researcher, Dr. David Elliot, is employed on the project. He is developing and enhancing an individual based model of Acartia tonsa to evaluate how hypoxic conditions might affect the population dynamics of the copepod in the Chesapeake Bay. In addition, he is conducting development rate experiments to explore the non-lethal effects of hypoxia on the copepod.

One presentation for this project was made at the ICES 2011 ASC in Gdansk, Poland:

Pierson, J.J., Stoecker, D.K., Roman, M., Elliott, D., Houde, E., Decker, M.B., Liu, K., Barba, A.
Plankton trophic dynamics in hypoxic waters: seasonal effects and foodweb implications
Oral Presentation, ICES ASC 2011
The prevalence of hypoxia in coastal regions and estuaries, and concern over its effects on aquatic ecosystems, is increasing worldwide, including within the ICES region. A substantial body of research has addressed causes and controls of hypoxia, as well as effects on benthic and demersal organisms. Far less attention has been directed at effects on pelagic and planktonic organisms, and especially on the sublethal effects of hypoxia on foodwebs. We are investigating trophic interactions in planktonic foodwebs that experience seasonal hypoxia through a concerted process‐oriented field programme in Chesapeake Bay. To discern the effects attributable to hypoxia, we compared aspects of plankton ecology from two sites with similar temperature and salinity regimes but with different bottom‐layer oxygen concentrations. Specifically, we documented vertical distributions of phyto‐, microzoo‐, mesozoo‐, and ichthyoplankton, as well as gelatinous and juvenile fish predators. Grazing, reproductive, mortality, and migration rates of the copepods were also measured in both hypoxic and normoxic water columns. Results indicate that impacts of hypoxia vary seasonally, and the contribution of microzooplankton to trophic transfer between primary producers and mesozooplankton was enhanced with increasing hypoxia in summer. Mesozooplankton dependence on microzooplankton remained high through autumn with the retreat of hypoxia. The implications of these findings are examined in light of the current trends of hypoxia worldwide and in conjunction with warming coastal seas and estuaries.

Three presentations for this project were made at the 2012 CERF meeting in Daytona Beach :

Barba, A., Roman, M. R., Pierson, J. P.,
ZOOPLANKTON RESPONSE TO HYPOXIA IN THE CHESAPEAKE BAY
Poster Presentation, CERF 2011
Hypoxia is a common occurrence in fresh and salt water worldwide and can have negative effects on local fish and zooplankton including in the Chesapeake Bay. Copepods, specifically Acartia tonsa, are the most abundant type of zooplankton in the mesohaline reaches of the Bay. They occupy the base of the food web in many aquatic systems, including in Chesapeake Bay, and play a large role in transferring energy and material to higher trophic levels. We compared copepod behavior and fitness at both a hypoxic and anoxic site over three seasons, spring, summer and fall. It is hypothesized that low oxygen water will reduce the fitness of copepods and alter the migration behavior. To test this hypothesis, we observed copepod behavior and fitness using nets and traps, and we focused on migration patterns, population dynamics and RNA/DNA ratios

Liu, W., Decker, M., Pierson, J. J.
EFFECTS OF HYPOXIA ON PREDATION OF COPEPODS BY GELATINOUS ZOOPLANKTON IN CHESAPEAKE BAY
Oral Presentation, CERF 2011
The main channel of the Chesapeake Bay is characterized by hypoxic (DO < 2 mg/ L) bottom water from May to September. The goal of this research is to understand the effects of hypoxia on the distribution of
scyphomedusae and ctenophores in Chesapeake Bay and predation pressure of these gelatinous predators on copepods. During cruises in May, August, and September 2010, we sampled gelatinous zooplankton every four
to five hours at two stations, North (38? 31.32? N, 076? 24.48? W) and South (37? 43.68? N, 076? 12.0? W). The water column at the South station was oxic during most of the sampling. By contrast, the North station
experienced severe bottom-layer hypoxia in August and September, and even anoxia near the bottom in August. We found a few Mnemiopsis leidyi and Cyanea sp. on the May cruise, high abundances of M. leidyi and
Chrysaora quinquecirrha in August, and lower abundances of M. leidyi and C. quinquecirrha in September. In addition, many Beroe ovata were observed on the September cruise. M. leidyi and C. quinquecirrha were
sampled from the surface, pycnocline, and bottom layer at both stations and immediately preserved in formalin. Gut contents were identified and the tentacle bulb lengths of individual ctenophores were measured to
estimate wet weight. All data were analyzed with respect to hydrographic conditions and ambient zooplankton abundance to understand the predation impact of gelatinous zooplankton on copepods.

Roman, M., Elliott, D., Pierson, J.,
THE INFLUENCE OF DISSOLVED OXYGEN CONCENTRATION ON THE VERTICAL DISTRIBUTION OF LIFE STAGES OF THE COPEPOD, ACARTIA TONSA, IN CHESAPEAKE BAY
Oral Presentation, CERF 2011
In order to assess the influence of bottom water hypoxia on the vertical distribution of copepods in Chesapeake Bay, we conducted diel studies at stations with more/less bottom hypoxia and during the beginning, peak
and end of seasonal hypoxia. Whole water samples (10 liter Niskin) for copepods were collected from specific depths along with CTD, dissolved oxygen and fluorescence measurements. We enumerated copepod eggs and
the developmental stages of the dominant copepods from the collected samples. Separate samples treated with the vital stain Neutral Red were used to assess the live/dead fraction of copepods from our collections. Using
multivariate statistical techniques we will assess the influence of light, degree of stratification, temperature, salinity, fluorescence, oxygen and the predator field on the vertical distribution and abundance of the life stages
of Acartia tonsa.

Three presentations related to this project were made at the 2012 Ocean Sciences Meeting in Salt Lake City, Utah:

Barba, A. P., Roman, M. R., Pierson, J. J.
ZOOPLANKTON RESPONSE TO HYPOXIA IN CHESAPEAKE BAY
Poster Presentation, OSM 2012
Hypoxia is a common occurrence in fresh and salt water worldwide and can have negative effects on local fish and zooplankton including in the Chesapeake Bay. Copepods, specifically Acartia tonsa, are the most abundant type of
zooplankton in the mesohaline reaches of the Bay. They occupy the base of the food web in many aquatic systems, including in Chesapeake Bay, and play a large role in transferring energy and material to higher trophic levels. We
compared copepod behavior and fitness at both a hypoxic and an oxic site over three seasons, spring, summer and fall for two years. It is hypothesized that low oxygen water will reduce the fitness of copepods and alter the
migration behavior. To test this hypothesis, we observed copepod behavior and fitness using nets and traps, and we focused on migration patterns, population dynamics and RNA/DNA ratios

Yeager, D. E.,
THE EFFECTS OF HYPOXIA ON VERTICAL DISTRIBUTION OF CHESAPEAKE BAY ACARTIA TONSA
Poster Presentation, OSM 2012
Summer hypoxia within the Chesapeake Bay has played a major role in reshaping the vertical migratory behavior within the zooplankton community. Higher trophic levels have been affected as a direct result of lower oxygen
vailability and zooplankton abundance. This study focused on the zooplankton species of Acartia tonsa, prevalent within estuarine waters, including the Chesapeake Bay. Through various sampling techniques aboard the RV Hugh R.
Sharp we were able to quantify the abundance of A. tonsa at different depths to examine how the diurnal vertical migration was affected by hypoxia. We also examined A. tonsa predator concentrations at specific depths to determine
whether hypoxia or predation played the more dominant role in A. tonsa vertical distribution. Results show that A. tonsa population abundance

and vertical migration behavior decrease throughout the summer months largely in conjunction with hypoxic conditions. It is imperative that we understand A. tonsa vertical distribution because of its role as a primary consumer of phytoplankton that links to secondary consumers such as larger fish within the marine ecosystem.

Roman, M., Elliot, D., Pierson, J.
HYPOXIA: REFUGE OR DEAD ZONE FOR COPEPODS?
Oral Presentation, OSM 2012
In coastal waters there are examples of copepods spending part of the day in hypoxic (oxygen < 2 mg L-1) bottom waters which may serve as a refuge from predation. Other studies have shown that copepods avoid hypoxic waters and aggregate higher in the water column where greater light levels may make them more susceptible to predation. We will review the hydrographic conditions that occur with these copepod different behaviors, compare species differences and review different physiological adaptions that facilitate life in low oxygen environments for copepods.

Findings: (See PDF version submitted by PI at the end of the report)

Training and Development:

Our students are learning how to deploy and maintain oceanographic equipment, sort zooplankton samples, and process and analyze hydrographic and plankton data.

Outreach Activities:

In year 2, we continued our shipboard cruise blog, which can be accessed here:
http://lifeinthedeadzone.org/

In summer 2011 we developed education modules as part of the COSEE Coastal Trends program. The education modules were developed through partnerships between two undergraduate students from Hampton University, two high school science teachers, and our science team. The science team included postdoc David Elliott, student Ali Barba, and PI Pierson. Input from the other PIs was also included.

Both the undergraduate students and the teachers participated in oceanographic cruises for this project and assisted with laboratory processing of samples from those cruises. In addition Daniel Yeager presented his work at the 2012 Ocean Sciences meeting as part of the ASLO Multicultural Program.

The education modules focused on two concepts:
1. Aquatic Food Webs
2. Plankton - Aquatic Drifters
Though broad topics, both encompassed some discussion of how hypoxia may impact the food web or the diversity in planktonic systems.

The modules can be viewed publicly at this website:
www.teachoceanscience.net

Journal Publications

Books or Other One-time Publications

Web/Internet Site

Other Specific Products

Contributions

Contributions within Discipline:

Contributions to Other Disciplines:

Contributions to Human Resource Development:
Training of two graduate students, three undergraduate students, two secondary school teachers, and one postdoc.

Contributions to Resources for Research and Education:

Contributions Beyond Science and Engineering:

Conference Proceedings

Special Requirements

Special reporting requirements: None

Change in Objectives or Scope: None

Animal, Human Subjects, Biohazards: None

Categories for which nothing is reported:

Any Journal

Any Book

Any Web/Internet Site

Any Product

Contributions: To Any within Discipline

Contributions: To Any Other Disciplines

Contributions: To Any Resources for Research and Education

Contributions: To Any Beyond Science and Engineering

Any Conference

We conducted three research cruises in each of 2010 and 2011. Each cruise had an identical cruise plan, consisting of an initial survey of the hydrographic conditions of the Chesapeake Bay from the Bay Bridge in the north to the Rappahannock shoals in the south, using a Scanfish with a top mounted optical plankton counter (OPC). Then we conducted two 56 hour stations, one in the southern, less hypoxic conditions between the Rappahannock and Potomac Rivers, and one in the mid-bay near the mouth of the Little Choptank River. At each 56 hour station, we spent approximately 28 hours at anchor, where we conducted CTD casts hourly and various shipboard observations on the vertical distribution of microplankton, zooplankton trapping series to determine the vertical migration of *Acartia tonsa*, and vital rate experiments on *A. tonsa* including grazing, egg production, and percent alive.

Most of our data processing and analysis is ongoing, and the table below shows which data have been processed (X means completed):

Data Type	DZZ1001 2010/05	DZZ1002 2010/08	DZZ1003 2010/09	DZZ1101 2011/05	DZZ1102 2011/07	DZZ1103 2011/09
SMS	X	X	X	X	X	X
Scanfish CTD	X	X	X	X	X	X
Scanfish OPC	X	X	X	X	X	X
CTD	X	X	X	X	X	X
Chlorophyll a	X	X	X	X	X	X
MOCNESS	X	X	X	X		
Z-Trap/Z-Tow	X	X	X	X		
Tucker Trawl	X	X	X	X	X	
Jellyfish Net	X	X	X	X	X	X
Microplankton	X	X	X	X	X	X
Grazing Rate	X	X	X	X		

Data can be accessed by participants at a password protected website:
http://www.hpl.umces.edu/~jpierson/DeZoZoo/index.html
Username: DZZ
Password: hypox

General observations

Below are results from the three surveys from 2011, showing the development of hypoxic conditions in the Bay. In May, there is strong hypoxia throughout the study region, in contrast with 2010 when hypoxia was not as well established in May (Fig. 1). In deed, sulfide was already present at our northern station in May, whereas sulfide was not observed until July in 2010 (unpublished, Jeff Cornwell pers com.). Salinity was also significantly lower in May 2011 than it was in May 2010. In July, hypoxia and anoxia is present throughout the region (Fig. 2). By September, much of the hypoxia has retreated from the south (Fig. 3). It is important to note that our September cruise was conducted three weeks after Hurricane Irene and Tropical Storm Lee inundated the region with rain.

In terms of our target copepod species, *Acartia tonsa*, preliminary and anecdotal evidence from examining some samples suggests that abundances were lowest in July compared to the May and September samples. Sea nettle abundance appeared to be lower in 2011 than in 2010, likely due to anomalously low salinities in the Chesapeake Bay that began in spring 2011 and persisted throughout the summer. Hypoxia and anoxia were more prevalent in 2011 than in 2010 which may contribute to other biological differences between the years (e.g. in zooplankton and fish abundances – which are part of ongoing analyses).

Further results are forthcoming.

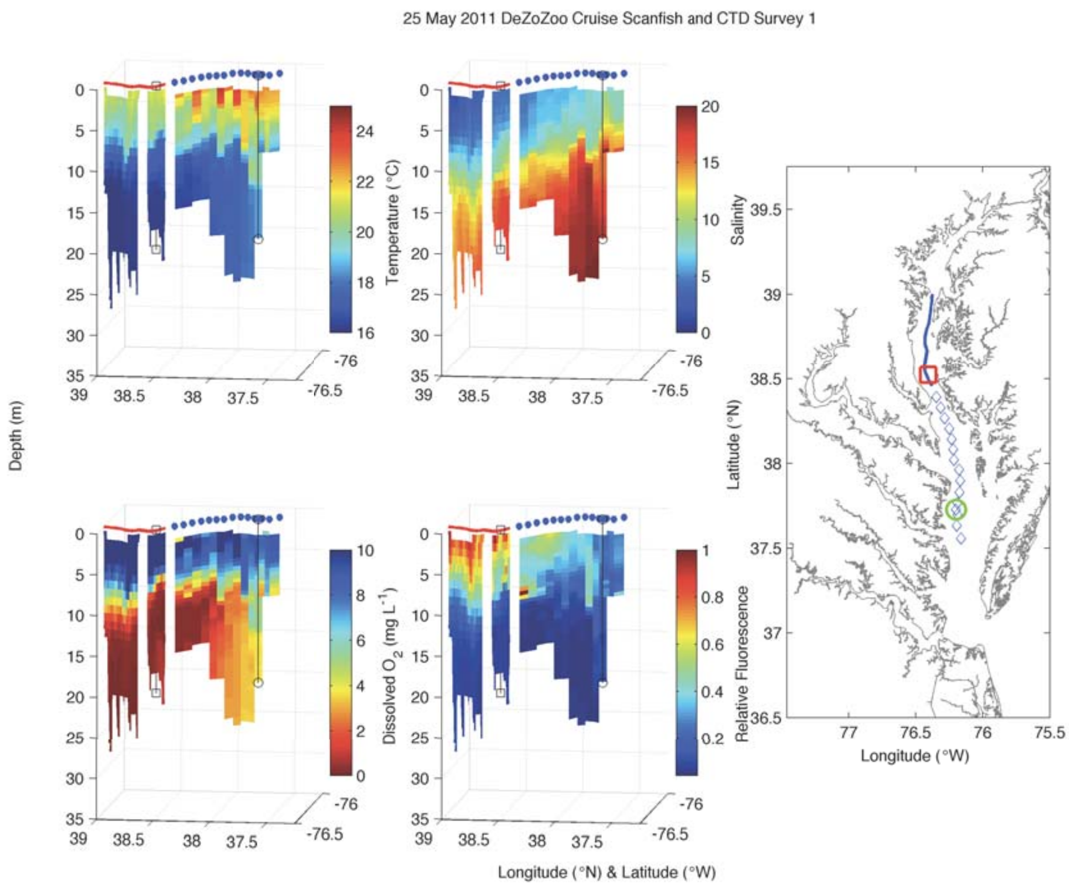


Figure 1. Hydrographic conditions from the Scanfish surveys of the mesohaline Chesapeake Bay in late May 2011.

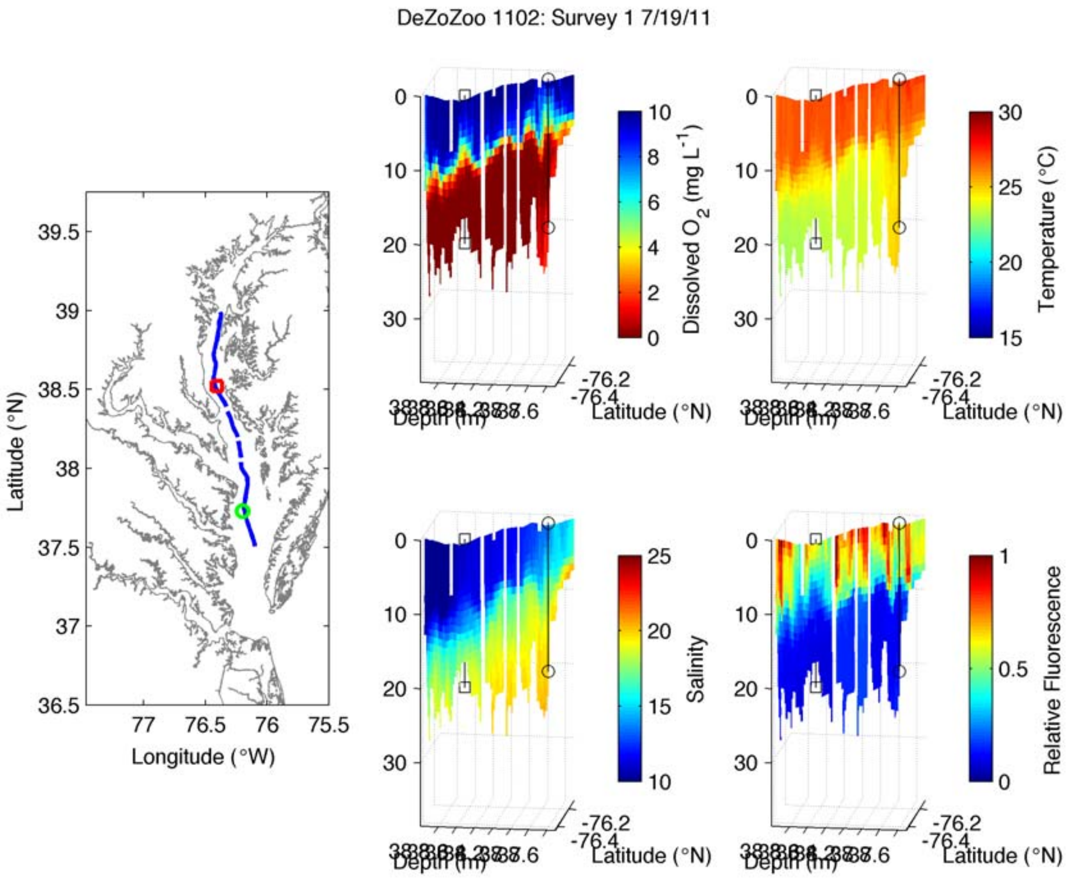


Figure 2. Hydrographic conditions from the Scanfish surveys of the mesohaline Chesapeake Bay in mid July 2011.

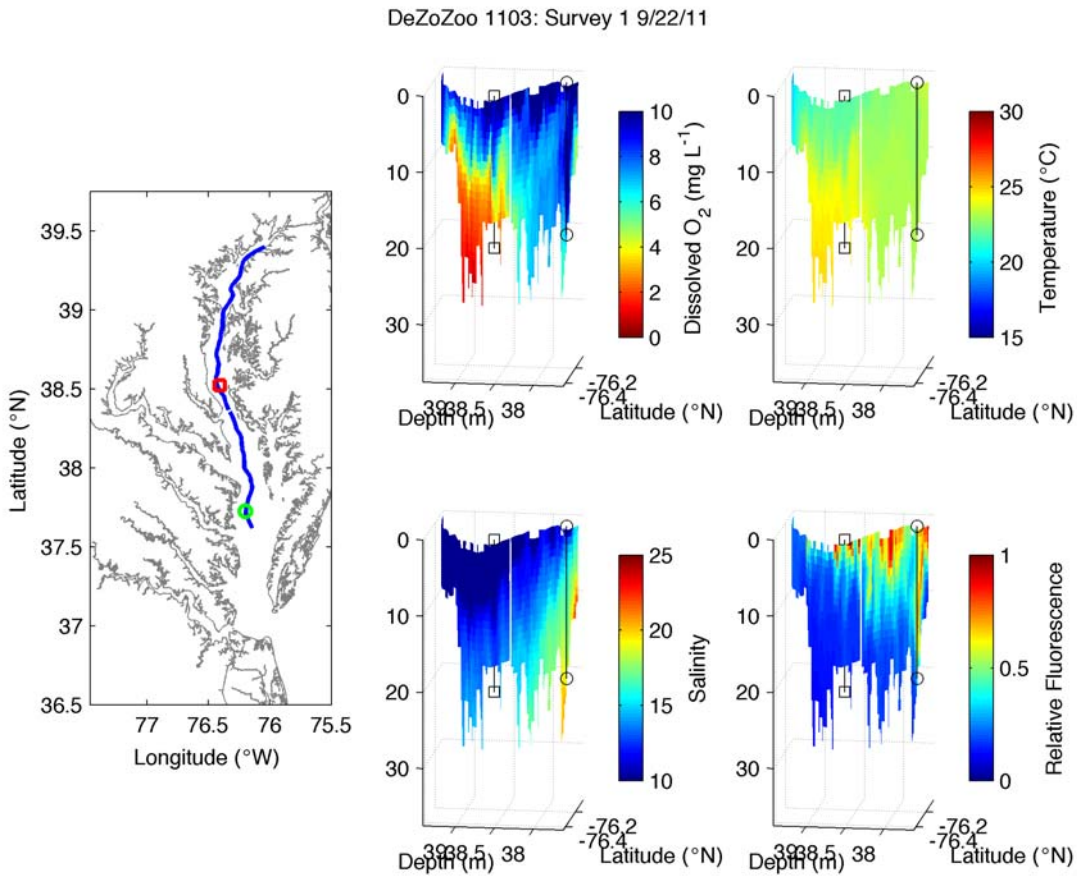
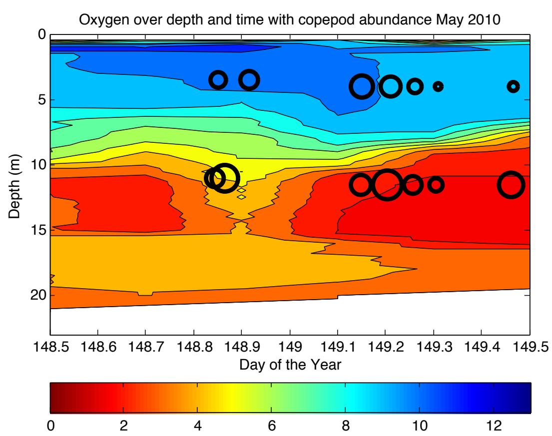


Figure 3. Hydrographic conditions from the Scanfish surveys of the mesohaline Chesapeake Bay in late September 2011.

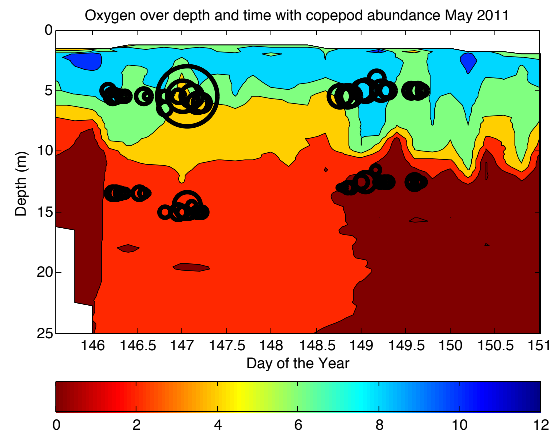
***Acartia tonsa* abundance and vertical distribution**

Hypoxia set in earlier and was more severe in 2011 than in 2010 resulting in low oxygen levels at the normoxic station in 2011. *Acartia tonsa* showed a distinct migration pattern at the south (normoxic) station and in 2010 and 2011. There was a stronger pattern in 2010 than in 2011. At the north station, *A. tonsa* showed little to no diel migration pattern and abundance was higher overall in 2010 than in 2011. A greater number of copepods remained in the surface layer in 2011.

South Station (Normoxic)



North Station (Hypoxic)



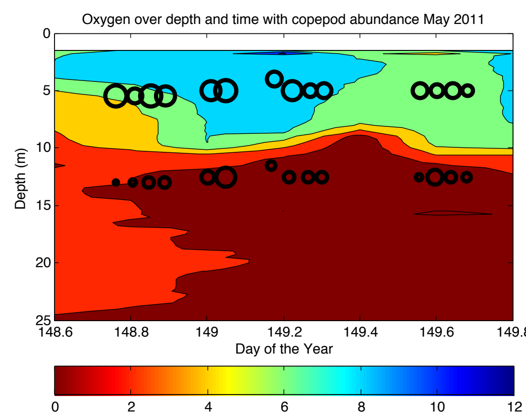


Figure 4. Dissolved oxygen contours from hourly CTD casts and *A. tonsa* relative abundance from vertical net tows in May 2010 (left panels) and 2011 (rightpanels) at the Northern hypoxic station (upper panels) and Southern oxic station (lower panels).

There was a significant decrease in abundance between May and August at the north and south stations in 2010 (Figure 5). Between August and September, abundances increased at the south station but remained comparable at the north station. There is a distinct diel vertical migration pattern in May at both stations and in September at the south station. For both August stations and the north station in September, the migration pattern is not as strong.

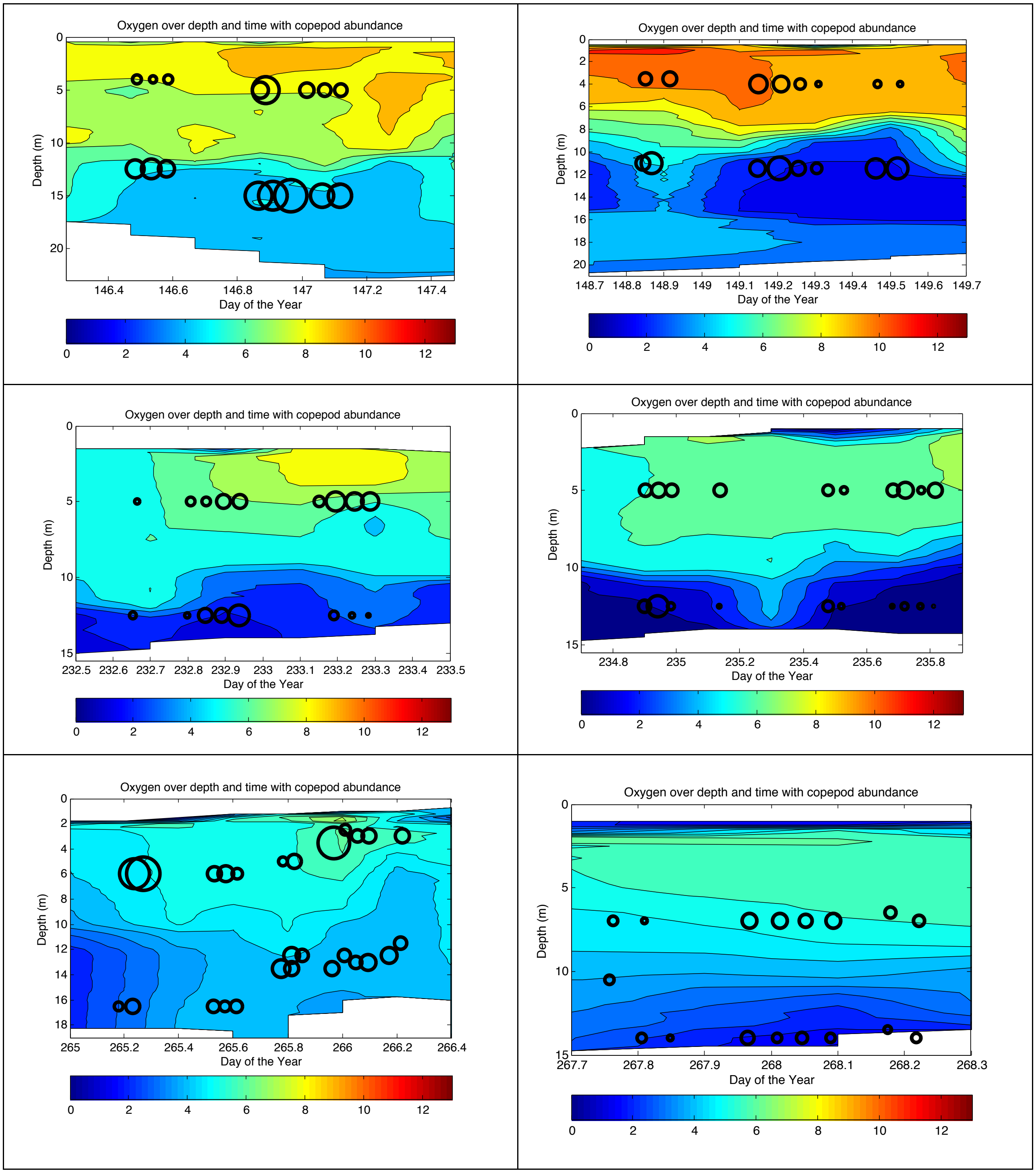


Figure 4. Dissolved oxygen contours from hourly CTD casts and *A. tonsa* relative abundance from vertical net tows in 2010. Data are from May (upper panels), August (middle panels), and September (lower panels) for the South (oxic, left panels) and North (hypoxic, right panels).

Ichthyoplankton Surveys, Collections, and Samples

Ichthyoplankton and juvenile/adult fishes were collected in depth-stratified tows of plankton-sampling gears (Tucker Trawl and MOCNESS) and a midwater trawl, respectively. Six survey cruises were conducted by DeZoZo during 2010-2011.

Three survey cruises were conducted in each year (Table 1). Sampling was carried out at two designated DeZoZo stations. The South station was nominally labeled "normoxic" and the North station, nominally labeled "hypoxic" (see figures 1-3 at the beginning of the report)

Sampling Gears and Mesh Sizes

A 1-m^2 mouth-opening Tucker trawl, with either 280-µm or 1-mm meshes was deployed at each station in four designated depth regions (near-bottom, near bottom to pycnocline, pycnocline, and pycnocline to surface). Each deployment and sample was obtained from a 2-min tow. Catches of ichthyoplankton in the Tucker trawl tows are summarized in Table 1, but have not been analyzed in this report.

A 1/4-m^2 MOCNESS sampler, with 200-µm meshes, was deployed to sample ichthyoplankton in 5-min tows in two depth segments (bottom to pycnocline and pycnocline to surface) at each station (Table 1). Ichthyoplankton data, summaries, and preliminary analysis in this report are derived from the MOCNESS data.

A midwater trawl was used to sample juvenile and adult fish in two survey cruises each year (Table 1). The trawl had a square mouth opening, 6-m on each side when fully stretched, and 3-mm cod-end mesh. The trawl was deployed twice at each station. It was fished obliquely in ten, 2-min steps from surface to the pycnocline, then retrieved to bring the fish catch to the deck. The trawl was immediately redeployed to fish in ten, 2-min steps from the pycnocline to bottom to sample the below-pycnocline layer.

Numbers of Samples and Fish Collected

A total of 496 ichthyoplankton and fish samples were collected (Table 1). As expected, the zooplanktivorous bay anchovy dominated the catches of ichthyoplankton (> 96%) and juvenile/adult fishes (90%).

Table 1. Summary of cruises, sampling gears, and numbers of fish eggs, larvae and juvenile/adult fish collected. MOC 200 = MOCNESS, ¼ m^2 with 200-µm meshes. TT = Tucker trawl, 1 m^2 with either 280-µm or 1-mm meshes. MWT = midwater trawl.

Survey	Gear	No. Samples	Total Eggs	Total Fish	Bay Anchovy Eggs	Bay Anchovy Fish
27-31 May 2010	TT280	72	418,745	68,661	411,580	67,107
	MOC200	10	70,161	7103	69,577	6776
	Subtotal	82	488,906	75,764	481,157	73,883
21-24 Aug 2010	TT1000	44	82	1508	76	1432
	MOC200	22	24,358	2324	17,280	2189
	MWT	22	ns	14,830	ns	14,649
	Subtotal	88	24,440	18,662	17,356	18,270
23-24 Sep 2010	TT1000	24	0	435	0	260
	MOC200	12	33	146	1	79
	MWT	12	0	6589	0	5980
	Subtotal	48	33	7170	1	6319
27-30 May 2011	TT1000	44	2559	75	837	25
	TT280	28	115,573	9499	113,298	9270
	MOC200	14	3977	32	3963	27
	Subtotal	86	122,109	9606	118,098	9322
21-24 July 2011	TT1000	48	1007	793	86	682
	MOC200	24	42,158	1411	40,248	1378
	MWT	24	ns	2179	ns	1718
	Subtotal	96	43,165	4383	40,334	3778
24-27 Sep 2011	TT1000	48	0	2591	0	2047
	MOC200	24	5	412	5	289
	MWT	24	0	27,912	0	25,325
	Subtotal	96	5	30,915	5	27,661
	Total	**496**	**678,658**	**146,500**	**656,951**	**139,233**

Sample Processing, Lab Analysis, and Data Management

Status of Sample Processing

Processing to identify taxa, determine numbers collected, and estimate fish lengths is complete for all ichthyoplankton and juvenile/adult fish samples. Stomach analysis of fish larvae is mostly completed but data analysis is still to be undertaken. Although otolith-aging and growth analysis on bay anchovy larvae are not yet initiated, many otolith samples have been prepared for analysis that will begin by summer 2012.

Data and Data Management

At present, all ichthyoplankton and fish data are entered into spreadsheets and stored in E. Houde's lab at the Chesapeake Biological Laboratory.

Ichthyoplankton Abundance and Concentrations

Concentrations (number per m^3) and abundances (number under a unit area) were calculated for fish eggs and larvae. In this report, concentrations are reported for the MOCNESS samples only. As analysis proceeds, abundance data and data from the Tucker trawl samples will be considered in future reports.

Egg and Larvae Concentrations

The overall mean concentrations of fish eggs and larvae in the MOCNESS tows were 24.96 and 1.85 m^{-3}, respectively. Bay anchovy was the most common species (mean concentration of eggs = 19.80 m^{-3}, 79.3% and mean concentration of larvae = 1.74 m^{-3}, 94.0%). Other common taxa represented by eggs and larvae included clupeids (possibly Atlantic menhaden), sciaenids (probably weakfish and Atlantic croaker), goby larvae, silversides larvae, and puffer larvae. Although bay anchovy dominated the ichthyoplankton at both the North and South station, diversity of taxa was higher at the South station than at the North station.

Mean concentrations of fish eggs and larvae are summarized in Tables 2 - 4. Because of instrument malfunctions, MOCNESS samples were not taken in the May 2010 cruise at the South station or in September 2010 at the North station. Concentrations of the abundant bay anchovy eggs and larvae were substantially higher above the pycnocline than below it (Tables 2 and 3), especially in summer months when hypoxia was prevalent below the pycnocline. Depth distributions of taxa other than bay anchovy were more uniform (Table 4).

Mean concentrations of bay anchovy eggs and larvae appear to be higher at the North station than at the South Station (Tables 2 and 3). This result is uncertain because of missing MOCNESS samples at the South station in May 2010 when anchovy eggs and larvae were abundant at the North station. Future analysis of the Tucker trawl samples may resolve this question.

Mean concentrations of eggs and larvae of ichythyoplankton taxa other than bay anchovy were not higher above the pycnocline than below it, and this result was consistent between years (Table 4). For bay anchovy, which dominated the eggs and larvae in collections, mean concentrations were higher above than below the pycnocline (Tables 2 and 3).

Table 2. Bay anchovy eggs. Mean concentrations, number per m^3. MOCNESS samples, Chesapeake Bay, North and South stations, 2010 and 2011. Pyc = pycnocline. All Depths = mean concentration in the entire water column. ns = no samples.

	North			South		
	All Depths	**Above Pyc**	**Below Pyc**	**All Depths**	**Above Pyc**	**Below Pyc**
2010	73.51	142.28	4.73	3.99	6.94	1.04
May 2010	128.57	248.57	8.57	ns	ns	ns
Aug 2010	18.45	35.99	0.90	7.98	13.87	2.08
Sep 2010	ns	ns	ns	~0.00	0	~0.00
2011	12.09	21.00	3.18	7.03	13.65	0.40
May 2011	4.53	4.46	4.61	0	0	0
Jul 2011	31.74	58.55	4.94	15.22	14.79	0.87
Sep 2011	~0.00	0	~0.00	~0.00	~0.00	~0.00
Total	**34.03**	**64.32**	**3.73**	**5.57**	**10.43**	**0.71**

Concentrations of eggs and larvae, especially bay anchovy, were higher in 2010 than in 2011. However, the pattern of depth distribution was similar in each year, with approximately order-of-magnitude greater concentrations above the pycnocline than below it. Between-years differences in total ichthyoplankton abundance were mostly attributable to higher concentrations of bay anchovy in 2010 (Tables 2 - 4).

Table 3. Bay anchovy larvae. Mean concentrations, number per m^3. MOCNESS samples, Chesapeake Bay, North and South stations, 2010 and 2011. Pyc = pycnocline. All Depths = mean concentration in the entire water column. ns = no samples.

	North			South		
	All Depths	**Above Pyc**	**Below Pyc**	**All Depths**	**Above Pyc**	**Below Pyc**
2010	6.70	12.80	0.61	1.37	1.96	0.77
May 2010	12.81	24.51	1.10	ns	ns	ns
Aug 2010	0.59	1.08	0.11	2.61	3.82	1.40
Sep 2010	ns	ns	ns	0.12	0.11	0.14
2011	0.49	0.89	0.09	0.23	0.32	0.16
May 2011	0.03	0.05	~0.00	0	0	0
Jul 2011	1.42	2.61	0.22	0.19	0.35	0.03
Sep 2011	0.03	0.02	0.05	0.30	0.28	0.32
Total	**2.71**	**5.15**	**0.38**	**0.77**	**1.09**	**0.45**

Bay Anchovy Egg and Larvae Concentrations and Dissolved Oxygen

There were generally positive relationships between concentrations of bay anchovy egg and larvae and dissolved oxygen (DO) level (Figures 5 and 6), especially during the July and August cruises when sub-pycnocline waters were hypoxic. The relationships were similar at the North and South stations. In the August 2010 cruise, bay anchovy egg and larvae concentrations were, on average, 3- to 4-fold higher above the pycnocline where DO levels were > 3.0 mg l^{-1} than below it where DO was lower. In the July 2011 cruise, bay anchovy mean egg concentrations were > 10-fold higher above the pycnocline and larvae mean concentrations were nearly 5-fold higher above the pycnocline where DO was > 3.0 mg l^{-1} than below it where DO levels were ≤ 2.0 mg l^{-1}. In the July and August cruises, concentrations of bay anchovy larvae fell off rapidly at DO levels < 1.5 mg l^{-1}.

Table 4. Fish larvae other than bay anchovy. Mean concentrations, number per m^3. MOCNESS samples, Chesapeake Bay, North and South stations, 2010 and 2011. Pyc = pycnocline. All Depths = mean concentration in the entire water column. ns = no samples.

	North			**South**		
	All Depths	**Above Pyc**	**Below Pyc**	**All Depths**	**Above Pyc**	**Below Pyc**
2010	0.31	0.47	0.14	0.12	0.13	0.13
May 2010	0.59	0.92	0.29	ns	ns	ns
Aug 2010	0.02	0.03	0	0.16	0.16	0.16
Sep 2010	ns	ns	ns	0.10	0.09	0.10
2011	0.01	0.02	0.01	0.06	0.03	0.09
May 2011	0	0.02	~0.00	0	0	0
Jul 2011	0.01	0.03	0.01	0.02	0.05	0
Sep 2011	0.01	0	0	0.12	0.08	0.16
Total	**0.11**	**0.17**	**0.06**	**0.10**	**0.10**	**0.10**

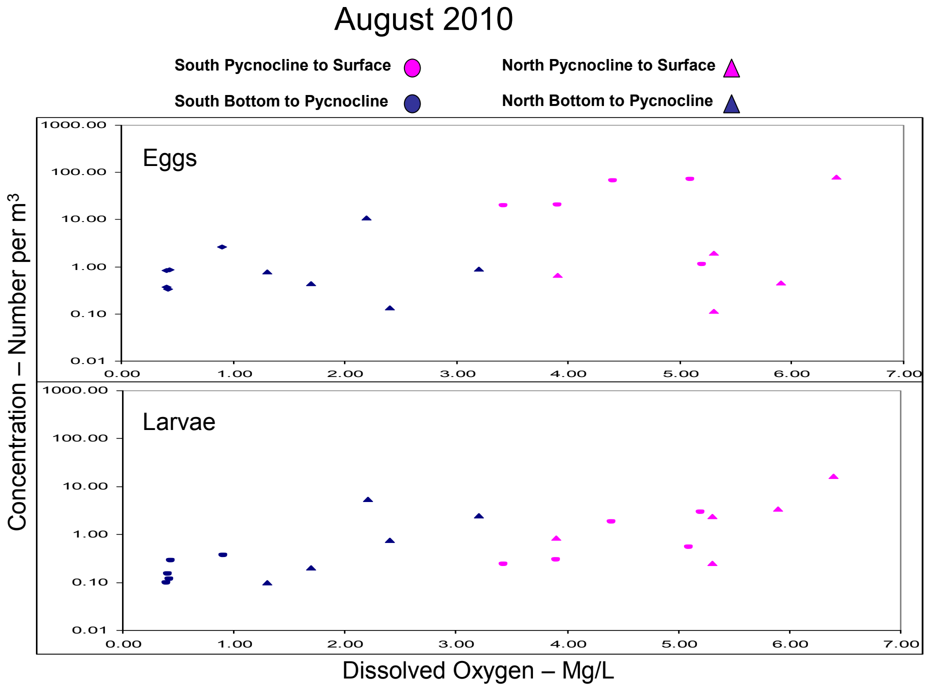


Figure 5. August 2010. Relationship between bay anchovy eggs (top panel) and larvae (bottom panel) concentrations (number per m^3) and dissolved oxygen (mg l^{-1}). Data for North and South stations, and for samples taken above and below the pycnocline.

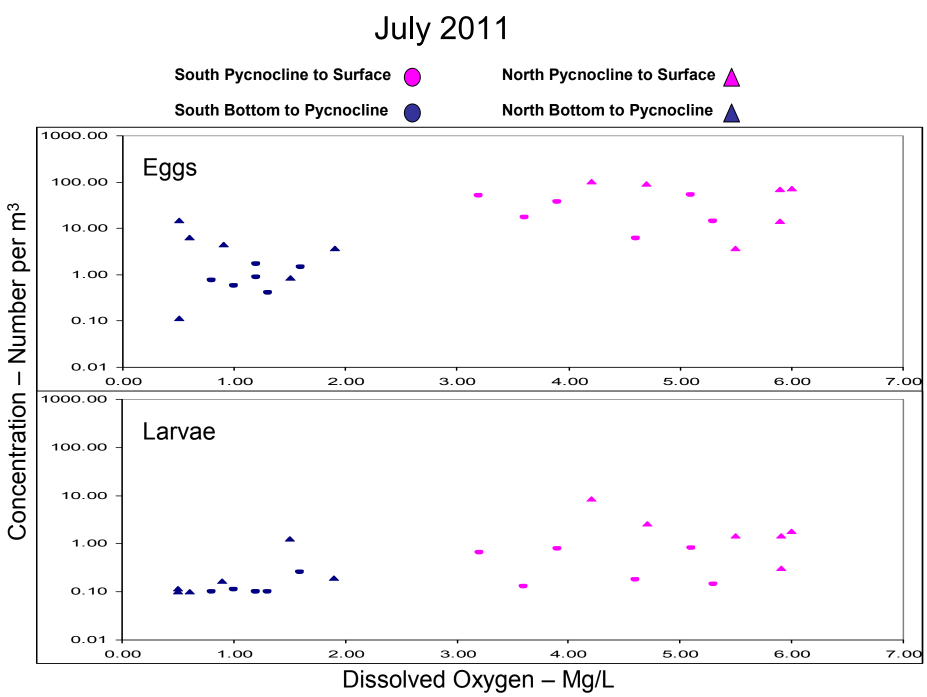


Figure 6. July 2011. Relationship between bay anchovy eggs (top panel) and larvae (bottom panel) concentrations (number per m^3) and dissolved oxygen (mg l^{-1}). Data for North and South stations, and for samples taken above and below the pycnocline.

Sizes of Bay Anchovy Larvae

Mean lengths of larvae of the abundant bay anchovy increased in collections made from May through September in each year (Table 5). May cruises were conducted near the beginning of the anchovy spawning season and small, newly-hatched larvae were collected (especially in 2010). Collections in July through September cruises included many larger larvae, including transforming individuals > 25 mm in length. By late summer (August and September), mean lengths of bay anchovy larvae were longer at the North station than at the South station (Table 5).

Table 5. Bay anchovy larvae. Mean total lengths, mm. MOCNESS samples, Chesapeake Bay, North and South stations, 2010 and 2011. Pyc = pycnocline. All Depths = mean length for the entire water column. ns = no samples.

	North			**South**		
	All Depths	**Above Pyc**	**Below Pyc**	**All Depths**	**Above Pyc**	**Below Pyc**
2010	4.43	4.37	5.74	7.85	7.96	7.56
May 2010	3.70	3.67	4.29	ns	ns	ns
Aug 2010	17.89	17.68	20.19	7.73	7.88	7.33
Sep 2010	29.02	28.13	29.36	10.46	10.51	10.41
2011	4.28	3.85	8.13	11.71	10.30	14.06
May 2011	3.03	3.03	3.00	ns	ns	ns
Jul 2011	3.87	3.87	3.85	8.77	8.55	11.04
Sep 2011	29.02	28.13	29.36	13.63	12.68	14.37
Total	**4.43**	**4.32**	**6.37**	**8.56**	**8.34**	**9.07**

Age, Growth, and Feeding by Bay Anchovy Larvae

Partially completed stomach analysis on bay anchovy larvae indicates that copepods are the dominant prey. Because most larvae had empty guts, large numbers of larvae must be analyzed to complete the diet and feeding analysis.

Otolith-aging, based on daily increment counts, will be conducted on otoliths that are being removed from larvae used for stomach analysis. Samples are now being prepared for analysis.

Bay Anchovy Juvenile and Adult Abundances

Midwater Trawl Collections

A total of 51,550 fish were collected in the midwater trawl on four survey cruises, two each in 2010 and 2011. Of these, 47,672 (92.5%) were juvenile or adult bay anchovy

(Table 1). The remainder consisted of a diverse assemblage of pelagic and demersal species, including Atlantic croaker, weakfish, spot, hogchoker, and harvestfish which were among the most common taxa collected.

The trawl catches of bay anchovy were similar in 2010 and 2011. Mean catches per tow were similar at the North and South stations and were similar above and below the pycnocline (Table 6). Unfortunately, no midwater trawl samples were available at the North station in 2010. Stomach analysis will be conducted on bay anchovy juveniles and adults to determine foods and diets.

Table 6. Juvenile and adult bay anchovy. Mean number per tow; midwater trawl, Chesapeake Bay, North and South stations, 2010 and 2011. All Depths = mean catch per tow for the entire water column. Pyc = pycnocline. ns = no samples.

	North			**South**		
	All Depths	**Above Pyc**	**Below Pyc**	**All Depths**	**Above Pyc**	**Below Pyc**
2010	1141 ± 896	2051 ± 1782	231 ± 156	384 ± 114	408 ± 175	356 ± 149
Aug 2010	1141 ± 896	2051 ± 1782	231 ± 156	270 ± 133	228 ± 94	354 ± 280
Sep 2010	ns	ns	ns	498 ± 195	619 ± 362	357 ± 61
2011	526 ± 232	309 ± 122	744 ± 448	577 ± 238	358 ± 146	778 ± 439
Jul 2011	70 ± 36	59 ± 55	81 ± 51	68 ± 58	132 ± 126	12 ± 10
Sep 2011	983 ± 431	559 ± 195	1406 ± 840	1128 ± 448	585 ± 240	1671 ± 841
Total	707 ± 305	812 ± 529	593 ± 321	482 ± 133	384 ± 117	584 ± 237

We conducted three research cruises in each of 2010 and 2011. Each cruise had an identical cruise plan, consisting of an initial survey of the hydrographic conditions of the Chesapeake Bay from the Bay Bridge in the north to the Rappahannock shoals in the south, using a Scanfish with a top mounted optical plankton counter (OPC). Then we conducted two 56 hour stations, one in the southern, less hypoxic conditions between the Rappahannock and Potomac Rivers, and one in the mid-bay near the mouth of the Little Choptank River. At each 56 hour station, we spent approximately 28 hours at anchor, where we conducted CTD casts hourly and various shipboard observations on the vertical distribution of microplankton, zooplankton trapping series to determine the vertical migration of *Acartia tonsa*, and vital rate experiments on *A. tonsa* including grazing, egg production, and percent alive.

Most of our data processing and analysis is ongoing, and the table below shows which data have been processed (X means completed):

Data Type	DZZ1001 2010/05	DZZ1002 2010/08	DZZ1003 2010/09	DZZ1101 2011/05	DZZ1102 2011/07	DZZ1103 2011/09
SMS	X	X	X	X	X	X
Scanfish CTD	X	X	X	X	X	X
Scanfish OPC	X	X	X	X	X	X
CTD	X	X	X	X	X	X
Chlorophyll a	X	X	X	X	X	X
MOCNESS	X	X	X	X		
Z-Trap/Z-Tow	X	X	X	X		
Tucker Trawl	X	X	X	X	X	
Jellyfish Net	X	X	X	X	X	X
Microplankton	X	X	X	X	X	X
Grazing Rate	X	X	X	X		

Data can be accessed by participants at a password protected website:

http://www.hpl.umces.edu/~jpierson/DeZoZoo/index.html

Username: DZZ

Password: hypox

General observations

Below are results from the three surveys from 2011, showing the development of hypoxic conditions in the Bay. In May, there is strong hypoxia throughout the study region, in contrast with 2010 when hypoxia was not as well established in May (Fig. 1). In deed, sulfide was already present at our northern station in May, whereas sulfide was not observed until July in 2010 (unpublished, Jeff Cornwell pers com.). Salinity was also significantly lower in May 2011 than it was in May 2010. In July, hypoxia and anoxia is present throughout the region (Fig. 2). By September, much of the hypoxia has retreated from the south (Fig. 3). It is important to note that our September cruise was conducted three weeks after Hurricane Irene and Tropical Storm Lee inundated the region with rain.

In terms of our target copepod species, *Acartia tonsa*, preliminary and anecdotal evidence from examining some samples suggests that abundances were lowest in July compared to the May and September samples. Sea nettle abundance appeared to be lower in 2011 than in 2010, likely due to anomalously low salinities in the Chesapeake Bay that began in spring 2011 and persisted throughout the summer. Hypoxia and anoxia were more prevalent in 2011 than in 2010 which may contribute to other biological differences between the years (e.g. in zooplankton and fish abundances – which are part of ongoing analyses).

Further results are forthcoming.

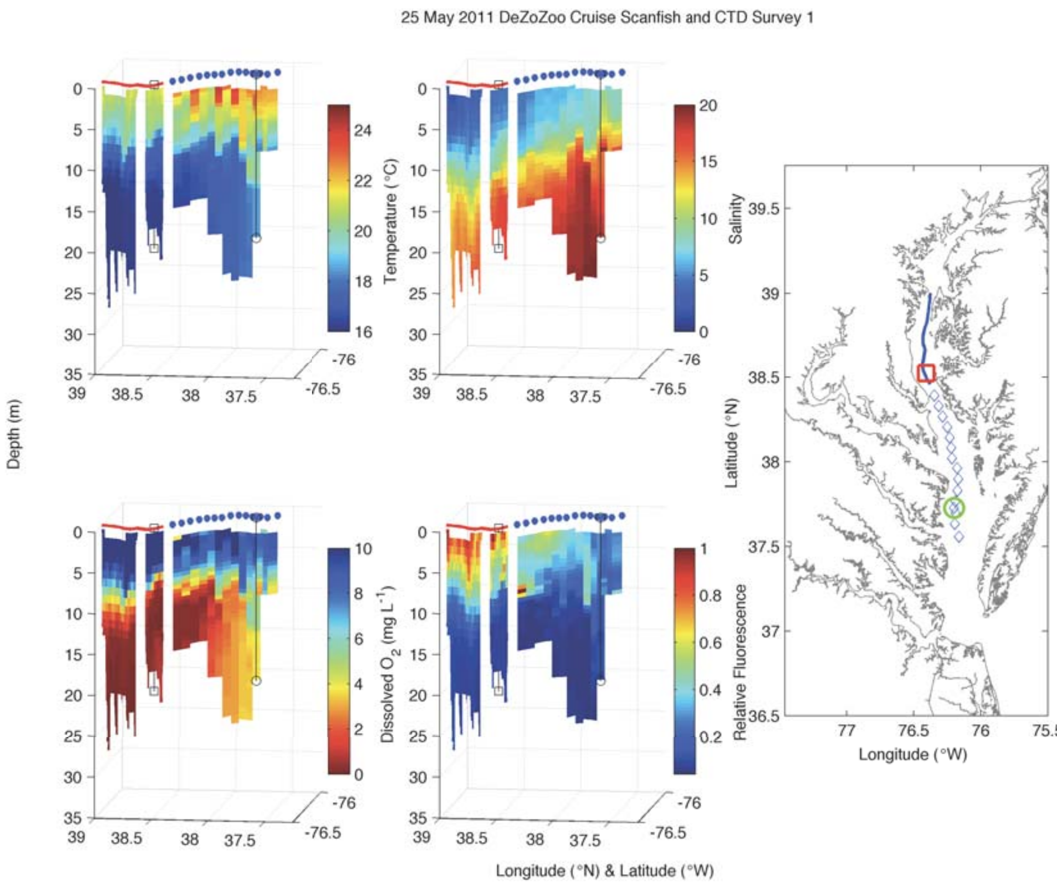


Figure 1. Hydrographic conditions from the Scanfish surveys of the mesohaline Chesapeake Bay in late May 2011.

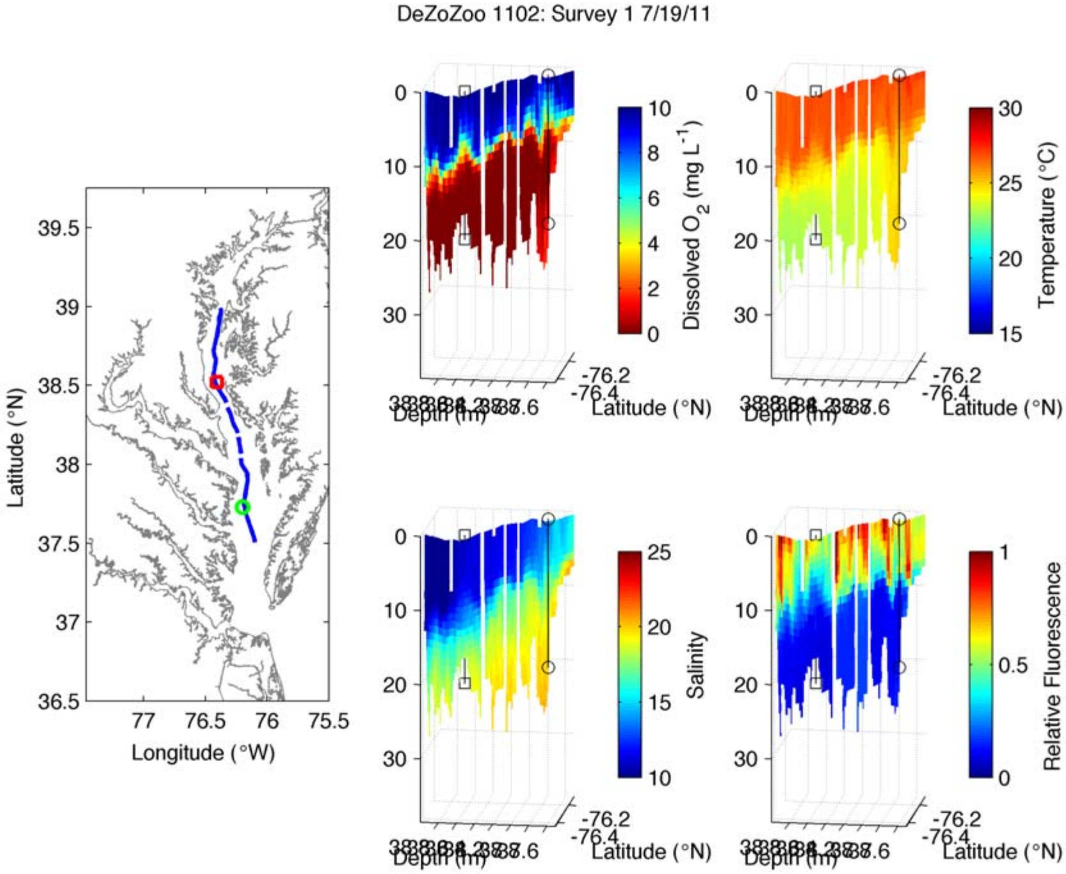


Figure 2. Hydrographic conditions from the Scanfish surveys of the mesohaline Chesapeake Bay in mid July 2011.

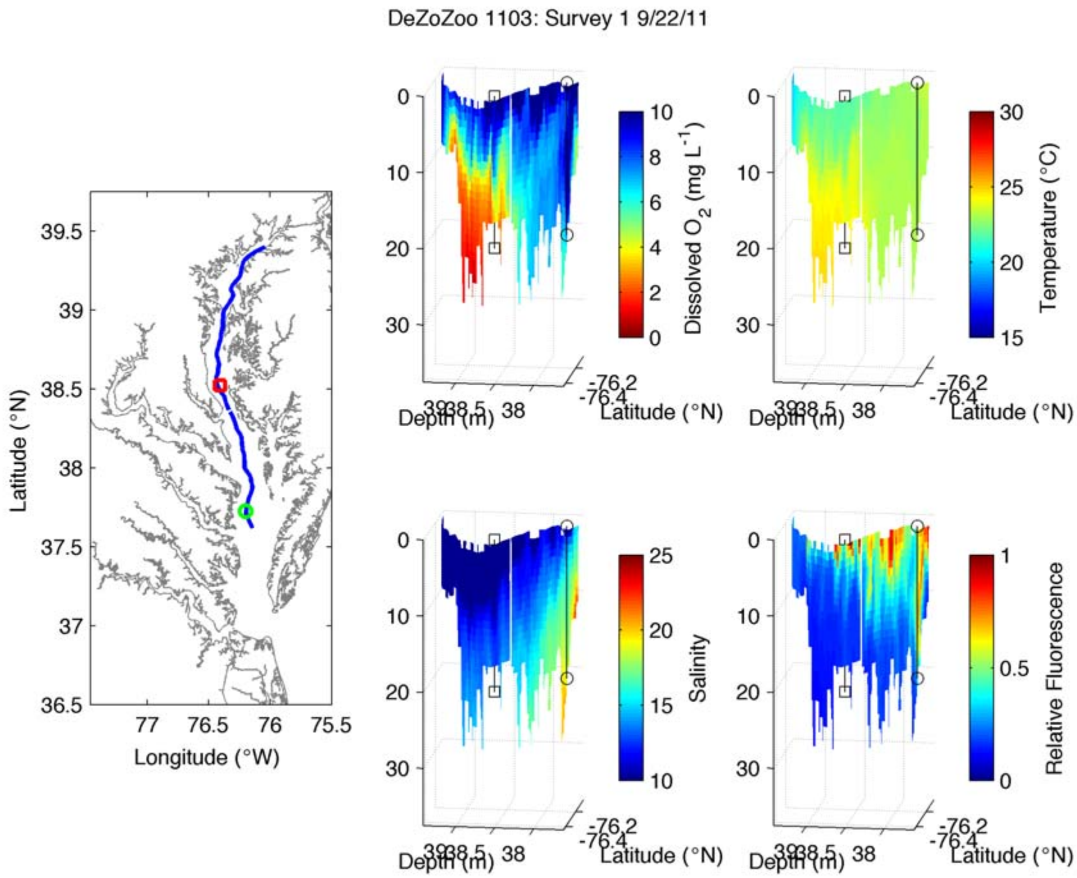


Figure 3. Hydrographic conditions from the Scanfish surveys of the mesohaline Chesapeake Bay in late September 2011.