Assessing the Chesapeake Bay Forage Base: Existing Data and Research Priorities

STAC Workshop Report

November 12-13, 2014

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Executive Summary

Forage species play an integral role in the Chesapeake Bay food web by supporting higher-trophic level production. "Forage" was interpreted broadly for this workshop and included invertebrate groups as well as vertebrates, in recognition of the importance of benthic invertebrates and plankton as forage in the Chesapeake ecosystem, and in response to needs outlined by the Sustainable Fisheries Goal Implementation Team (SFGIT) Executive Committee. Most forage species are not directly managed by the Atlantic States Marine Fisheries Commission (ASMFC) or Chesapeake Bay jurisdictions, yet these species are critical to sustaining production of economically and ecologically valuable fish species in the Bay. A better understanding of the content of the forage base, habitat areas critical for forage production, and predator-prey interactions involving these valuable species will be an important step toward ecosystem-based fisheries management in the Chesapeake Bay.

Much uncertainty surrounds the forage topic. Specifically, it is not clear: 1) what taxa constitute the forage base (species, groups, etc.); 2) how the scientific community can begin to quantify Chesapeake forage; 3) what data already exist to quantify the forage base; 4) what essential data and information are needed; and 5) how such information can be used in management decisions. A two-day workshop was held on November 12-13, 2014 to convene the necessary scientific and management expertise to address these uncertainties and to recommend feasible approaches to improve our collective understanding of the forage base.

The focus of the workshop was on producing a system-wide scientific synthesis of forage and develop actionable recommendations for its management in support of the managed fished species in the Chesapeake. Participants were encouraged throughout the workshop to consider how to develop and recommend workshop products that could best facilitate decision-making by fishery managers. The workshop was designed to address forage issues in a comprehensive way that is system-wide in scope, rather than focused on any one species or issue. The emphasis of the workshop, as proposed by the Steering Committee (SC; Appendix A), was to improve understanding of critical forage needs that support desirable functioning of the Chesapeake ecosystem. During the workshop, jurisdictional managers indicated that their primary interest was in describing the forage specifically required to support managed species. Consequently, much of the workshop discussion and content of this report are focused specifically on forage groups that support the managed and fished species of the Bay.

This workshop report summarizes outcomes and supports the SFGIT in development of both the "Forage Fish" and "Fish Habitat" Management Strategies, as specified by the Chesapeake Bay Program (CBP) Watershed Agreement (http://www.chesapeakebay.net/documents/FINAL_Ches_Bay_Watershed_Agreement.withsignatures-HIres.pdf).

Products

The workshop was designed and organized (Appendix B) to generate products that directly address uncertainties identified by the SFGIT. Products include preliminary tools and analyses drafted in advance of the workshop to inform and support workshop discussions and those developed at the workshop and then finalized in the following workshop report. These products include: a literature review (Appendix C); data and data-sources review (Appendix D); a prioritized list of forage species (or groups of species) that are most important for supporting Bay predators; identification of approaches needed to quantify the forage base to support managed species; identification and prioritization of urgent research needs to better understand the forage base and its importance to Bay predators; and recommended next steps.

Organization

The workshop was organized into four themes, with each theme charged to produce one or more workshop products. Fisheries managers from Maryland, Virginia, and the Potomac River Fisheries Commission each made an introductory statement of need at the start of the workshop and a concluding statement on the afternoon of day two to ensure that workshop participants remained focused on providing forage information that managers need to better inform decisions.

Theme I: *Chesapeake Bay Forage Base and Managed Predators*

Products developed in this theme included: refinement of the definition of "forage base" and prioritization of taxa identified as forage, based on a 1) literature review; 2) data review; and 3) a preliminary data analysis. The bulk of these three products was produced and shared with participants prior to the workshop to facilitate discussion at the workshop. However, the finalized workshop products resulted from presentations at the workshop, and deliberation and discussions by all workshop participants.

Identification of Key and Important Forage

Before the workshop, the SC decided to base preliminary identification of important forage groups for Bay predators on the 11-year (2002-2012) data set from ChesMMAP (The Chesapeake Bay Multispecies Monitoring and Assessment Program, www.vims.edu/research/departments/fisheries/programs/multispecies_fisheries_research/chesmmap/), a Bay-wide, fishery-independent trawl survey that includes in its design a clustered diet analysis of fish sampled in the survey. The preliminary list was discussed, modified, and expanded during the workshop to encompass the shared knowledge and expertise of participants. Species and trends identified with ChesMMAP data were verified by visual comparison of plots of diet compositions with those of other datasets that included gut content analyses. These included: CHESFIMS (The Chesapeake Bay Fishery-Independent Multispecies Survey) trawl survey (http://hjort.cbl.umces.edu/chesfims.html) and the CTILS project (Chesapeake Bay Trophic Interactions Laboratory Services; 2003-2007; http://www.vims.edu/research/departments/fisheries/programs/multispecies_fisheries_research/data_products/ctils_reports/index.php), which conducted gut content analyses of fishes captured in a variety of Bay surveys that did not include gut content analyses in their initial study designs. Survey samples from CTILS used to confirm important forage identified in the ChesMMAP analysis included: Virginia Institute of Marine Science (VIMS) trawl survey, Maryland adult Striped Bass monitoring survey, trammel net surveys, and juvenile seine surveys of both Maryland (Maryland Department of Natural Resources [MD DNR]) and Virginia (VIMS).

Of the 32 predator species available for diet analysis in the ChesMMAP data set, a subset of five diverse predator species were chosen as representative indicator species of the range of body forms and lifestyles of Chesapeake fish predators. The five predator species analyzed were: Striped Bass (*Morone saxatilis*, anadromous, piscivore), Summer Flounder (*Paralichthys dentatus*, mesohaline-polyhaline, piscivore), Atlantic Croaker (*Micropogonias undulatus*, oligohaline-polyhaline, omnivore), Clearnose Skate (*Raja eglanteria*, polyhaline, omnivore), and White Perch (*Morone americana*, oligohaline, omnivore).

“Important" forage groups were defined as those forage taxa or groups that composed at least 5% by wet weight of a predator's diet in at least one of the five ChesMMAP seasonal surveys conducted during at least one of the survey years. Preliminary ranking of relative importance of forage was based on consumption of the forage taxa by the five analyzed predators, e.g., a forage species or group that was important for three of the five analyzed predators was ranked as more important than forage taxa important for only two of the five predators. Any forage taxon or group important to more than one of the five analyzed predators was considered to be of "key" importance in this preliminary analysis.

Ten forage taxa or groups were determined to be of key importance and ten additional taxa or groups were important to only one of the five indicator predator species in the Chesapeake Bay. Only one forage species (Bay Anchovy, *Anchoa mitchilli*) was of key importance to four of the five indicator predators. For three of the predator species, six forage groups were of key importance: mysids (Family Mysidae); polychaetes (Subphylum Polychaeta); small Spot (*Leiostomus xanthurus*); small Weakfish (*Cynoscion regalis*); amphipods (Order Amphipoda); isopods (Order Isopoda); and Mantis Shrimp (Order Stomatopoda). Based on ChesMMAP data, three forage groups (small Atlantic Croaker), razor clams (Superfamily Solenoidea), and sand shrimp (*Crangon spp.*) were of key importance for two of the predator groups. The remaining ten forage groups that exceeded the 5% by weight minimum criterion were only important for one of the five indicator predators. Those forage groups (in alphabetical order) are: Atlantic Menhaden (*Brevoortia tyrannus*), Atlantic Rock Crab (*Cancer irroratus*), Blackcheek Tonguefish (*Symphurus plagiusa*), Blue Crab (*Callinectes sapidus*), flatfishes (Order Pleuronectiformes), kingfish (*Menticirrus spp.)*, Lady Crabs (*Ovalipes ocellatus*), macoma clams (*Macoma spp.*), mud crabs (Superfamily Xanthoidea), and Spotted Hake (*Urophycis regia*).

Participants suggested several modifications and additions to the initial list of 20 prioritized forage groups. There was general agreement that key (primarily) freshwater species were under-represented in the preliminary analysis and that Atlantic Silverside (*Menidia menidia*), Mummichog (*Fundulus heteroclitus*), other common killifishes (*Fundulus spp.*), and small bivalves should be added to the list of important forage. Participants also conveyed that Atlantic Menhaden should be considered "key" forage because of (1) its importance in the diets of larger predators that were under-represented by the survey design and analysis, and (2) its importance in Bay and coastal fisheries. American Shad (*Alosa sapidissima*) and river herrings (*Alosa spp.*) were recognized by participants as historically important forage whose restoration may be important in supporting predator production in the Bay.

Theme II: *Limiting Factors for Forage Species*

Plenary presentations and breakout groups recognized several broad and often inter-related categories of biotic and abiotic factors that act to control or limit abundance of forage species. The list of limiting factors discussed for forage included: habitat, shoreline armoring, land use, climate change and sea level rise (SLR), water quality, predation pressure, food availability, fishing, and socioeconomic factors. Participants noted that factors limiting forage abundance or productivity are likely to limit abundance of their predators and that such factors differ among forage taxa. Accordingly, the Bay Program should recognize factors limiting forage groups (beyond water quality) and consider them a priority. The newly drafted Management Strategies (http://www.chesapeakebay.net/managementstrategies) which specifically incorporated a forage management strategy to support the goals of the new Bay Agreement, (http://www.chesapeakebay.net/chesapeakebaywatershedagreement/page) constitute a positive step towards accomplishing this goal.

Though taxonomically diverse, most forage species are short-lived and experience large fluctuations in abundance annually and seasonally and are subject to environmental variability and stressors that control productivity and reproductive success. Resource managers need to understand the environmental and anthropogenic factors that limit forage abundance and be armed with responsive and adaptive plans to ensure the long-term well-being of the forage base. The regional and Chesapeake Bay Program managers can act to monitor some of these factors, generally by implementing programs to conserve or restore habitat, to improve water quality, or to regulate catches of managed species. In other instances, however, factors are beyond the control of managers. Consequently, mitigation or adaptation may be necessary to stabilize or minimize effects of habitat loss and declines in water quality that adversely affect forage resources.

Habitat, and its availability, distribution, and quality, may limit forage taxa in the Chesapeake ecosystem. Important habitats for forage include pelagic and benthic habitats but shallow water, tributaries, marshes, Oyster (*Crassostrea virginica*) reefs, and SAV (submerged aquatic vegetation) beds are especially important. A large portion of important forage habitat in the Chesapeake Bay is likely to be lost through a complex interaction of factors, including shoreline armoring, upland development, climate change, SLR, and water quality. Direct and indirect effects of such factors resulting in habitat loss have been described previously (Pyke 2008, Titus et al. 2009) and documented for some forage species (e.g., Atlantic Croaker, Atlantic Menhaden, Bay Anchovy, Spot; Funderburk et al. 1991, Jung and Houde 2003, 2004) in nearshore areas, but specific impacts on other forage (e.g., abundance and productivity of benthic invertebrates and small forage fishes such as killifishes or silversides) remain unknown.

Other factors that potentially limit forage include availability of food for forage species, predator demand, socioeconomic pressures, and fishing. Food availability for forage, though not directly regulated by fishery managers, is nonetheless important if managers are to understand recruitment and abundance trends of the forage. Monitoring and surveying phyto- and zooplankton as well as small benthic organisms can quantify forage prey abundances, follow trends, and recognize any major shifts that may occur. Fisheries managers can control predation pressure on forage indirectly (by controlling managed fish populations) but they have little or no power over unmanaged predators (e.g., birds, invasive species). Improving our understanding of predator demand and the development of forage targets and thresholds to support production of managed and unmanaged predators is an important research need, especially in light of increasing populations of predatory birds and invasive catfish (blue-, *Ictalurus furcatus* and flathead catfish, *Pylodictis olivaris*) in the Bay. Complex socioeconomic factors (e.g., perceived value of forage) directly affect decisions on managed forage species (e.g., Atlantic Croaker, Atlantic Menhaden, Blue Crab, Spot, Weakfish) or indirectly affect forage through the management of predators of the forage. However, the consequences of management actions on forage species are not always well understood. Consequently, risk analyses of different management options are advisable and the application of a management strategy evaluation (MSE) approach may help managers to determine which policies have the best potential to mitigate risk.

Theme III: ***Development of forage metrics or indicators and proxies that can inform management where direct information is lacking***

A widely acknowledged goal of fisheries managers is to avoid collapse of the forage base and the predators dependent on that forage. It is important, therefore, to recognize practices that elevate risk to the forage base and lead to loss of predator production. To accomplish this, indicators or metrics are needed that synchronously track abundance trends of key forage groups and trends in habitat extent and water quality (i.e., water column habitat). Setting targets and thresholds based on these indicators that can trigger management actions is a desirable objective. Useful metrics or indicators should 1) reflect the current state of the Chesapeake ecosystem; 2) be collected routinely; and 3) be actionable (i.e., linked to realistic management actions and targets or thresholds that trigger such actions).

Indicators and metrics of abundance and productivity of forage taxa provide managers with knowledge of the status and trends in the forage base. For managed forage species, indicators and reference points generally include fishing and natural mortality rates, growth estimates, and measures of biomass or fecundity over time that are often derived from stock assessments (e.g., Atlantic Menhaden, Blue Crab). For unmanaged species, targets and thresholds for management actions can be developed from indicators and trends in surveyed abundances, metrics of habitat and water quality status, metrics of forage consumption and demand by predators, evaluation of nutritional quality of forage, and model-derived parameters of predator-prey dynamics, among others. Wherever possible, metrics and indicators should be estimated spatially and periodically, since changes in spatial or temporal distribution of forage or forage habitats will be important for management actions.

Workshop participants identified and proposed indicators and metrics that can inform understanding of status and trends in both managed and unmanaged forage species in Chesapeake Bay. It was widely agreed by participants that there is no single approach or action that is sufficient to assess or track trends of forage and to predict consequences for the Bay ecosystem. Instead, managers and scientists should work collaboratively to determine a suite of metrics and indicators to evaluate forage status and trends.

Theme IV: ***Identification of priority research needs & management recommendations***

Research needs

Though diverse, several common recommendations were voiced and were considered to be high priority research needs. Three priority needs are: 1) a coordinated analysis of currently available data to develop forage metrics; 2) the development of a suite of indicators useful for decision-making; and 3) increased shallow water monitoring of forage and habitats to complement current surveys.

Participants recognized the importance of the continuing development of models to integrate information from various data sets to allow modelers and managers to frame management questions in an ecosystem context. Models are needed, for example, to identify and evaluate abundance thresholds or critical habitat levels and to better understand ecosystem effects of large-scale changes to the forage base, especially for conditions and stressors for which data are lacking (e.g., climate change). Application of existing conceptual models (e.g., Baird and Ulanowicz 1989, Christensen et al. 2009) was widely agreed to be an important first step to facilitate iterative communication needed for managers and scientists to identify knowledge gaps and advance understanding of Bay forage status.

Participants identified additional surveys and data collection improvements needed to develop an effective suite of indicators of forage health in the Chesapeake ecosystem. Participants recommended that surveys should be conducted seasonally, that all life history stages of predators and forage be sampled, and that sampling should be allocated in all important habitats. Indicator or sentinel sites for forage monitoring, sampled seasonally, could potentially minimize the costs of new monitoring over time; however, such sites must include both healthy, resilient sites and highly stressed sites.

Management Recommendations

Managers and workshop participants agreed that there is a critical disconnect between the biological importance of forage and stakeholder understanding of its importance. Improved messaging to stakeholders about forage importance is recommended. An educational video, perhaps produced by a CBP partner, might be effective.

There was general agreement that the quickest way to communicate to constituents and stakeholders the need to protect critical forage is through the protection of productive habitat, which the public would understand more readily than the importance of forage itself. It was also agreed that it is important for fishery managers and the SFGIT to work in close partnership with both the Habitat- and Water Quality-GITs to successfully manage forage in the Chesapeake system. Inter-GIT cooperative efforts to study, map, and manage habitats important for production and maintenance of forage, with an emphasis on shoreline habitat, land-use change, and developments in tributaries throughout the watershed, were proposed as approaches for successful forage management.

Participants recognized that defining thresholds and, in some instances, targets for forage abundance is important for long-term management of the forage base supporting managed fisheries. It was suggested that managers should consider current forage status relative to available records of historical forage abundances and distributions, especially for species (e.g., shads and river herrings) that were once important as forage but are no longer abundant. Such information can support development of benchmarks for restoration plans and targets. Additionally, participants suggested that managers align indicators of health of Bay forage with those under development by ASMFC and the Mid-Atlantic Fishery Management Council (MAFMC) where appropriate for coastal species.

Participants recognized the importance of including socioeconomic metrics in the suite of forage-related indicators for managers to consider. Although experts in socioeconomics did not participate in the workshop, it was widely agreed that stresses on and subsequent collapses of important forage groups could have far-reaching economic consequences for Bay communities.

Prioritized Recommendations

Eleven summarized research and management recommendations, all of which were endorsed by participants during workshop discussion, were circulated (Steering Committee and invited participants, n=28) in a survey after the workshop. Each participant ranked each recommendation based on perception of degree of urgency (range of 5 levels from "least urgent" to "immediate."). The results are as follows:

1 - Strategic review and data-mining of all available current data to support forage quantification.

2/3 (tied) - Re-establish zooplankton monitoring to develop an index of feeding conditions for key forage (e.g., Bay Anchovy, Atlantic Menhaden) and to develop abundance indices for key forage taxa (e.g., mysids).

2/3 (tied) - Develop a standard set of metrics and indicators (including proxies until direct information is available) to track forage abundance; use these to set targets and thresholds for triggering management actions.

4 - Relate forage trends to predator trends.

5 - Improve understanding of forage dynamics and trends, especially those with limited or no current data (e.g., mysids, Bay Anchovy), both at a system-scale and at specific habitat-scale.

6 - Establish shallow water monitoring in soft-bottom, marsh, and SAV habitats (to complement long-term seine and B-IBI monitoring surveys[1]), including up-tributary habitats.

7 - Expand diet studies to broadly cover predator ages and sizes.

8 - Estimate predator demand and forage supply by habitat. Utilize models as well as monitoring data.

9/10 (tied) - Determine (or summarize available information) prey nutritional quality; relate to nutritional needs of key predators.

9/10 (tied) - Need for habitat-focused management to facilitate management of forage species; implicit in this need is an understanding of habitat use by key forage groups.

11 - Need for educational video & web-based materials that show the importance of forage (i.e., change the view that "forage is just bait and it doesn't matter").

Next Steps

Workshop products and outcomes have provided a foundation for developing a practical guide for fishery

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[1] Benthic Index of Biological Integrity; http://sci.odu.edu/chesapeakebay/data/benthic/BIBIcalc.pdf; for more information on the current B-IBI, see Weisberg et al. (1997) and Alden et al. (2002)

managers to account for forage trends in the Chesapeake Bay. Fishery managers will need to set clear management objectives for forage, which in turn will serve to identify the specific metrics and indicators that are most appropriate for implementation. Once a suite of metrics and indicators has been chosen to assess the forage base and habitats that support it, key data gaps will be able to be identified and efficiently filled. Scientists and managers can initiate activity to develop benchmarks and indicators for current forage levels and associated factors in the Bay. Through continued, adaptive re-evaluation of the indicators and forage thresholds with respect to benchmarks, managers will have the ability to adopt appropriate actions and in turn improve management of the fished species that depend on forage. Once management objectives are set and indicators chosen, managers can estimate the costs of investments and alternatives to achieve forage-related objectives, in both the near and long term.

Introduction

Forage species play an integral role in the Chesapeake Bay food web by supporting higher-trophic level production. "Forage" was interpreted broadly for the effort described here, to include invertebrate groups as well as vertebrates, in recognition of the importance of benthic invertebrates and plankton as forage in the Chesapeake system, and in response to discussion at the December 2013 Sustainable Fisheries Goal Implementation Team (SFGIT) meeting by the SFGIT Executive Committee (ExCom). Most forage species are not directly managed by the ASMFC or Chesapeake Bay jurisdictions, yet these species are critical to sustaining production of economically and ecologically valuable fish species in the Bay. A better understanding of the forage base, habitat areas critical for forage production, and predator-prey interactions involving these valuable species will be an important and needed step toward ecosystem-based fisheries management in the Chesapeake Bay.

The Fisheries Ecosystem Planning for the Chesapeake Bay report (Chesapeake Bay Fisheries Ecosystem Advisory Panel 2006; henceforth panel is abbreviated as "CBFEAP") stresses the importance of the "complex of species," identifying both habitat and predator-prey dynamics as significant factors affecting the productivity of fisheries in the Chesapeake. That report emphasizes the need to not only identify key predator and prey relationships for target species, but to quantify those relationships. Directed by those goals, a 2-day workshop was held on November 12-13, 2014 at University of Maryland Center for Environmental Science - Chesapeake Biological Laboratory (UMCES - CBL) to provide managers with the information essential to begin to accomplish both of these tasks.

The SFGIT ExCom recognized, and subsequently made clear at the December 2013 meeting of the full SFGIT, that much uncertainty surrounds the forage topic. Specifically, it is not clear: what taxa constitute the forage base (species, groups, etc.); how to begin to quantify Chesapeake forage; what data already exist to quantify the forage base; what essential data are needed; or, how such information can be used in management decisions. This workshop was designed to bring together the necessary scientific and management expertise to address these uncertainties and to recommend feasible approaches to improve the collective understanding of the forage base.

This report synthesizes workshop outcomes and is intended to support the SFGIT in development of the Forage Fish Management Strategy, as specified by the CBP Watershed Agreement (http://www.chesapeakebay.net/documents/FINAL_Ches_Bay_Watershed_Agreement.withsignatures-HIres.pdf), by June 2015.

The focus of the workshop was on producing a system-wide scientific synthesis and actionable recommendations for forage management in the Chesapeake. Participants (Appendix A) were encouraged throughout the workshop to consider how to develop and recommend workshop products that could best facilitate decision-making by fishery managers. The workshop was designed to address forage issues in a comprehensive manner that is system-wide in scope, rather than focus on any one species or issue, since the emphasis of the workshop was to improve understanding of critical forage needs that support desirable functioning of the Chesapeake ecosystem.

Steering Committee and Invited Workshop Participants

The 12-member Steering Committee (SC) for the workshop broadly represented multiple jurisdictions and disciplines (Appendix A). The SC included species-specific experts, fishery scientists, ecologists, modelers, managers, and data experts. The SC developed the workshop agenda (Appendix B) and list of invited participants. Workshop participants included experts on the following topics: forage; predator-prey interactions; trophic linkages, habitats and water quality (i.e., water column habitat), fishery stock assessment, system dynamics, and ecology of the Chesapeake. Participants were experienced and knowledgeable of existing data sources for Chesapeake forage groups; they were familiar with quantitative metric and indicator development, and with management needs for Chesapeake fisheries.

Workshop Products

The workshop was designed to produce several products. Products include both preliminary tools and analyses drafted in advance of the workshop that were prepared to inform and support workshop discussions and those to be developed at the workshop and finalized in this report. These products include:

- Literature review – includes summaries of previous research efforts that the SC and workshop participants considered useful to the understanding of forage both in the Chesapeake and outside the region (Appendix C)
- Data review – compiled list of identified data sets that could be useful in the development of forage indicators, with a description and intended management application of each (Appendix D)
- Definition and identification of "forage base" – a prioritized list of the species or species groups comprising the most important forage that directly support predators in the Chesapeake Bay system; the initial list was based on preliminary analyses of available data, but the list was enhanced by discussions among invited participants at the workshop
- Recommendations of approaches to use existing and new data to develop a suite of Bay-specific indices or metrics to quantify the forage base
- Identification of prioritized research needs and monitoring gaps that, if addressed, would contribute to understanding the trophic transfer between forage species and their predators
- Recommendations on how to begin addressing the highest priority research needs

The workshop was organized into four themes, with each theme charged to produce one or more of the workshop products. This report addresses each theme, summarizing outcomes and priorities, participant discussions, and conclusions. Major conclusions and recommendations are presented in a final chapter of the report.

Theme I: *Chesapeake Bay Forage Base and Managed Predators*

The products developed in this theme included: refinement of the definition of "forage base" and a prioritization of taxa identified as forage based on a literature review, data review, and preliminary data analysis. The bulk of these three latter products was produced and shared with participants prior to the workshop to facilitate discussion at the workshop. However, the final workshop products resulted from presentations at the workshop, deliberation and discussions by all workshop participants, and some post-workshop analyses and clarification.

Theme II: ***Limiting Factors for Forage Species***

Five participants (D. Bilkovic, R. Seitz, D. Breitburg, D. Prosser, and E. Houde) were invited to present information on limiting factors for forage in Chesapeake Bay. The products for this theme included identification and discussion of natural and anthropogenic limiting factors, both those that may be controlled and those that cannot, but still must be understood to manage the forage base, its predators, and habitats to the benefit of the Chesapeake ecosystem.

Theme III: ***Forage Metric/Indicator Development***

Four invited workshop presenters (S. Gaichas, Yvonne deReynier, G. Nesslage, and M. Wilberg) summarized their experiences on strategies and lessons learned concerning the development of metrics and indicators for forage management (or ecosystem-based management). Regional presentations were made on the Mid-Atlantic, North Atlantic, Pacific west coast, and the Bering Sea. Workshop breakout groups deliberated and discussed specific needs for indicators and metrics that define the forage base, its dynamics, relationships to predators, and status and trends for the Chesapeake Bay.

Theme IV: ***Identification of priority research needs and management recommendations***

This theme and its outcomes were based on the summary discussions of four breakout groups and ultimately, a survey of all participants. The needs and recommendations identified during this portion of the workshop benefited greatly from deliberation and discussion throughout the two days as participants contributed to Themes I, II, and III, and input and recommendations from managers. Priority concerns were identified at the workshop and later summarized into 11 specific recommendations. Following the workshop, a survey of all participants was conducted to prioritize participants' views concerning the urgency of each recommendation. Concerns of stakeholders were brought forward by invited SFGIT members who had been asked to attend and who subsequently participated in the Theme IV discussion.

Fisheries Management Panel: Part 1 - Management Needs

Fisheries managers from Maryland, Virginia, and the Potomac River Fisheries Commission (PRFC) began the two-day workshop with a brief summary of their current efforts to manage, monitor and protect forage, important issues related to forage, and what they would like to see accomplished at the workshop.

Marty Gary (Executive Secretary, Potomac River Fisheries Commission):

> The PRFC perceive important forage to be both fish and invertebrates and believe that forage groups that rely on the lower salinity portions of the Bay (e.g., Gizzard Shad (*Dorosoma cepedianum*), Mummichog (*Fundulus heteroclitus*)) should be considered important in the discussion. The PRFC is especially concerned about the increasing population of invasive Blue

Catfish, and would like to understand how it is affecting the Bay's forage. Tools that managers can use would be a helpful outcome from the workshop.

Lynn Fegley (Deputy Director, Maryland Dept. of Natural Resources Fisheries Service):

> MD DNR requires actionable information (e.g., coastal surveys, diet studies, critical habitat, cause and effect) to identify management decisions which can functionally drive change. A large, complex ecosystem model is less important than having answers on simple tradeoffs. DNR staff would like to understand if existing information can be integrated into tools that would facilitate decision-making.

Joe Grist (Deputy Chief, Fisheries Management Division, Virginia Marine Resources Commission):

> The Virginia Marine Resources Commission (VMRC) is a regulatory agency whose management depends on the current indices (e.g., trawl survey, shad and river herrings survey) that are utilized for setting bycatch limits, to enforce current moratoria (shad and river herring), and to manage predators. VMRC staff are especially interested in Bay-wide issues that affect multiple jurisdictions. Most desired information includes life histories of unmanaged forage species that may be less publicized historically, but of equal or greater importance for the Chesapeake Bay than Menhaden, such as Bay Anchovy.

Theme I: *Bay Forage Base and Managed Predators*

Literature Review

A review of literature relevant to the topic of forage was assembled and distributed to workshop participants prior to the workshop. Topics identified by the SC as important to inform forage discussions included predator-prey interactions, predator diet studies, forage production, environmental impacts on forage species, harvest and managed forage species, ecosystem-based fishery management, and management case studies in other regions. An effort was made to include all literature available (both peer-reviewed and grey literature) for the Chesapeake region as well as literature from other regions that was thought to be relevant to the Chesapeake. Workshop participants identified additional literature throughout the workshop and during the development of this report. The resulting compilation of literature is categorized by topic and review and is attached in Appendix C.

Data Review

The SC identified a wide variety of existing data sets prior to the workshop to inform discussions and provide perspective on available data during the meeting. Additional data sets were added to the preliminary review at the workshop by participants. The final assemblage of currently available data is attached as Appendix D. A general description is provided for each data set, including goal(s) of data collection, years available, gear(s) employed, home institute, and contact information for the current data manager.

Defining the Forage Base

The SC agreed that a preliminary list of forage species would facilitate productive discussion in the two-day workshop. The preliminary list was to be modified and expanded during the workshop to encompass the shared knowledge and expertise of participants.

Methods

The SC reviewed available data to define the key forage taxa in the Chesapeake ecosystem. To discern key forage taxa, ideally, long-term, fishery-independent surveys of predator diets covering both broad spatial scales and sensitive life stages are needed. The SC found that useful fishery-independent data were available to accomplish this task. The SC also concluded that existing literature (both peer-reviewed and grey literature) on diet analyses and existing fishery-dependent data sets were inadequate to address this particular question because previous research was largely limited in scope to analyses of forage needs of typically one to a few predator species, or restricted in spatial scale, and could not provide the intended system-level scope of forage utilization or requirements. Further, fishery-dependent surveys were constrained by a lack of survey design and a bias for larger sized predators, making it impossible to reach conclusions about forage needs of the younger, more abundant and most sensitive life stages.

Two fishery-independent surveys include gut content analyses of predators captured in the surveys. These include ChesMMAP (Bonzek et al. 2014) (www.vims.edu/research/departments/fisheries/programs/multispecies_fisheries_research/chesmmap/), and CHESFIMS (http://hjort.cbl.umces.edu/chesfims.html). In addition, the VIMS Trawl (http://www.vims.edu/research/departments/fisheries/programs/juvenile_surveys/index.php) survey is conducted in tributaries of Virginia and gut contents of that survey have been analyzed through the Chesapeake Bay Interactions Laboratory Services (CTILS) project (see below).

Each survey targets variable species and sizes, which is potentially useful, and utilizes different gears and survey designs. CHESFIMS was a midwater trawl survey (2001-2006) that targeted mainly juvenile-adult fishes in the entire mainstem; ChesMMAP is a bottom trawl survey (2002-present) conducted in the mainstem of the entire Bay that targets late juvenile-adult fishes; and the VIMS Trawl (1955-present) is a bottom trawl survey targeting primarily juveniles in both the mainstem and deeper waters of tributaries, but is limited to Virginia waters and the Potomac River. Sampling designs differ among surveys (ChesMMAP, VIMS Trawl: random stratified; CHESFIMS: combination of random and fixed).

Additionally, the CTILS project (2003-2007) (http://www.vims.edu/research/departments/fisheries/programs/multispecies_fisheries_research/data_products/ctils_reports/index.php) was designed to conduct gut content analyses of fishes in Bay surveys that do not include such analyses in their initial design. In addition to performing diet analyses on specimens from the VIMS Trawl survey (noted above), CTILS also analyzed gut samples from the Maryland adult Striped Bass monitoring survey (2003-2005), trammel net surveys (2004, 2005) from Virginia, and the juvenile seine surveys of both Maryland (MD DNR) and Virginia (VIMS). See Appendices D and E for details on the survey designs and results, respectively.

Only ChesMMAP was designed for a cluster analysis of the predators sampled in the survey. A cluster-sampling estimator can produce very different predictions of dietary importance compared to the more traditional analytical approach (Fig. 1). Often, traditional diet analyses incorrectly assume that (1) all fish caught in a single trawl tow (or similar) are independent of one another, and that (2) each trawl is equally representative of the population, regardless of the number of fish captured in each trawl. A cluster-sampling estimator (Bogstad et al. 1995, Buckel et al. 1999) addresses violation of these two assumptions by (1) accounting for correlation and greater dietary similarity among individuals caught in the same tow (i.e., addressing that these individuals are more similar to one another than fish randomly selected from the population), and (2) weighting the diet information in each tow by how many of the predators (in number) were caught in that tow to generate a diet estimate more representative of the overall predator population. The SC decided to base its preliminary analysis primarily on the ChesMMAP data and to use the other available survey data to qualitatively verify trends of prey importance predicted from the ChesMMAP data.

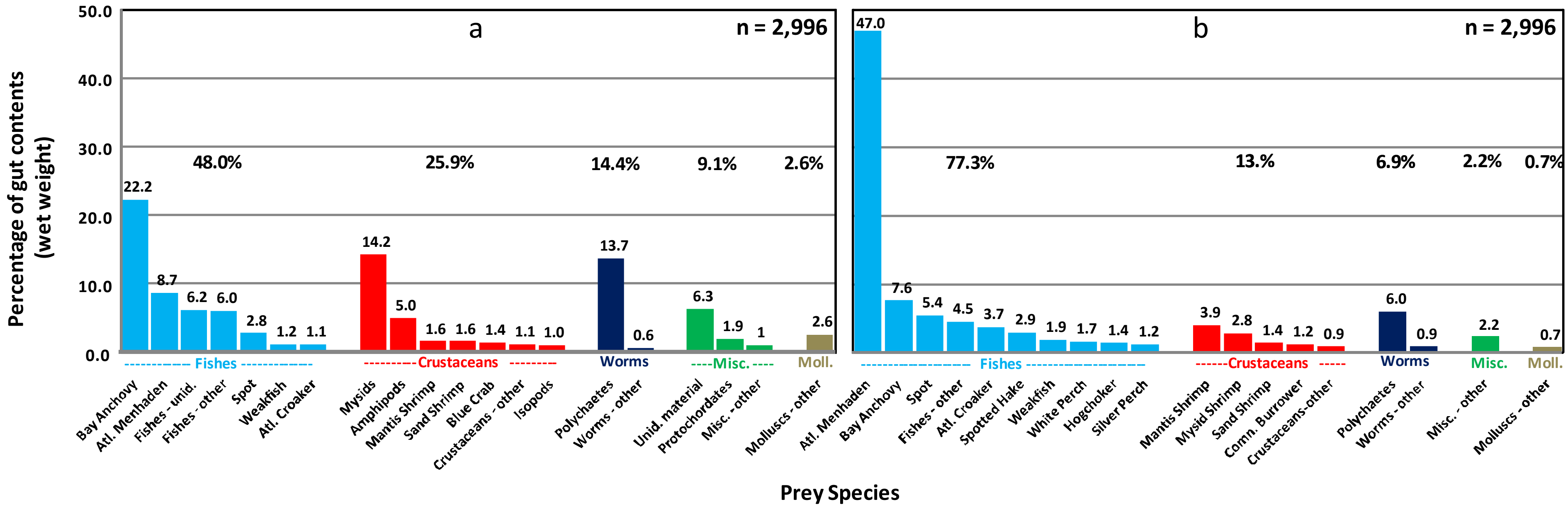

Figure 1. Diet analyses for striped bass from the ChesMMAP dataset (C. Bonzek, VIMS). Statistical accounting for clustering of samples by tow can make an important difference in the perceived importance of different prey items for a predator captured in a survey. In this example, predator diet is analyzed with (a) an analysis that accounts for clustering, and (b) in a standard analysis that does not account for the clustered nature of a tow. Failing to account for clustering overemphasizes the importance of some fish. For example, when a predator encounters a school of prey, it can easily fill its stomach, under-representing other available prey. Moreover, when the predator is captured in a particular tow, that predator is likely to be encountered with other predators that also encountered the same schools of prey, further strengthening the biased signal, and further under-representing other prey. Finally, the assumption that each predator fish is an independent sample results in an analytical anomaly in which a very small number of predators (or even a single predator) with large prey (e.g., large Atlantic Menhaden) in their stomachs can mathematically overwhelm data from dozens or hundreds of samples from the same predator species whose stomach contained only small prey items. Accounting for the clustered nature of diet samples and the abundance of predators in each tow decreases bias in estimates of prey importance for a predator population.

There were 32 predator species available for diet analysis in the ChesMMAP data set (2002-2012). Results of analyses on these species can be found in Appendix E (e.g., diets, size-frequency distributions). For the workshop, a subset of five diverse predator species was chosen as representative indicator species for the range of body forms and lifestyle types of Chesapeake fish predators. It was assumed that a preliminary analysis of the prey consumed by these 5 predatory species would be representative of forage consumed by the Chesapeake predatory fish assemblage.

The five predator species analyzed were: Striped Bass (*Morone saxatilis*, anadromous, piscivore), Summer Flounder (*Paralichthys dentatus*, mesohaline-polyhaline, piscivore), Atlantic Croaker (*Micropogonias undulatus*, oligohaline-polyhaline, omnivore), Clearnose Skate (*Raja eglanteria*, southern-Bay, polyhaline, omnivore), and White Perch (*Morone americana*, northern-Bay, oligohaline, omnivore).

The minimum criterion to be considered an "important" forage group was that a forage taxon or group had to compose at least 5% by wet weight of a predator's diet in at least one of the five ChesMMAP seasonal sampling cruises (March, May, July, September, November) taken during any year of study. Once the "important" forage groups were identified, preliminary ranking of their relative importance was based on how many of the five analyzed predators were found to depend on that particular forage species or group (e.g., a forage species or group that was important for three of the five analyzed predators was ranked as more important than a forage species or group important for two of the five predators). Any forage important to more than one of the five analyzed predators was labeled as being of "key" importance in this preliminary analysis.

Results of diet analysis

Raw data for all forage, grouped by major taxa or commonly used assemblages (i.e., fishes, crustaceans, worms, molluscs, and misc.), are shown in Figure 2. Only forage that exceeded 5% (by wet weight) of total gut contents of any one forage group for any of the five seasonal surveys (March, May, July, September, November; years pooled) are shown in Figure 3, along with a prioritized list (see caption) of forage for each of the five predators.

Ten forage taxa or groups were of key importance and ten additional taxa or groups were important to one of the five indicator predator species (Table 1, columns a and b, respectively) in the Chesapeake Bay. Only one forage species (Bay Anchovy, *Anchoa mitchilli*) was of key importance to four of the five indicator predators. For three of the predator species, six forage groups were of key importance: mysids (Family Mysidae), polychaetes (Subphylum Polychaeta), Spot (*Leiostomus xanthurus*), Weakfish (*Cynoscion regalis*), amphipods (Order Amphipoda)/ isopods (Order Isopoda), and Mantis Shrimp (Order Stomatopoda). Based on ChesMMAP data, three forage groups (Atlantic Croaker, razor clams (Superfamily Solenoidea), and sand shrimp (*Crangon spp.*) were of key importance for two of the predator groups. The remaining ten forage groups that exceeded the 5% minimum criterion were only important for one of the five indicator predators. Those forage groups (in alphabetical order) are: Atlantic Menhaden (*Brevoortia tyrannus*), Atlantic Rock Crab (*Cancer irroratus*), Blackcheek Tonguefish (*Symphurus plagiusa*), Blue Crab (*Callinectes sapidus*), flatfishes (Order Pleuronectiformes), kingfish (*Menticirrus spp.)*, Lady Crabs (*Ovalipes ocellatus*), macoma clams (*Macoma spp.*), mud crabs

(Superfamily Xanthoidea), and Spotted Hake (*Urophycis regia*). While these ten groups are acknowledged as important, they were not categorized as being of key importance to Chesapeake predators during sensitive life stages based on analysis of the 11-year ChesMMAP data set. Later consideration of CTILS data (see below) revealed that Blue Crab is also important to the diet of juvenile White Perch, but Blue Crab remains in column 'b' (Table 1) in accordance with the study design (see below for further information). It should be noted that the ChesMMAP samples included in this analysis under-represent the smallest, youngest, and the largest, oldest fish, and as a consequence, diets are representative of relatively young, adult fish. However, the key forage taxa identified in this analysis are also supported by another recent analysis (Buchheister and Latour 2015) that accounts for size-based dietary differences.

CHESFIMS, VIMS Trawl, and gut samples from the various surveys analyzed through the CTILS program patterns qualitatively confirmed most of the patterns described from the ChesMMAP data and, once spatial differences were considered, did not appear to contradict those patterns. As noted above, analysis of the CTILS data set revealed that Blue Crab was important in the diet of juvenile White Perch, as indicated by gut contents of White Perch captured in the Virginia juvenile seine survey data (Fig. E71); however, Blue Crab did not register as important to this species in the ChesMMAP trawl survey data (Fig. 2). Whether this pattern is consistent or reliable remains unknown, since the CTILS project was short-lived and gut contents for the juvenile seine survey catch are not typically analyzed by either Virginia or Maryland.

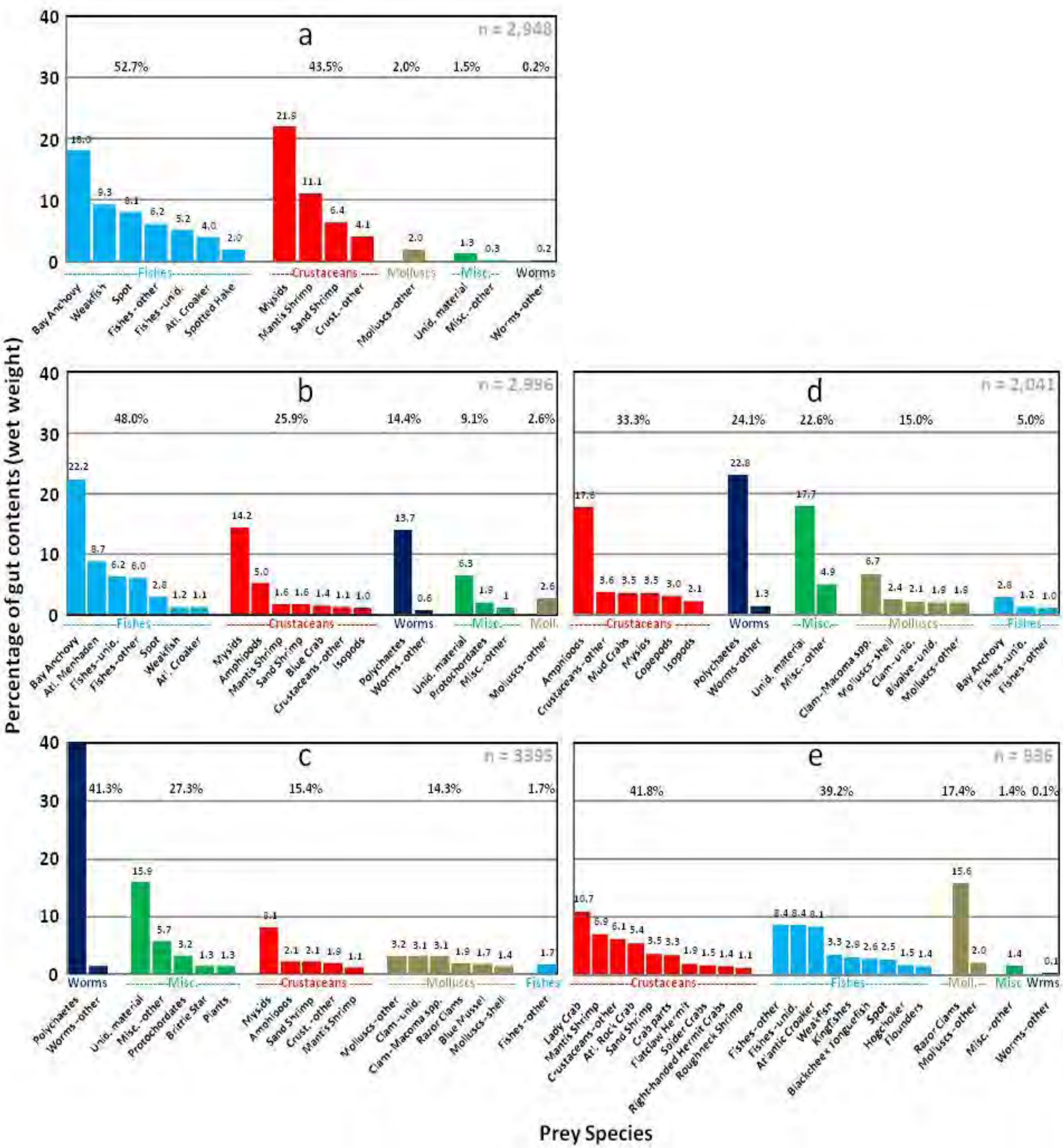

Figure 2. Diet analyses for (a) Summer Flounder (b) Striped Bass, (c) Atlantic Croaker, (d) White Perch, and (e) Clearnose Skate, based on all ChesMMAP surveys (5 surveys/year, 2002-2012).

Table 1. (a) Key and (b) important forage taxa or species in the Chesapeake Bay, as indicated by diet analyses on five indicator predators sampled in the ChesMMAP survey (2002 - 2012), a fishery-independent, Bay-wide bottom trawl conducted five times a year in the months of March, May, July, September, and November; and (c) by expert knowledge of workshop participants. Predators used as indicators included a wide range of body forms, trophic levels, and life histories (Summer Flounder, Striped Bass, Atlantic Croaker, White Perch, and Clearnose Skate).

A **Key taxa or species (in order of importance)**	***b*** **Additional important taxa or species (alphabetical)**	***c*** **Additional important taxa or species identified by participants as under-represented in diet analysis**
Bay Anchovy	Atlantic Menhaden	American Shad & river herrings
Polychaetes	Atlantic Rock Crab	Mummichog & Killifishes
Mysids	Blackcheek Tonguefish	Gizzard Shad
Amphipods and Isopods	Blue Crab*	Atlantic Silverside
Mantis Shrimp	Flatfishes	Small Bivalves**
Spot	Kingfish	
Weakfish	Lady Crab	
Sand shrimp	*Macoma* clams	
Atlantic Croaker	Mud crab	
Razor Clams	Spotted Hake	

* Blue Crab was important to only one indicator species in the ChesMMAP data (Striped Bass), as described in the criteria for determining "key" or "important". However, Blue Crab was also important in juvenile White Perch diets in the CTILS study of catch from the Virginia juvenile seine survey.

** Other than *Macoma* spp. or razor clams

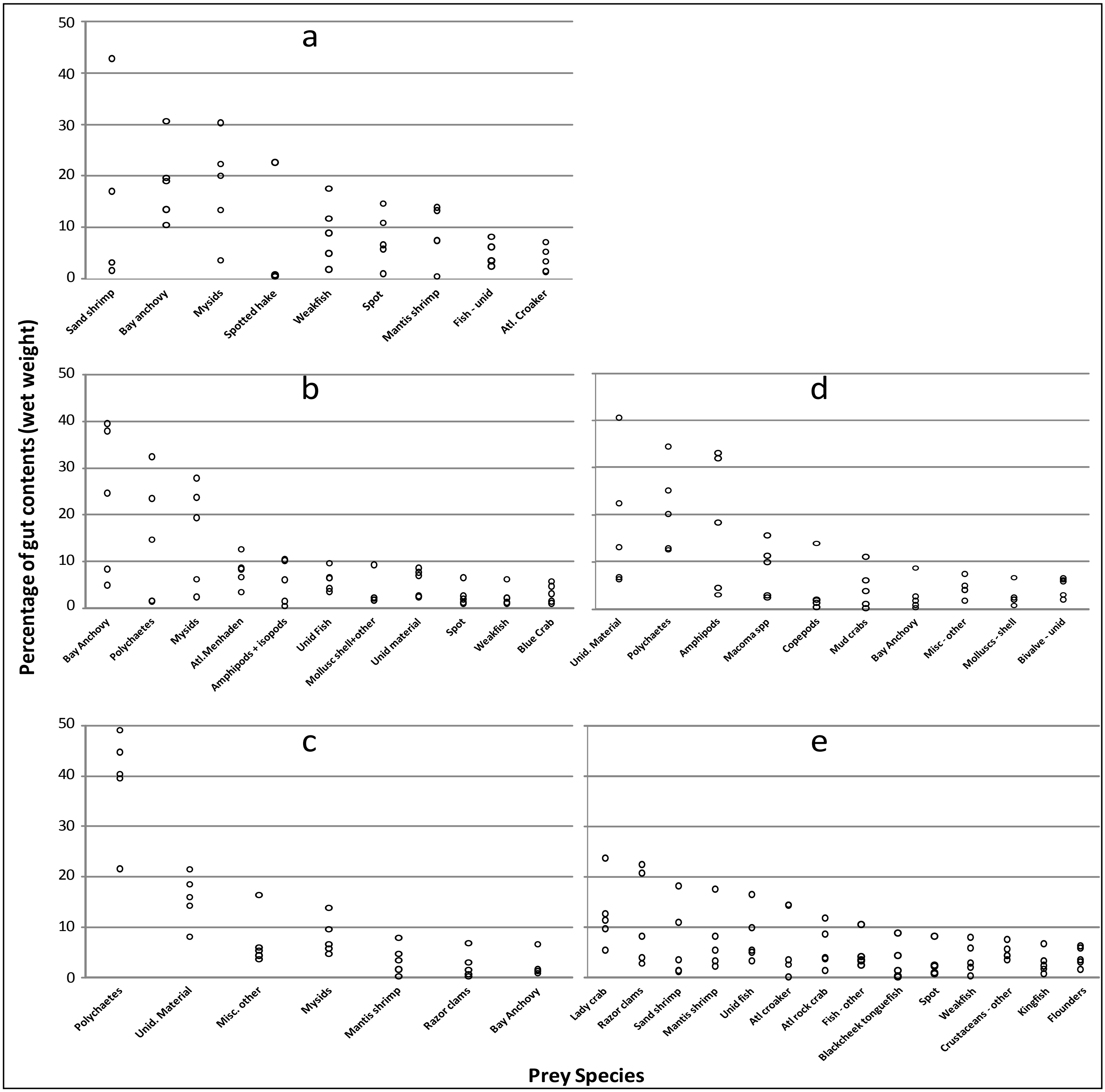

Figure 3. Survey variability for (a) Summer Flounder, (b) Striped Bass, (c) Atlantic Croaker, (d) White Perch, and (e) Clearnose Skate, based on all ChesMMAP surveys (5 surveys/year, 2002-2012). All forage groups shown here contributed at least 5% (by wet weight) of total gut contents for all fish caught in at least one of the five seasonal surveys (March, May, July, September, November; years pooled). Identifiable priority forage for each predator, based on both proportion (wet weight) of predator diet and consistency throughout the year, were (in order of importance): Summer Flounder: Bay Anchovy, mysids, sand shrimp; Striped Bass: Bay Anchovy, polychaetes, mysids; Atlantic Croaker: polychaetes; White Perch: polychaetes, amphipods, *Macoma* spp.; Clearnose Skate: Lady Crab and razor clams. Regarding Clearnose Skate diet, this predator was more of a generalist than the other predators examined, consequently, total proportions for all priority forage were relatively low, and correspondingly, sand and Mantis shrimps, Atlantic Croaker, and Atlantic Rock Crab were also quite important in the diet of this predator.

Discussion

Roughly half (11 of 20) of the forage groups identified in the analysis as "key" or "important" were invertebrates. The importance of invertebrates to predator diets of the Chesapeake is even more noteworthy when one considers that many of the Chesapeake's invertebrates (e.g., polychaetes, mysids) were of key importance in spite of being relatively soft-bodied, and thus, easily broken-down into unidentifiable matter in the gut contents of predatory fishes.

Some of the critically important finfish forage groups are not typically thought of as "forage," and are themselves predators that are managed or at least monitored (ASMFC manages Atlantic croaker and Weakfish, and Spot is currently monitored). It is notable that small individuals of these species were key prey, suggesting that complex predator-prey interactions based on size- and age-specific predation may control abundances of some managed species.

Sampling and gear bias

ChesMMAP and CHESFIMS sampled only the mainstem and although both the Virginia and Maryland juvenile seine surveys and the VIMS Trawl survey all sample the tributaries, none of the surveys sampled very shallow waters of the tributaries or the mainstem Bay in marsh, submerged aquatic vegetation (SAV), or Oyster habitats. Consequently, shallow, nearshore areas are underrepresented in the surveys and presumably in this preliminary analysis. Finfish are highly mobile, and consequently, this bias could be small for these species but the bias remains unknown and could be important.

The ChesMMAP trawl gear under-samples both very young fish and the largest, older fish. ChesMMAP samples were complemented by CHESFIMS and CTILS analyses for VIMS Trawl and Maryland and Virginia seine surveys, which target young adult fish (CHESFIMS, VIMS Trawl) and juveniles (seine surveys). Therefore, none of the surveys specifically target the largest, older fish. Although ChesMMAP does sample large fishes (e.g., Striped Bass 60-105 cm), these larger individuals are weakly represented in some of our analyses (Fig. 3) because samples were pooled across all size classes within a species. However, the identification of the key forage groups is not overly sensitive to the pooling of data across sizes, given the agreement of these results with that of a separate stomach analysis that did account for size-based dietary differences within the ChesMMAP data (Buchheister and Latour 2015). The results of the Buchheister and Latour (2015) study supports conclusions of the workshop's analyses, although the size-based analyses by Buchheister and Latorun demonstrate the importance of Menhaden to large individuals of Striped Bass, Bluefish (*Pomatomus saltatrix*), Weakfish, Sandbar Shark (*Carcharhinus plumbeus*), and Spiny Dogfish (*Squalus acanthias*). The ChesMMAP survey is one of the largest surveys of fish diets for any estuary in the world and its data represent a robust and comprehensive source of information on trophic interactions within Chesapeake Bay.

Workshop additions from participant discussions (discussion took place under Theme IV, day 2)

Some forage taxa absent on the preliminary list of critical forage from the diet data analysis are also important. Invited workshop participants recommended expanding the list of important forage to include some taxa that are: important managed species; forage groups and predators that were thought to have been missed by the survey gear or sampling design; or species not in the analysis because populations of these forage are currently at historically low levels (e.g., shads and river herrings).

Two "important" forage species (Table 1, column b) are also important managed species: Atlantic Menhaden and Blue Crab. Menhaden has long been noted as a key forage species in the Chesapeake Bay (Baird and Ulanowicz 1989). It was surprising to many workshop participants that Atlantic Menhaden was only determined to be important to one of the five predator species (Striped Bass) chosen for the present analysis. Consequently, Menhaden was not identified as a "key" prey in the data analysis performed here. However, workshop participants recommended that Menhaden also be considered "key" forage given that (1) it is important in the diets of larger individuals of predator species (e.g., Striped Bass, Weakfish, Bluefish) (Hartman and Brandt 1995b) that were under-represented by the ChesMMAP design and this analysis, and (2) Menhaden and several of their top predators support fisheries managed by the ASMFC, Maryland, Virginia, and the Potomac River Fisheries Commission.

Blue Crabs are believed to be important as forage to additional species at particular times of the year and in specific habitats; however, this conviction is not represented in currently available data. Subsequently, participants recognized that shallow, muddy habitats are poorly sampled in the analysis and the importance of a particular forage in predator diets could be under-represented in ChesMMAP, CHESFIMS, and VIMS Trawl data (however, participants also recognized that gut residence time of this prey is longer than finfish prey, so Blue Crab is a less likely prey to be under-represented). As a result of this discussion, workshop participants noted that shallow, muddy, and vegetated habitats not currently surveyed in a fishery-independent survey (i.e., those habitats not currently included in the CBP Benthic Index of Biological Integrity [B-IBI], or the state juvenile seine surveys) represent an important data gap for the Chesapeake.

Participants further advised that, like Blue Crab, other potentially important forage groups are not on the preliminary list of forage prepared prior to the workshop because these groups often live in habitats far up tributaries that are not currently surveyed. As a consequence, participants noted that important, mainly oligohaline and freshwater forage, should include: Atlantic Silverside (*Menidia menidia*), Mummichog and killifish (*Fundulus* spp.), and small bivalves.

An additional managed species, the catadromous American Eel (*Anguilla rostrata*), was suggested by participants to be important forage for Striped Bass. ChesMMAP samples are taken 5 times each year, but American Eel never composed a large enough fraction of stomach contents to be represented in any of the plots of the gut content analysis for Striped Bass. Eels may have been under-represented in the analysis due to their mainly freshwater life history. However, given that gut content analyses included many freshwater species other than American Eel (e.g., Striped Bass diets, Figures E4, E6 - E10), it seems unlikely to be a significant source of forage for striped bass.

Concern was expressed that some historically-important forage groups were not represented in the preliminary list of critical and important forage of the Chesapeake ecosystem. Participants identified shads and river herrings (*Alosa* spp.) as historically important forage. Some participants believed these taxa should be recognized to emphasize prioritization of their restoration in the Chesapeake.

Theme II: *Limiting Factors for Forage*

Invertebrates and fishes that serve as key forage for a diverse assemblage of fish and bird predators in Chesapeake Bay are subject to the same factors that limit productivity and sustainability as other organisms in the Bay and its tributaries. In plenary sessions and breakout groups, workshop participants recognized several broad, and often inter-related, categories of factors that can act to control or limit abundances of forage species:

- Habitat
- Shoreline hardening/ armoring / protection
- Land use and watershed development
- Climate change and sea level rise
- Water quality
- Predation
- Food resources for forage species
- Fishing and catch removals
- Socioeconomic factors

To date, Bay Program efforts to support abundant and sustainable living resources in the system have been focused on, and largely limited to, improving water quality (specifically, limiting nutrient and suspended sediment inputs). However, workshop participants recognized that additional factors limiting forage abundance or productivity are likely to also limit abundance of their predators, and such factors differ among forage taxa. Consequently, the Bay Program should consider factors limiting forage groups (beyond water quality) as a priority, and the newly drafted Management Strategies (http://www.chesapeakebay.net/managementstrategies; accessed 15 March, 2015) which specifically incorporate a forage management strategy to support the goals of the new Bay Agreement (http://www.chesapeakebay.net/chesapeakebaywatershedagreement/page; accessed 15 March, 2015), are a positive step towards accomplishing this. For some managed forage species (e.g., Atlantic Menhaden, Blue Crab), fishing is a potentially strong limiting factor not shared by unfished, unmanaged species. It was noted that overfishing on a managed forage species could shift predation pressure to other available forage, potentially initiating trophic cascades and unanticipated effects on the Bay ecosystem.

Forage species are taxonomically diverse and may inhabit either benthic or pelagic habitats. Most are short-lived and experience large swings in abundance annually and seasonally, subject to environmental variability and stressors that control productivity and reproductive success. Resource managers need to understand the environmental and anthropogenic factors that limit forage abundance and be armed with responsive and adaptive plans to ensure the long-term well-being of the forage base.

The Chesapeake Bay Program and managers can act to control some of these factors, generally by implementing programs to conserve or restore habitat, to improve water quality, or to regulate catches of managed species. In other instances where factors are beyond the control of managers, mitigation or adaptation may be necessary to stabilize or minimize effects of habitat loss and declines in water quality that adversely affect forage resources.

The public has limited knowledge or appreciation of forage and its role in the Chesapeake Bay. As such, socioeconomic factors may limit interest and constrain development of regulations or directed fishery management to benefit forage taxa. However, indirect actions such as managing predators via regulation of fishing on economically important piscivores, spatial and temporal management of fished forage species, and protection or restoration of productive habitats, are alternative approaches that, under some circumstances, also have the potential to conserve forage.

Habitat

The amount, distribution, and quality of habitat may limit forage taxa in the Chesapeake ecosystem. Estuarine habitats are structured, nurtured, and impacted by the surrounding watershed and human activities. Forage groups in estuaries such as Chesapeake Bay are taxonomically diverse and all habitats of the Bay and tributaries are home to some forage species. Workshop participants recognized a clear need to guard against habitat loss and to maintain productive areas and the forage these habitats sustain or produce. Habitats recognized by participants to be important for forage groups included the pelagic and benthic habitats of the mainstem Bay, but especially the shallow waters, tributaries, marshes, Oyster reefs, and SAV beds. Losses and modifications of habitats (e.g., hardening of shorelines [see below] and other shoreline modifications) are likely to limit valuable habitat for the production of forage.

Habitats are stressed and limited in their productive potential by both human activities and climate change stressors. Documented responses to shoreline development, specifically shoreline armoring and riparian alteration, that potentially affect forage resources include:

- Habitat loss and fragmentation forest, wetlands (Peterson and Lowe 2009).
- Altered sediment supply and transport (Bozek and Burdick 2005, NRC 2007).
- Increased scouring and turbidity (Bozek and Burdick 2005).
- Increases in invasive species (Chambers et al. 1999).
- Decreases in diversity or abundance of fish, invertebrates, reptiles, and birds (Peterson et al. 2000, Seitz et al. 2006, Bilkovic and Roggero 2008).
- Prevention of natural migration of habitats with sea level rise (Titus et al. 2009, Bilkovic 2011).
- Reduction in amounts and quality of habitats adjacent to the shoreline (e.g., SAV; Patrick et al. 2014).

Land Use and Watershed Development; Shoreline and Upland Development

Related to habitat stressors are factors and activities that result in loss of habitat and declines in water quality in estuaries that originate in the watershed, sometimes far from the Bay, and the surrounding landscape. Notable among these human-induced stresses are agricultural practices, housing developments, increases in impervious surfaces, contaminated runoff, damming, and shoreline hardening (also called coastal or shore "protection" or "armoring"; Patrick 2014). These practices and trends may lead to declines in productivity in tributaries and nearshore habitats that are important for production of forage.

Dams and their effects on waterways have had important consequences in the Chesapeake region for nearly 300 years. Reservoirs behind dams changed the character of tributaries, resulting in losses of riverine habitat. Spawning migrations of anadromous fishes, especially alosines (shads and river herrings), have been reduced or eliminated in most tributaries as a result of dams (Limburg and Waldman 2009, Maryland Sea Grant 2011). Loss of passage to spawning adults and to downstream migrations of young alosines that historically were important forage in the Chesapeake ecosystem has reduced or eliminated this resource for piscivores. Other activities that have modified or reduced amounts of highly productive habitat for forage include dredging, filling, destruction of marshes and wetlands, and modification of both natural shorelines and other nearshore areas.

While the practices and general effects of human developments in the watershed are well known, the specific impacts on forage, e.g., benthic invertebrate abundance and productivity or abundance/productivity of small forage fishes (e.g., killifishes, silversides, etc.) in the tributaries and nearshore zones are poorly documented. Many forage fishes (e.g., Atlantic Croaker, Atlantic Menhaden, Bay Anchovy, Spot) are less abundant in nearshore areas with hardened shorelines, while generally higher abundances of these taxa are associated with riparian shorelines (Fig. 4).

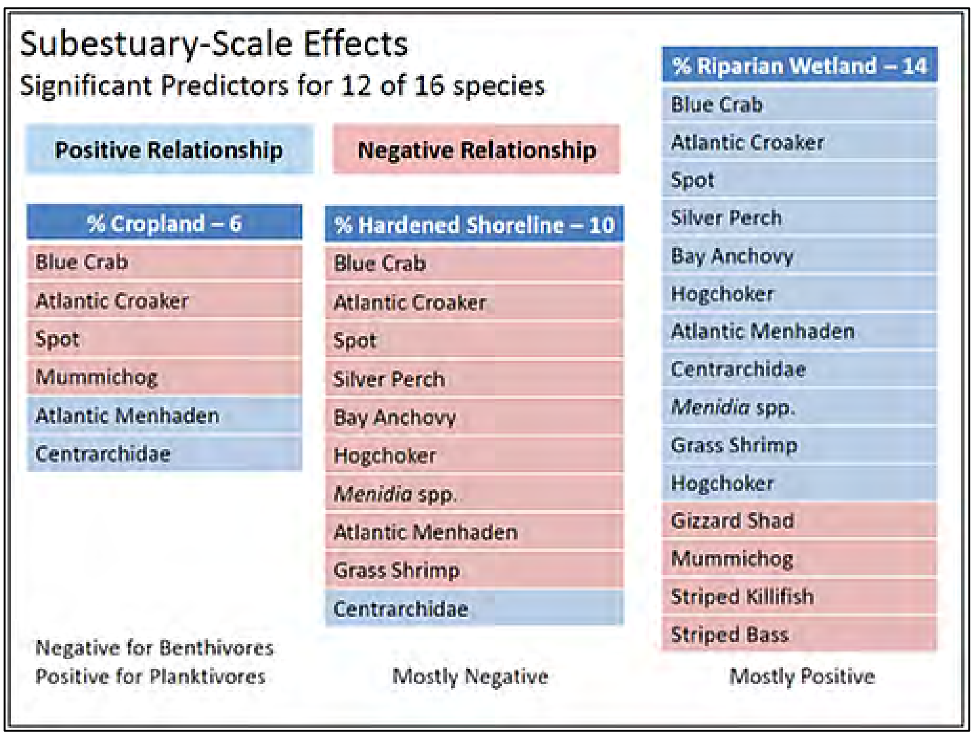

Figure 4. Abundances of common Chesapeake Bay fishes and Blue Crab as related to adjacent terrestrial land use and modification. Many forage species are negatively affected by shoreline hardening and agricultural land use (source: D. Breitburg, unpublished data).

Watershed practices can have particularly strong effects, both direct and indirect, on benthic organisms that serve as important forage (Fig. 4). Overall, there is a need to conserve natural habitats to maintain benthic communities and the forage base. Effects of coastal modifications include:

- Shoreline trends related to negative effects of hardening.
- Significant negative effects of upland use and sub-estuary development on diversity and biomass (Fig. 5). Decreases in infaunal biomass with increasing percentage of developed land, resulting in less available food and ramifications up the food web.
- Multiple stressors have negative effects on the diversity and biomass of benthic species important as forage for fishes (Fig. 5), and
- Hypoxia attributable to nutrient loading and watershed practices reduces benthic biomass (Sturdivant et al. 2014).

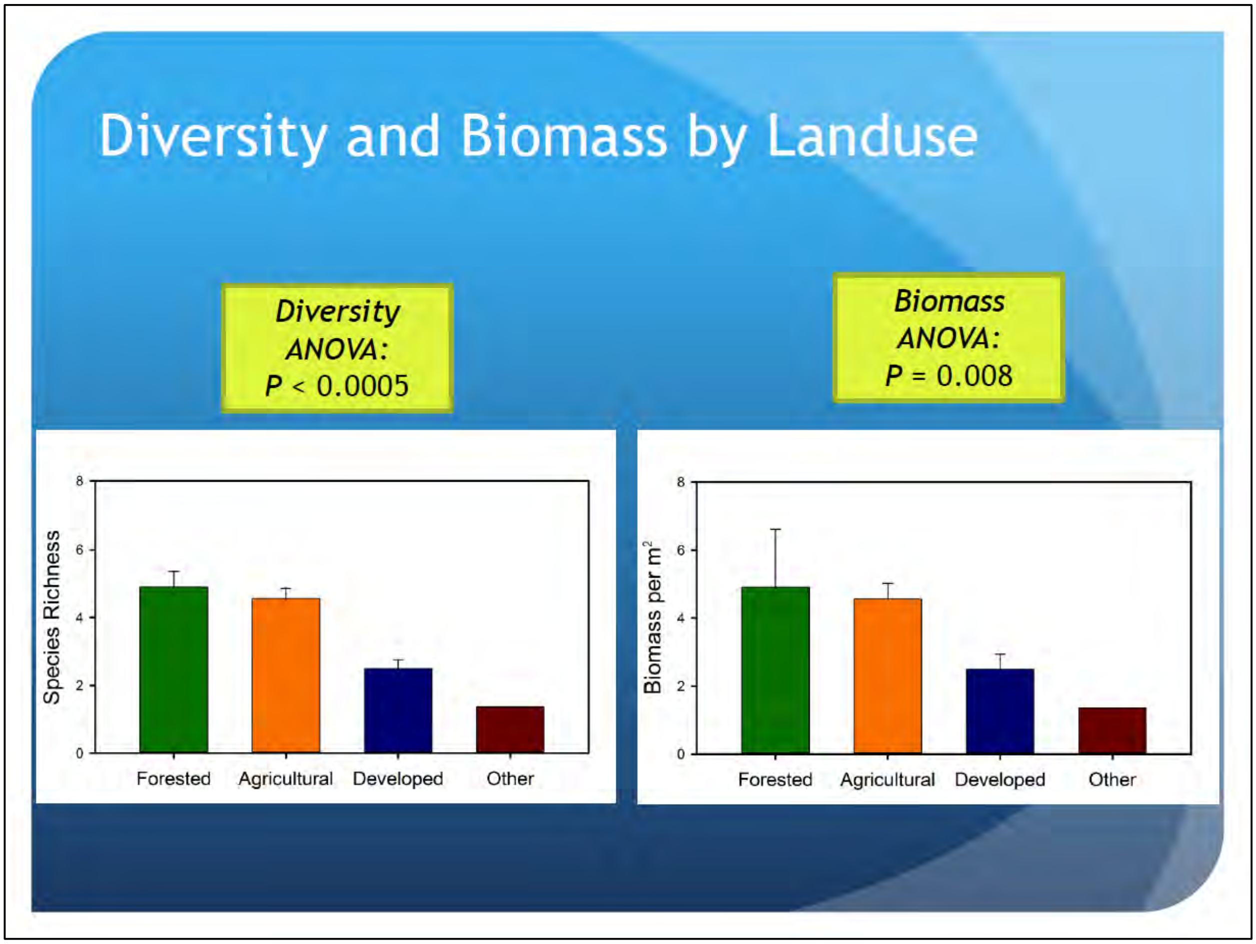

Figure 5. Chesapeake Bay watershed land uses and relationships to species richness and biomass of benthic organisms important as forage for fishes (presented by R. Seitz).

Species richness and biomass of benthos clearly declines in developed watersheds of Chesapeake Bay (Fig. 5). Recent research on the Chesapeake nekton assemblages show similar responses, namely, lower diversity near armored shorelines compared to that near natural marshes (Bilkovic and Roggero 2008). It is probable that living shorelines and restored habitats improve fish and shellfish nursery habitats (Davis et al. 2006, Currin 2008, Bilkovic and Mitchell 2013), although there remains a need to demonstrate enhanced production and trophic transfer of forage to higher trophic levels in these habitats.

Climate Change and Sea Level Rise

In combination with coastal hardening and development, climate change and sea level rise (SLR) have the potential to eliminate or reduce many shoreline habitats (Fig. 6; Titus et al. 2009), directly impacting forage that depend on these essential habitats. Pyke et al. (2008) and Cahoon et al. (2009) have reviewed and summarized the potential complex impacts of climate change on coastal habitats. Effects thought to directly impact forage are: 1) increasing temperatures - expected to have multiple effects on growth and productivity of coastal wetland vegetation and more generally, altering plant assemblages, distribution, and habitat area in the Chesapeake that are available to forage; 2) increased precipitation can affect salinity levels (Pyke et al. 2008) - stressing plants, and causing shifts in distributions of both forage animals and plants; and 3) SLR (Najjar et al. 2010) - increasing water depth in combination with anticipated shoreline armoring will also likely reduce available habitat for forage, since coastal habitats need to move landward as water rises to find the preferred elevation in the tidal zone for survival, but cannot when shorelines are armored (Titus et al. 2009; Bilkovic 2011). Anticipated indirect effects of ongoing climate change include: increasing turbidity and nutrient levels due to increased runoff (from increased rainfall), raising the probability of hypoxia and reducing light availability for SAV (Moore and Jarvis 2008) and increased risk of intense and extreme weather events (from increased temperatures), which can physically remove the SAV beds and marsh plant habitats that forage groups depend on.

Although there is uncertainty about the level of impact climate-stress effects will have on Chesapeake Bay forage resources, the effects are likely to be substantial and must be considered in long-term management of the forage base, primarily through habitat conservation approaches. Additionally, managers must be ready to respond to substantial changes in the Bay's food web, should they occur. Shifts in distribution and changes in levels of relative abundance of dominant forage species and their predators can be expected, as can behavior or changes in life-history characteristics (e.g., Blue Crab may no longer overwinter in torpor). Some forage species now uncommon or even new to the Chesapeake Bay may become established (e.g., Penaeid shrimps, mullets, subtropical sardine/herring species) in future decades. Ongoing monitoring will be critical in documenting climate-induced shifts and modifications to species assemblages in the Bay and to inform managers of the need to respond. It should be recognized that not all effects of climate change will have negative impacts on biological community structure and productivity. However, with respect to SLR, the human response to combat its effects will likely be large-scale projects to armor more shorelines (Najjar et al. 2010) further reducing the extent of nearshore, natural habitats needed for the production of forage species.

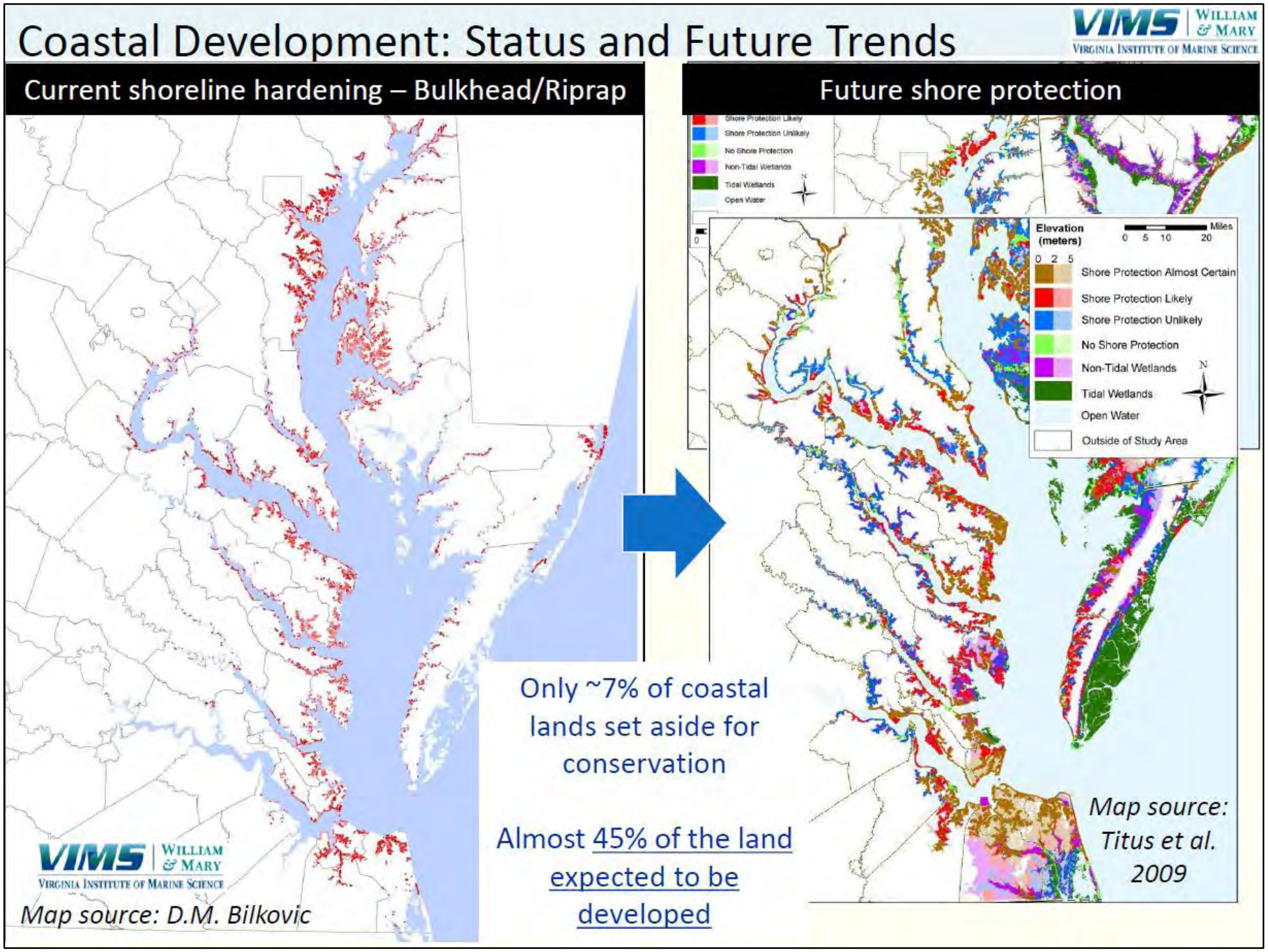

Figure 6. Coastal development, Chesapeake Bay status and trends. Shoreline protection and hardening will increase dramatically in coming decades (source: Titus et al. 2009).

Water Quality

Water quality is closely linked to land use and watershed development. Runoff, nutrient loading, sediment loads, and other sources of contaminants reduce the productive capacity of the Bay. Excess nutrient loading is responsible for eutrophication of the Bay and tributaries (Kemp et al. 2005). Eutrophication leads to hypoxia in a large portion of the Bay each summer and limits production of benthic organisms that are key prey of managed (e.g., Atlantic Croaker) and monitored (e.g., Spot) fish species and alters the distribution and productivity of plankton. Additionally, the shading caused by excessive algal growth has strong negative impacts on SAV, an important habitat to many forage species. A future threat of acidification attributable to increases in CO_2 is also of concern for estuarine productivity, including specific concerns related to: the reproductive success of anadromous fishes in tributaries (e.g., alosines), the health and productivity of forage fishes (via increased hypoxia under acidified conditions), and the production of many invertebrates with carbonate exoskeletons (Maryland Task Force 2015; http://bit.ly/MDOATF_finalreport).

Predation

Forage taxa provide a key ecosystem service by supporting production of managed and unmanaged predators. Predation is a major limiting factor for forage production. In size-structured ecosystems (e.g., aquatic systems), predation exerts strong top-down control over the abundance of forage. Predators can limit forage abundance and, in turn, forage availability can limit abundance and production of predators.

It is important to understand relationships between forage abundance and predator demand and to determine what levels of forage are critical or limiting (targets and thresholds) to support predators (see Theme III metrics and indicators). The question of how much forage is required to support production of managed (e.g., some fish) and unmanaged (e.g., birds) predators is important to managing fisheries and conserving sustainable populations of unmanaged predators.

In recent decades, the introduction of invasive predator fishes to Chesapeake Bay and its tributaries has placed additional pressure on forage fishes and perhaps benthic invertebrate resources. The Northern snakehead (*Channa argus*) and the Blue and Flathead Catfishes are noteworthy examples of predatory invasive fishes. These large predators create high demand for forage species and compete with native predators for limited forage fish resources.

Relationships between predator and prey and how their respective abundances affect ecosystem dynamics and productivity were important considerations at the workshop. The question of how much forage is required (and what type or quality) to maintain healthy populations of economically and ecologically important predators in Chesapeake Bay was recognized as central to understanding the trophic structure and functioning of the Bay ecosystem.

Many birds and waterfowl consume a diverse array of forage in Chesapeake Bay. Benthic resources in particular are critical for many waterfowl. Pelagic fishes sustain terns, cormorants, osprey, bald eagle, mergansers, brown pelican, and loons (see The Birds of North America Online [P. Rodewald, Ed.].

Ithaca: Cornell Laboratory of Ornithology; The Birds of North America Online database: http://bna.birds.cornell.edu/BNA/; retrieved August 2015). Consumption can be substantial, e.g., 5000 cormorants in Chesapeake Bay can consume 300 tons of fish annually (Fig. 7).

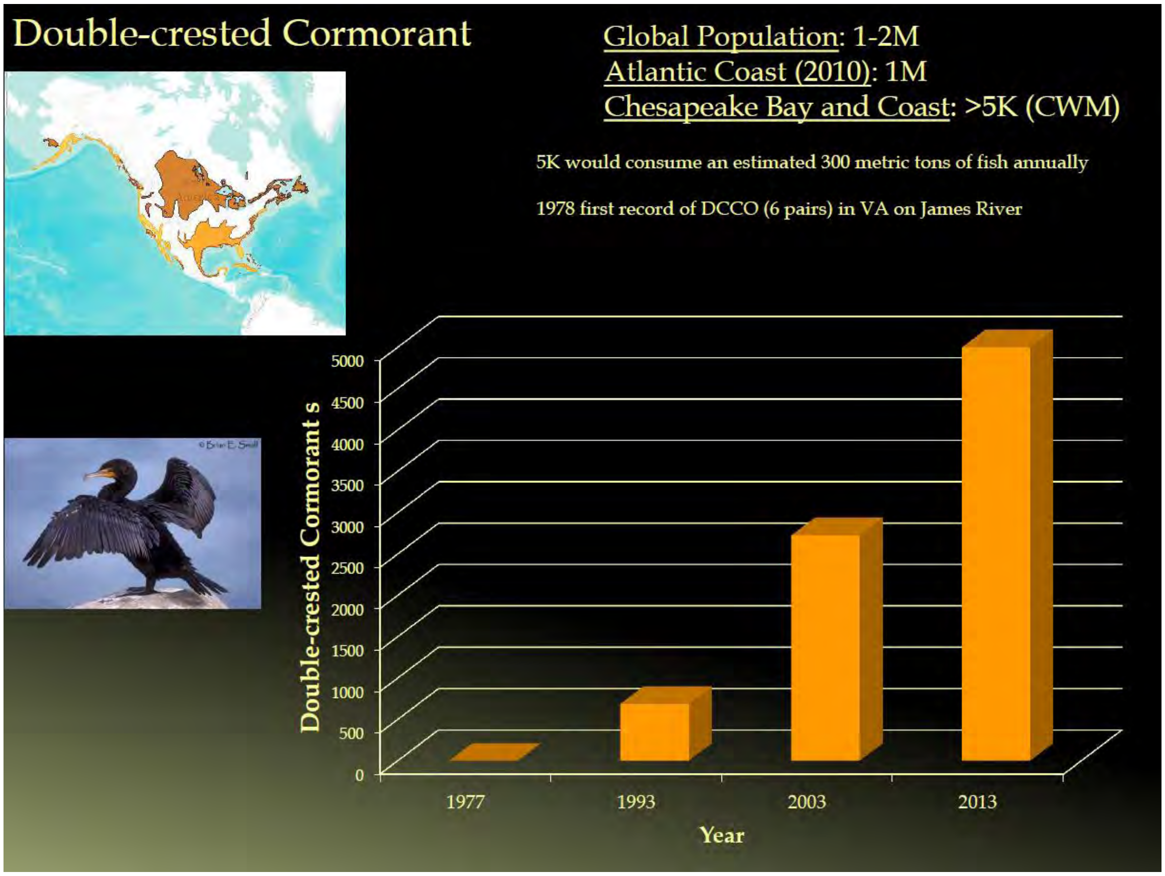

Figure 7. Increasing numbers and forage demand of Double-crested Cormorant in the Chesapeake Bay (presented by D. Prosser, source: Maryland DNR, personal communication).

Food resources for forage species

Workshop participants recognized the importance of understanding the quality and quantity of food required to produce and sustain the forage base in Chesapeake Bay. Diverse foods (living and non-living) are consumed by small forage taxa, including phytoplankton, zooplankton, microbenthos, and detritus. While there is a general appreciation and knowledge of the kinds of food consumed by forage, understanding specific requirements and demand, and critical levels or thresholds of food abundance, are poorly known.

Monitoring and surveying of phyto- and zooplankton as well as small benthic organisms that support production and recruitment of forage fishes and invertebrates is needed to quantify abundances and amounts of these foods, follow trends, and to recognize any major shifts that may occur. Workshop participants proposed that maintenance of high-quality habitat and water quality, and the practices that conserve habitat quality and availability, may be the best pathways to ensure that food resources for forage species are maintained above limiting thresholds.

Fishing and catch removals

Most forage taxa in Chesapeake Bay are not currently exploited by fisheries. However, several species of fishes that are exploited (e.g., Spot, Weakfish, Atlantic Croaker; Table 2) were recognized by gut analysis performed for the workshop (Table 1) as key or important forage during their juvenile stages; and one species, Atlantic Menhaden, is targeted by a purse seine fishery.

Atlantic Menhaden, identified here as an important forage species, supports the Bay's (and the Atlantic coast's) largest fishery, with annual Bay landings exceeding 180,000 tons in the 1970s to 1990s (Smith 1999; Maryland Sea Grant 2009; SEDAR 2015). Smaller catches in recent years are, in part, related to regulations that capped the purse-seine fishery at 109,020 tons in 2006 and then 87,216 tons in 2013. The Menhaden fishery accounts for >60% of Chesapeake Bay fish landings (Fig. 8). A phenomenon (labeled "localized depletion") that describes the potential for local reductions in Menhaden abundance from fishing to lead to local reductions in abundance of predator fishes such as Striped Bass has concerned recreational fishermen. Substantial fishing on Menhaden and declines in its abundance could impact production of numerous large, piscivorous species (e.g., Striped Bass, Bluefish, Weakfish, fish-eating birds, and marine mammals). The most recent stock assessment of Atlantic Menhaden (SEDAR 2015), however, indicates that the species is not currently overfished and that overfishing is not occurring.

With the exception of Menhaden, fishery managers have rarely taken into account the critical interactions and dependencies between forage and predator abundances in Chesapeake Bay and how fishing may limit production of predator and prey or affect interactions between them. Declines in the populations of Atlantic Croaker, Weakfish, and Spot would affect Bay forage overall, and subsequently the production of predators, since juveniles of these species are of key importance to a wide variety of predator groups thought to be representative of the Bay's predatory demand. Of these three species, Weakfish has been in decline coastwide according to the latest stock assessment (Northeast Fisheries Science Center 2009), and the negative trend is reflected in the 50-, 10-, and 5-year average catches of Weakfish in the Chesapeake Bay (Table 2). In contrast, Atlantic Croaker and Spot harvests have been relatively stable over time (Table 2).

Historically, juvenile alosines (shads and river herrings) once supported large fisheries (Limburg and Waldman 2009; Maryland Sea Grant 2011) and likely were also important forage for fish and bird predators in Chesapeake tributaries and in throughout the Bay. The current low abundances of alosines have led to closure of their fisheries. The low abundances of adult alosines and low egg production ensure low production of young that could serve as prey for piscivores.

Fished invertebrates (e.g., juveniles of Blue Crabs, clams and Oysters) are also consumed as forage by many predators, and Blue Crab was identified as an important forage species in this workshop (Table 1). The Blue Crab and Oyster are managed species in Chesapeake Bay. Juvenile stages are consumed by a variety of predators (CBFEAP 2006), including managed fishes and unmanaged species such as Cownose Ray (*Rhinoptera bonasus*) and seabirds.

Table 2. Commercial landings (metric tons) of selected species from Chesapeake Bay. Landings of forage species, predator species, and a category "forage/predator" are listed. The "forage/predator" category represents species whose young are important as prey for larger, piscivorous fishes. The 50-yr mean is based on landings from 1964-2013; 10-yr mean, 2004-2013; 5-yr mean, 2009-2013 (source: NOAA-NMFS Commercial landings (http://www.st.nmfs.noaa.gov/commercial-fisheries/commercial-landings/)).

Chesapeake Bay landings (metric tons). Selected species.

Trophic role	Species	50 year mean	10 year mean	5 year mean
Forage fish	Alewife	2,827	104	129
	American shad	522	6	3
	Atlantic menhaden	121,280	104,724	100,000*
	Blueback herring	-	2	3**
	Hickory shad	9	4	3
Forage/predator	Atlantic croaker	2,491	4,205	3,541
	Spot	1,218	1,330	1,200
	Weakfish	923	85	24
Predator	Black drum	41	31	32
	Blue catfish	-	405	728
	Bluefish	624	257	218
	Black Sea Bass	568	234	223
	Channel catfish***	-	-	456
	Cownose ray	-	-	25
	Sheepshead	-	3	3
	Smooth dogfish	-	217	269
	Spiny dogfish	-	1,070	1,060
	Striped bass	1,573	1,979	2,034
	Summer flounder	1,847	1,542	1,694
	White perch	588	619	787

*Approximate. Capped at 109,020 metric tons beginning 2006.
**2010-2012
***2009-2013

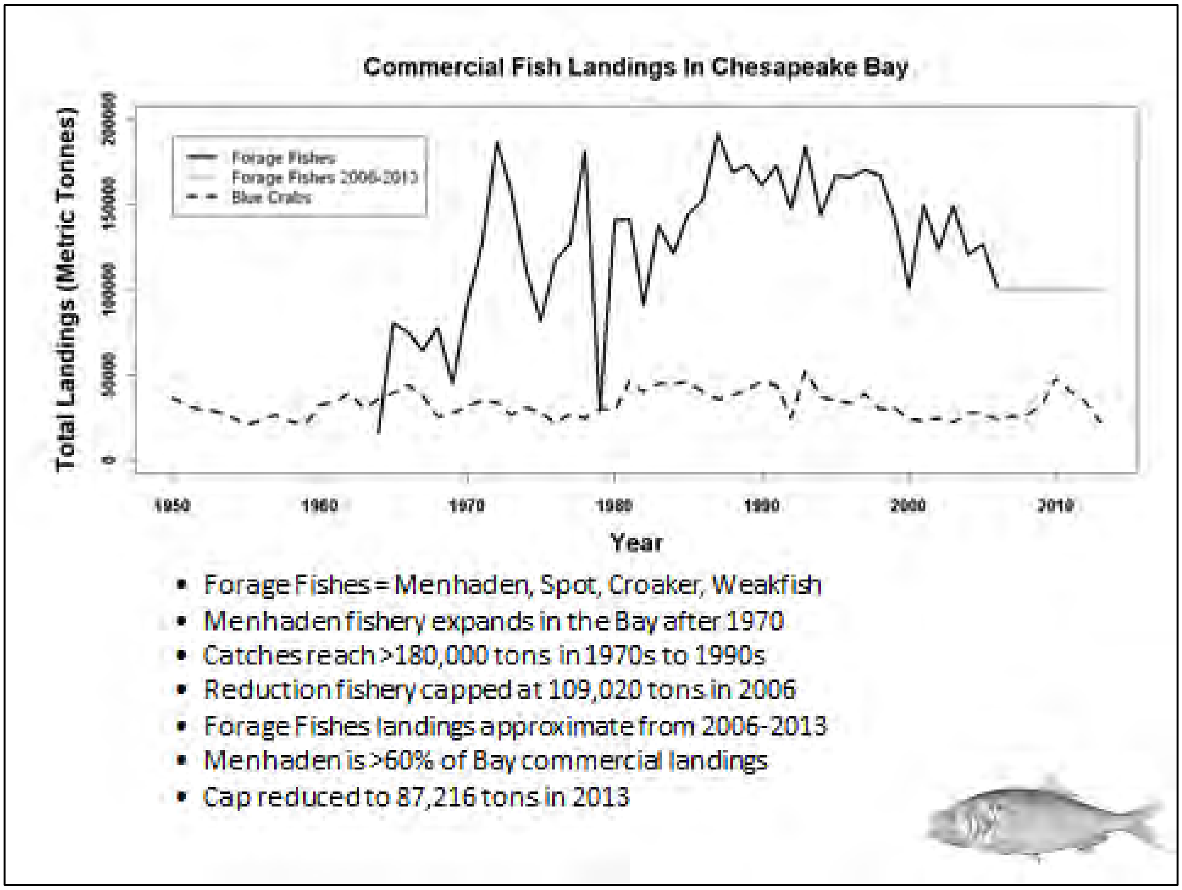

Figure 8. Commercial landings in Chesapeake Bay. Forage species landings, including the forage/predator category, are dominated by Atlantic Menhaden. Landings of forage fishes since 2006 are limited by the cap on Menhaden landings imposed by management agencies. Forage species, primarily Menhaden, have contributed 91%, on average, to the commercial fish landings from Chesapeake Bay over the past 50 years (source: presented by E. Houde; http://www.st.nmfs.noaa.gov/commercial-fisheries/commercial-landings/).

Socioeconomic Factors

Socioeconomic factors, while important in reaching decisions on how to manage forage species or in the development of policies ensuring sustainable levels and production of forage, were not addressed in depth at the workshop. The value of forage species may not be perceived by stakeholders and some managers as being at a level sufficiently high to warrant active, direct management, which may limit development or implementation of specific management plans. However, policies aimed at improving habitat and water quality for the overall benefit of the Bay are likely to have broad public support and such policies will benefit forage species.

In the case of Atlantic Menhaden, fishing traditionally has been an important use of the resource. In recent decades, consideration of the additional ecosystem services of Menhaden as forage has broadened perceptions of Menhaden's value. It has been suggested in the past that Menhaden also have the potential to improve water quality through filter-feeding on phytoplankton (Gottlieb 1998, Dalyander and Cerco 2010). If true, this would constitute an additional ecosystem service attributable to Menhaden. Recent laboratory research (Lynch et al. 2010) however, suggests that only juvenile Menhaden consume phytoplankton as a large fraction of their diet, and that adults consume mostly zooplankton. The Chesapeake Bay is home to both juvenile and adult Menhaden, and both life stages excrete nitrogenous wastes that, on balance, may add to phytoplankton production (Durbin and Durbin 1998) and potentially negatively affect water quality (Lynch et al. 2010). Although the net effect of Menhaden of all ages combined remains uncertain (Dalyander and Cerco 2010), this example indicates how tradeoffs must be considered in developing management objectives for forage species.

Alternative actions available to managers are limited for most forage species. Protecting and improving habitat and water quality by reducing levels of identified stressors is an avenue open to managers. Before undertaking major and costly programs to improve, alleviate, or mitigate for the benefit of forage, a risk analysis on major limiting factors is desirable in which the probability and severity of a factor's impact are considered. One means to accomplish this could be through a formal Management Strategy Evaluation (MSE) approach (Sainsbury et al. 2000) to determine which management policies have the best potential to avoid risk.

Theme III: *Forage Metric/Indicator Development*

An objective of the workshop was to identify strategies to improve the quantification of the forage base of the Chesapeake Bay ecosystem. Participants discussed and recommended indicators and metrics for managers to aid in the development of a strategy for assessing the forage base available for predatory species and in implementation of actions to manage forage and predator resources. The identified indicators, metrics, and reference points are required to fulfill a commitment by the SFGIT in the CBP's new Watershed Agreement. Nearly a decade ago, the CBFEAP (2006) recognized the need to quantify relationships between predators and prey (i.e., forage) as an important step to understand fisheries production in the Chesapeake Bay and to advance ecosystem-based fisheries management. The CBFEAP report stressed the need to not only identify key predator and prey relationships for managed species but to quantify the diverse habitat and water-quality factors that contribute to production and sustainability. More recently, Maryland Sea Grant coordinated efforts of Chesapeake Bay Program partners and experts from the Chesapeake region to specify key habitat, water quality, and trophic factors that limit alosine, Striped Bass, Menhaden and Blue Crab populations (www.mdsg.umd.edu/programs/policy/ebfm/, webpage last accessed 15 March, 2015), but the needs identified by the CBFEAP, i.e., to quantify both predator-prey relationships important to managed species and the habitat and water-quality factors, have yet to be met.

There is broad agreement that maintaining an adequate forage base in marine ecosystems is a desirable goal. It is presently not clear what "adequate" means in terms of quantities, production, and production potential, as managers do not have clear objectives or policies in place. A generally accepted goal of fisheries managers is to avoid collapse of the forage base and predators dependent on that forage, i.e., the managed fishes and unmanaged species (many fishes, birds, and mammals). Indicators and metrics of abundance and productivity of forage taxa can provide information on the status and trends in the forage base. For managed forage species, indicators and reference points like fishing and natural mortality rates, estimates of growth, and measures of biomass or fecundity, can often be derived from stock assessments (e.g., Atlantic Croaker, Atlantic Menhaden, Blue Crab, Spot, Weakfish). For unmanaged species, targets and thresholds for management actions can be developed from indicators and trends of abundance, metrics related to habitat and water quality, metrics of forage consumption and demand by predators, and model-derived parameters of predator-prey dynamics, among others (Table 3).

In considering metrics and indicators, several questions were posed to workshop participants to guide their choices and recommendations:

- Are some forage species more important than others?
- What predators (including humans) consume the most forage?
- How much habitat is available for forage species?
- How much forage is consumed by predators?
- How much food energy is needed by predators?
- How much of the energy input to the ecosystem is directed to forage production?
- How well are the predators doing, i.e., are predators able to consume enough prey? Are predators showing increased prevalence of disease?
- Do we understand the spatial dynamics of predators and forage?

The proposal for this workshop emphasized the need to identify approaches that could use existing data to develop a suite of Bay-specific indices or metrics to quantify the forage base. In addition, it recognized that new indicators and strategies to incorporate them into evaluation or assessment programs would be needed to meet management objectives.

To accomplish this, there is a need to develop indicators or metrics - and targets and thresholds based on these indicators - that concurrently track abundance trends of key forage with trends in habitat extent and water quality. Useful metrics or indicators should 1) reflect the state of the Chesapeake ecosystem; 2) be collected routinely; and 3) be actionable, i.e., linked to realistic management actions, and targets and thresholds that trigger such actions.

Workshop participants identified and proposed indicators and metrics that can inform understanding of status and trends in forage species in Chesapeake Bay. The group also discussed the potential to combine metrics from various categories in order to derive a suite of information on the status of forage. Recommended indicators fell into several categories (Table 3).

Table 3. Types of indicators and metrics useful to understanding and managing the forage base in Chesapeake Bay. Not in prioritized order.

Type of Metric	Method to Obtain	What Organisms?	Indicators/Management Use
Estimated abundance, biomass, or energy equivalents	Monitoring surveys, fishery-independent surveys	Forage fishes and invertebrates; predators (fishes and birds)	Forage numbers, biomass, or calories/energy (total and scaled to area or volume) to support current abundance, biomass, or caloric need of predators at key life stages
Spatial distributions	Mapped abundances	Forage fishes and invertebrates, both pelagic and benthic, and predators	Areas of occurrence; spatial overlaps. Prioritize habitat protection for highly productive areas
Habitat	Area, volume, distribution, diversity, health surveys	Forage fishes and invertebrates, both pelagic and benthic	Identify critical habitats. Compare available habitat to habitat requirements/ thresholds for forage species; prioritize habitat protection or restoration for highly productive areas
Water quality	Nutrients, hypoxia, sediment and clarity, contaminant monitoring	Forage fishes and invertebrates, both pelagic and benthic;	Compare available water quality to requirements/ thresholds. Prioritize water quality protection or restoration for highly productive areas.
Environmental and hydrographic Factors	Use available indices of temperature, freshwater flow, primary production, NAO[1], AMO[2], nutrients, hypoxia	Forage fishes and invertebrates, and predators	Track levels of environmental metrics. Determine relationships to forage well-being and abundance, and to availability to predators. Restore conditions to target levels when feasible.
Sentinel sites	Standardized, long-term monitoring sites	Diverse measurements of forage, predators, and environmental covariates	Analyze trends and status; respond with management actions when thresholds are reached.
Predator diets and gut contents	Stomach analysis in fishery-independent surveys	Predators	Compare gut contents to diet preference; determine changes in forage availability over space and time. Manage habitat and water quality to maintain key forage taxa above thresholds and targets.
Condition and nutritional quality of forage and predators	Conduct proximate and biochemical analyses, develop condition indices	Forage species and predators	Protect habitat, water quality, and productivity

Type of Metric	Method to Obtain	What Organisms?	Indicators/Management Use
Forage species dynamics	Species-specific research: age, growth, abundance, biomass, mortality, recruitment	Key forage species, e.g., Bay Anchovy, polychaetes, mysids, benthos, and zooplankton	Maintain abundance levels and reproductive capacity above targets and thresholds to ensure healthy predator populations.
Stock assessment data and reference points	Apply single and multispecies models	Forage species: Atlantic Menhaden, Atlantic Croaker, American Shad/river herrings, Blue Crab	Spawning stock biomass, fishing mortality, fecundity, recruitment
Forage-predator ratio metrics	Monitoring surveys, fishery-independent and fishery-dependent surveys	Forage fishes, benthos, zooplankton; managed and unmanaged predators (fish and birds)	Determine relative availability of prey to key predators and trends in the relative abundances. Take management actions to assure that prey levels are sufficient to support predators.
Sentinel species	Select key species from monitoring surveys	Key forage species, e.g., (Table 1, column a)	Monitor trends in abundances of the sentinel species. Protect or restore habitat and water quality to assure favorable conditions for their production.
Report cards	Summarized statistics	Key forage and predator species	Produce annual report cards on status and trends of key forage species and their predators. Report cards are highly visible to the public and influential in publicizing the need for action.

[1]NAO is the North Atlantic Oscillation; [2]AMO is the Atlantic Multidecadal Oscillation

Abundance Surveys

Monitoring surveys of abundance, biomass, and their energy equivalents of key forage taxa must be conducted, or continued where already in place (e.g., fish surveys, Blue Crab surveys), reinstituted in some cases (e.g., zooplankton, which is a major prey and energy source for many forage species), and perhaps expanded or intensified (e.g., benthos, fish). Workshop participants noted in particular a lack of survey data in shallow waters and tributaries of Chesapeake Bay. In addition to metrics on status and trends of key forage species, aggregated statistics on abundance or biomass of guilds (i.e., aggregations of species that exploit similar resources in similar ways) and combined taxa are desirable in many instances.

When available, historical records of forage taxa abundance can be analyzed to identify benchmarks and inform managers in setting targets or thresholds that would trigger management actions. In the case of the unmanaged, unfished species of forage, such actions are likely to be directed at improving habitat and water quality to ensure sustainability or increase abundance of forage species.

Aggregated abundance and biomass statistics of forage and predator taxa, and their trends over time, are useful measures of ecosystem state and can signify regime shifts or other changes. Specifically, measures of the aggregated biomass of trophic groups such as apex predators, pelagic foragers and forage fishes, benthic foragers, benthic forage, and zooplankton are the key metrics and indicators needed to document forage and predator groups. These metrics can be obtained from periodic surveys (many synchronously from a single survey vessel).

Distribution of Forage

The distribution and occurrence of forage fishes and benthic organisms that serve as forage are potential indicators of the quality of forage habitats. Mapped distributions of forage, including nearshore, shallow areas and tributaries and structured habitats (i.e., seagrass beds, marshes, Oyster reefs) not currently surveyed by sampling programs in the Bay, can provide strong quantitative and visual indication of regional forage distributions, including centers of abundance. Information on changes in spatial or temporal distribution of forage or their habitats will be especially important for managers. Retrospective analysis and mapping when data are available can document distributions in past decades for comparisons with present distributions. Such analysis and mapping may be particularly important as future changes are driven by ongoing climate change. Surveying programs to update maps periodically (e.g., every five years) will indicate shifts and changes in distribution and abundance of key forage and forage habitats. Metrics derived from mapped abundances and distributions could be adopted as targets for management decisions.

Habitat, Water Quality, Oceanographic/Environmental Factors

A majority of management approaches for forage will depend on recognizing and responding to environmental, habitat, and water quality factors that govern and control production and distributions. Habitat and water quality maps can complement surveyed forage abundances to delineate areas of high productivity that have priority for conservation. Many organisms (forage and predators) respond to inter-annual and seasonal environmental conditions and variability, for example, freshwater flow conditions that exercise strong control over plankton productivity and fish reproductive success (e.g., Martino and Houde 2010). Some effort to relate Bay forage trends to large, recognized, periodic oceanic shifts (e.g., North Atlantic Oscillation) may prove to be useful for prediction. Habitat Suitability Index (HSI) models can be developed to describe the capacity of a given habitat to support specified forage species; HSI's represent the interactions of habitat and a species. They can provide metrics to improve management decisions based on forage species-habitat relationships. Habitat, water quality, and environmental data also can be analyzed in multivariate statistical modeling approaches for key forage taxa (see "Suites of Indicators" below). Simple indices of environmental quality can allow managers to prioritize areas and develop policies to improve habitat and water quality, but such indicators should not be used in isolation and should be considered among a suite of other indicators to capture all relevant processes in the system (Link 2010).

Gut Contents, Diets, Rations

Gut content data document the relative importance of a given prey in predators' diets. Ongoing sampling of fish stomachs, and feeding of other predators (e.g., birds), can show shifts in major prey and inter-annual variability. Combined with knowledge of digestion times, gut content data can be used to estimate rations and predator demand for particular prey. Under some circumstances, and with appropriate assumptions, gut content data may serve as a proxy to delineate distributions and abundances of forage taxa that are difficult to sample (e.g., Mysids). Gut contents, combined with information on predator sizes and environmental temperature, can be incorporated into bioenergetics models to estimate prey demand by fish and bird predators.

There are numerous past and ongoing diet studies on fishes in Chesapeake Bay and the adjacent coastal ecosystem (Appendix C). These studies provide metrics and indicators, not only for single-species management of forage and predator species, but also serve as valuable indicators in multi-species management and as the basis for ecosystem-based reference points. Gut contents of predators can delineate trends in key forage species or in guilds of forage taxa. Shifts or trends in such metrics may signal major shifts in ecosystem productivity and structure related to climate change or environmental perturbations and should be considered when possible in managing Chesapeake Bay fisheries.

Condition and Nutritional Quality of Forage and Predators

The quality, amount, and distribution of forage resources can have marked consequences on the condition of predators, influencing growth, mortality, disease resistance, maturation, and fecundity through a variety of physiological and behavioral mechanisms (Brett and Groves 1979). Nutritional quality of forage varies taxonomically, with some species being more digestible and energy rich, but it also varies ontogenetically, temporally, and spatially as predators shift their energy allocation from growth to storage, or as trophic linkages and productivity in the lower food web changes (e.g., Wuenschel et al. 2006, Pothoven and Fahnenstiel 2014). Energy flow within food webs is ultimately dependent on the energy content of prey and predators and the strength of those linkages. Thus, the nutritional quality of forage is an important component in developing bioenergetics or food web models, assessing the resources available to predators, and understanding the dynamics of predator-prey relationships.

Various physiological, biochemical, and physical metrics have been developed for measuring condition. Condition indices based on length and weight (e.g., Fulton's condition factor; Fulton 1904) provide simple but informative estimates of the relative size of individuals that can be correlated to health, growth, and survival (Froese 2006). Energy content of entire organisms or individual tissues can be assessed directly by bomb calorimetry, or it can be calculated indirectly from proximate composition analysis which measures the proportion of protein, lipid, carbohydrate, water, and ash in tissues. Percent dry weight and percent water content in particular have been shown to be strongly correlated with fat content in fishes (Hartman and Brandt 1995a). Alternatives to these more time-intensive approaches include the use of bioelectrical impedance analysis (Hartman et al. 2011) and other similar technologies to quickly and non-lethally estimate condition proxies for fishes.

Forage Species Dynamics

Dynamic properties of forage populations, for example individual growth, natural mortality, and reproductive rates, are metrics that document the ability of a population to grow and sustain itself in the face of natural predation, fishing, or other stressors. These properties can be estimated from appropriate survey data, especially if size distributions and/or age data of the forage species can be obtained from the survey catches and samples. In the case of Atlantic Menhaden and Blue Crab, age-specific estimates of dynamic properties are available from the stock assessments conducted by ASMFC for Menhaden on a coast-wide basis and for Blue Crab in Chesapeake Bay.

Assessment Data, Metrics, and Reference Points

For species that are fished and under management, stock assessment data and indicators and metrics derived from assessment models are available, though most are not specific to the Chesapeake Bay. Most of the managed, fished populations that occur in Chesapeake Bay during part of the year have been assessed for the coastal populations. Blue Crab is an exception and is assessed as a Chesapeake Bay stock. Estimates of natural and fishing mortality, age-specific abundances, and threshold fishing mortality rates and abundance (biomass) are specified for assessed populations and can be applied to Chesapeake stocks with caution. The only typical forage fish in Chesapeake Bay that is assessed is Atlantic Menhaden, but its assessment metrics are derived for the coastal Atlantic population, not the Chesapeake Bay. Blue Crab is assessed in Chesapeake Bay and assessment metrics, and target/threshold reference points delineate trends in its stage-specific abundance and mortality rates.

Considering forage species that are fished, assessed, and managed, a range of fishing mortality and biomass reference points have been proposed (Table 4). In Chesapeake Bay, only Atlantic Menhaden is in this category at the present time. Fishery reference points proposed for forage tend to be conservative relative to those recommended for non-forage species, i.e., fishing mortality targets and thresholds are lower and biomass targets and thresholds are higher than those recommended for non-forage species (Smith et al. 2011, Pikitch et al. 2012). Target levels for exploited forage species are subject to tradeoffs that managers consider in assessing the risk of forage species collapse under high fishing mortality and its consequence for predators and the ecosystem. Other important tradeoffs to be considered include the monetary and societal value of the forage species as directed catch versus value as prey to other commercial species and predators. In many instances, metrics from stock assessments and reference points for exploited forage species can be derived from established indicators, selection methods, performance testing, and management strategy evaluations that are now commonly applied in assessments of non-forage species. However, methods to adjust coast-wide metrics and reference points to apply to Chesapeake Bay-specific estimates are not always straight forward.

Table 4. Example proposed reference points for forage fish that are exploited by fisheries. Empirical mortality- and biomass-based reference points. F is the fishing mortality rate; F_{msy} is the F level to achieve maximum sustainable yield; M is the instantaneous natural mortality; F_{ERP} is an ecological reference point for F; B_{ERP} is an ecological reference point for biomass; and B_0 is virgin biomass.

Mortality-based reference points	Source
$F = M$	Beverton1990
$F = 0.87\ M$	Zhou et al. 2012
$F = 0.67\ M$	Patterson 1992
$F_{ERP} = (0.2, 0.5 \text{ or } 0.75)\ F_{msy}$	Pikitch et al. 2012
Biomass-based reference points	Source
$B_{ERP} = 0.75\ B_0$	Constable et al. 2000, Smith et al. 2011
$B_{ERP} = (0.8, 0.4, \text{ or } 0.3)\ B_0$	Pikitch et al. 2012

Ecological reference points (ERPs) are being developed by the Atlantic States Marine Fisheries Commission for Atlantic Menhaden. Presently, natural mortality rates (M) of age-0 and age-1 menhaden are derived from a Multispecies Virtual Population Analysis (MSVPA). The ASMFC Technical Committee plans to develop ERPs, exploring a variety of methods (e.g., nutrition indicators, production models, multispecies age-structured models) (SEDAR 2015). The ASMFC and other researchers will conduct simulation testing of ERPs and multispecies models to propose approaches to effectively manage Menhaden to maintain both sustainable fisheries and ecosystem services. One candidate method is a multispecies statistical catch-at-age model (MSSCA) that can provide estimates of Menhaden time-varying natural mortality at age and consumption. An MSSCA is currently developed but its performance is not fully tested against the performance of other multispecies models. The ERP models and reference points for Menhaden are for the coast-wide population and are not specific to Chesapeake Bay. Estimates of predation mortality (M_2) are not available for the age-0 and age-1 components of other managed species that are also key prey of managed predators, e.g., Atlantic Croaker, Spot, and Weakfish (Table 1 column a).

Metrics Based on Forage-Predator Ratios

Ratio estimates of abundances (or biomasses) of forage relative to abundance of predators can serve as benchmark indicators and metrics of relative prey availability. The ratio indicators can be expressed as numbers, biomass, or energy equivalents. Trends over time are indicators of shifts in relative availability of particular prey types. Indicator ratios can be derived for individual forage species or for aggregated forage taxa at the guild or other prescribed aggregation level. Careful consideration of methods and assumptions is required to properly calculate a ratio that serves as an index of forage availability or utilization. Particularly important are considerations of seasonality, habitat specificity, spatial overlap of occurrences, and sizes of predator and forage (see SEDAR 2015; Appendix E for a review of such concerns with examples pertaining to Atlantic Menhaden). Forage-predator ratios can be derived from fishery-dependent or fishery-independent data sources.

Suites of Indicators

No single metric is likely to serve as a basis for management of forage in Chesapeake Bay. In many cases, a suite of metrics and indicators discussed above will be needed to characterize the status and describe trends in key forage species abundances and availability to predators (Link 2010). For example, to evaluate the health of the forage base in general, metrics evaluating overall system production and habitat quality/availability might be combined with metrics related to the individual status of key forage species populations and key predator populations. Simulation analysis and management strategy evaluation can be used to evaluate combinations of individual indicators to determine which of them best assess forage species status and trends relative to management objectives. Multivariate statistical modeling can also play a role in selecting indicators or metrics that have best predictive capability in evaluating abundance and productivity of forage (Rice and Rochet 2005, Link 2010).

Sentinel Species

Workshop participants recognized that a few key species dominate the diets of many predators. For example, gut contents analyses indicated that Bay Anchovy, mysids, and polychaetes were key components of the diets of many predators. Carefully tracking abundance and trends of such species, and setting target or threshold levels on their abundance Bay-wide or regionally, could be used to designate targets that would trigger management actions that could include regulation of fishing mortality rates on predators or the forage species, or perhaps habitat restoration actions.

Report Cards

Report cards on ecosystems such as the Chesapeake Bay have become a common and popular way to inform the public on the status and trends of Bay resources. To ensure that report cards are not misleading, careful choice of metrics is important. Some important forage species in Chesapeake Bay, e.g., Bay Anchovy and Blue Crab, already are included in the annual report card on Chesapeake Bay produced by the UMCES Integration and Application Network (http://ian.umces.edu/ecocheck/report-cards/chesapeake-bay/2013/). Metrics for the report card are derived from relative abundance estimates based on monitoring surveys that sample these species. Similarly, the biannual report card produced by the Chesapeake Bay Foundation (http://www.cbf.org/about-the-bay/state-of-the-bay-report-2014) includes metrics on abundance and status of Blue Crab and American Shad that are derived from available information and statistics. Report cards provide a snapshot of current status. It should be noted that workshop participants recommended that estimates of status should always be presented in the context of trends, for example forage species trends relative to their predators.

Theme IV: *Research Needs and Management Recommendations*

Research needs

Research needs were identified by workshop participants in the four break-out groups held during Theme IV. Though identified needs were diverse, several common recommendations were voiced across all groups and, as such, were considered to be high priority research needs to better understand the forage base of the Chesapeake ecosystem, including 1) a coordinated analysis of currently available data to develop forage metrics; 2) the development of a suite of indicators useful for decision-making; and 3) shallow-water monitoring to complement current surveys.

All breakout groups identified a clear need for coordinated and thorough analysis of current data sets. Information should be integrated where possible, metrics developed (by habitat and where feasible by life stage), and utilized as indicators of forage health in the Bay. Breakout groups further agreed that it is important that such indicators should be accessible and usable by managers, and that scientists should clearly communicate to managers the utility and priorities of the metrics, and their relevance to Bay fisheries management, explicitly describing linkages of metrics to management decisions. Attention should be given in particular to the development of threshold levels in metrics for managers to consider in decision-making. Targets also are important but may be less useful to reach decisions. Consideration should also be given to evaluating the performance of indicators and to adaptively removing, modifying, or adding new indicators, accordingly.

Participants suggested a suite of key indicators be developed to inform fishery managers of the relative state of forage for the Bay. Though not an exclusive list, and not encompassing the breadth of indicators necessary for such a suite, specific indicators consistently identified by all breakout groups were: trends in forage abundance, predator demand, and the energy content of forage groups.

All break-out groups identified a need for additional monitoring in shallow-water habitats that are currently under sampled or unrepresented in the existing CBP long-term benthic monitoring program and in the trawling and juvenile seine surveys of both Maryland and Virginia. Such monitoring should include invertebrate sampling from the sediments and both invertebrate and vertebrate sampling from within SAV, marsh, and hard-bottom (e.g., Oyster) habitats. Participants recognized and expressed a need to quantify the relative importance of Bay habitats. Shallow-water monitoring of presently unrepresented habitats would facilitate determining their importance.

Participants acknowledged the importance of the continued development of models to integrate various data sets which allows managers and modelers to frame management questions in an ecosystem context. Models are needed, for example, to identify and evaluate abundance thresholds or critical habitat levels and to better understand ecosystem effects on the forage base of large-scale changes on the ecosystem, especially for those circumstances for which we have little to no existing data (e.g., climate change). Application of existing conceptual models (e.g., Baird and Ulanowicz 1989, Christensen et al. 2009) was widely agreed to be an important first step to facilitate the iterative communication needed for managers and scientists to identify knowledge gaps and advance our understanding of Bay forage status.

Throughout the meeting, participants identified additional survey and data collection improvements as requirements needed to develop an effective suite of indicators for forage health in the Chesapeake system (see Theme III above, and Prioritized Recommendations below). Participants recommended that surveys should be conducted throughout the year, that all life history stages of predators and forage should be sampled, and that sampling should take place in all representative habitats. Indicator sites for forage should include both healthy, resilient sites and highly stressed sites. It was proposed and agreed that a limited set of indicator (or sentinel) sites should be strategically located around the entire Bay system where a full suite of indicators (i.e., habitats, predators, forage, and water quality) could be sampled seasonally and, over time, would be effective in documenting relative change in forage health and could potentially minimize the costs of new monitoring.

Participants also identified the importance of including socioeconomic metrics in the suite of forage-related indicators for managers to consider. Although experts in socioeconomics did not participate in the workshop, it was recognized that collapse of an important forage group could potentially have far-reaching economic consequences for people living in the Bay watershed (see Theme II).

Management Recommendations

The workshop breakout groups put forward management recommendations. Participants agreed that a key recommendation is for the CBP SFGIT to work closely with the Habitat GIT to study, map and manage areas and habitats important for the production and maintenance of forage, with special emphasis on shoreline habitat, land use change, and developments in the tributaries throughout the watershed.

Participants recognized that defining thresholds and, in some instances targets, for forage abundance is important for long-term management of the forage base supporting managed fisheries. It was suggested that managers should consider current forage status relative to available records of historical forage abundances and distributions, especially for species (e.g., shads and river herrings) that were once important as forage but are no longer abundant. Such information would be useful for development of restoration plans and targets. Additionally, participants suggested that, where appropriate for coastal species, managers align indicators of the health of Bay forage with those currently under development by ASMFC and the MAFMC.

A suite of research and management recommendations was developed during the course of the workshop. Recommendations suggested repeatedly and, consequently thought to be most important, are included in the Prioritized Recommendations section below.

Existing Data of Potential Use for Indicator Development Identified

Several existing data sets were identified by participants during the Theme IV discussion (and throughout the workshop) as potentially useful for data mining and indicator development. These data sources are documented in Appendix D.

Workshop participants recognized that data on avian forage needs and consumption have seldom been considered in questions related to fisheries management in the Chesapeake Bay. However, participants agreed that seabird abundance is likely to have an appreciable impact on the forage base and that the well-being of the birds is related to the health of the forage base. Moreover, given shifting trends in abundances of some birds (Brinker et al. 2007, Costanzo and Hindman 2007, Williams et al. 2007), it appears that available data on abundance (relative or absolute counts) of some species could be useful as a component of a suite of indicators of forage demand by birds and of Bay forage health.

Beyond existing data sets identified and described (Appendix D), participants also identified that upcoming enhancement to the ChesMMAP survey will add to the currently available data for understanding specific forage groups and their trends. Along with continuing the current bottom trawl sampling, ChesMMAP enhancements will include: small mesh mid-water trawls to quantify small pelagic and semi-pelagic fishes; night-time plankton monitoring including estimates of mysid abundance; and bottom grabs to enumerate benthic invertebrates (a year of pilot studies has already been completed, but permanent survey enhancements are dependent on the completed construction of a new vessel, scheduled for 2018).

Fisheries Management Panel: Part 2 - Management Needs Refined

Some active members of the SFGIT had expressed interest in participating in the workshop and were invited to join discussions during the second day of the workshop. Jim Price (Chesapeake Bay Ecological Foundation) and Jim Cummins (Interstate Commission on the Potomac River Basin) joined the meeting prior to the presentation of the Manager Summaries.

Manager Summaries

Marty Gary (Executive Secretary, Potomac River Fisheries Commission):

> [We] need science to communicate with constituents. We must be able to knowledgably answer questions from fishermen who come to managers with forage concerns and striper guts full of Blue Crabs or Menhaden. We need to be able to answer the question of whether the current forage base is adequate to support the well-being of managed fish species on an ongoing basis.

Lynn Fegley (Deputy Director, Maryland Dept. of Natural Resources Fisheries Service):

> Managers need a practical guide to manage fisheries with respect to forage. Managers need to assure constituents that there is credible science behind management decisions. Specifically, managers need enough information to: develop and establish conceptual models, set objectives, develop indicators for forage abundance and health, adopt management tools to affect change in the indicators, and identify metrics to inform thresholds (which are better than targets). Managers want to know what can be done sooner rather than later and what the cost will be to produce a viable forage indicator.

Joe Grist (Deputy Chief, Fisheries Management Division, Virginia Marine Resources Commission):

> Managers do need a practical guide to manage the forage and people. Managers need a better understanding of what forage exists, their life histories, their health, and their abundances, to help make decisions and to develop a sustainable plan. There is a need for answers to current, pressing questions, e.g., how do we lift moratoria, what will be the effects on forage due to:

shoreline hardening, invasive Blue Catfish, and more predators? Managers need more (and/or better) surveys of forage that include invertebrates, more scrutiny of existing surveys, and a better understanding of changing trends. Perhaps surveys for a full suite of forage indicators would only need to be repeated every few years, or surveys of abundance of indicator predator species (e.g., birds) will be useful. The biggest thing needed is to better understand how the Chesapeake Bay system is integrated, and then to relate this knowledge effectively to constituents. There is a need to move beyond the public perception that "forage is just bait, and it doesn't matter."

The managers and workshop participants agreed that there is a critical disconnect between the biological importance of forage and stakeholder understanding. A clear need for better messaging to constituents about forage importance was widely acknowledged by the group, and it was suggested that an educational video may be effective and was a "low-hanging fruit" that might be produced by a CBP partner at little or no cost to the SFGIT. It was suggested that the successful approaches of some non-governmental organizations (e.g., The Pew Charitable Trusts and Oceana have had very successful messaging to the public on the importance of forage protections on the west coast, even for species that are not fished) might be good examples for Chesapeake Bay efforts to emulate.

There was general agreement that the quickest way to communicate to constituents the need to protect critical forage is through protection of productive habitat. It was widely accepted that the public would understand habitat needs more readily than forage. It was also agreed that it is important for fishery managers and the SFGIT to work in close partnership with both the Habitat- and Water Quality GITs to successfully manage forage in the Chesapeake system.

Participants acknowledged that simple approaches may not answer many of the questions related to forage management. For instance, if managers only wished to know the effects on Striped Bass to a change in forage, effectively addressing that question would require accounting for broader ecosystem effects and the potential cascading effects of management measures or of a regime shift in the Bay ecosystem (e.g., climate effects). The question is not really "is this fish healthy?" as was posed during a discussion, but is "If we do this, will this *improve* the health of the fish?" The complexity of many forage issues may require ecosystem modeling approaches to predict directional change, and thus provide strategic advice required to manage aggregate system components such as the forage base. Modeling approaches can be conducted adaptively by small workgroups (of both managers and modelers) to iteratively model, discuss, and set (and re-set) objectives. Understanding potential effects of all available management options is important to understand risk and in considering consequences of alternative management decisions. However, participants also noted that in the absence of a fully-developed ecosystem model, some specific hypothesis-testing based on existing monitoring data can be a useful first step to providing managers with directional advice.

It was widely agreed by participants that there is no "silver bullet" to assess or track trends of forage and their consequences for the Bay system. No single approach will be sufficient. Instead, managers and scientists should work collaboratively to choose a suite of metrics and indicators. The best way to reach this objective may be to adopt a combination of both empirical and modeling approaches, and to apply MSE.

Outcomes and recommendations from this workshop could constitute a foundation for a "practical guide" on forage management that managers need.

Prioritized Recommendations

Recommendations made throughout the two-day workshop are summarized and prioritized here. During the Theme IV discussion, an attempt was made to summarize research and management recommendations made throughout the workshop. However, that discussion (see above) focused on only a subset of recommendations that were made throughout the two-day meeting. Recommendations that follow (Table 5) are a summary of recommendations voiced most frequently and repeatedly during the two-day workshop. Summary recommendations were circulated to all participants and steering committee (Appendix A) in a survey, where the recommendations were presented in no particular order. Each participant then ranked each recommendation separately based on their perception of its degree of urgency on a scale of 1 - 5, where "1" was least urgent, and "5" was "immediate." To provide context, it is important to recognize that on the whole, workshop participants believe all of the prioritized recommendations listed in Table 5 should be addressed. Rankings shown in the last two columns of Table 5 indicate the degree of urgency that managers and scientists separately assigned to each recommendation, respectively.

Table 5. Prioritized recommendations. These 11 recommendations encapsulate statements made by participants most frequently, by multiple individuals, and that were recorded in multiple discussions throughout the two-day workshop. As such, they were identified as representative of the highest priority actions needed to understand and maintain the Chesapeake Bay forage base. Results are ranked based on a survey questionnaire sent to all participants after the workshop (93% response rate; n=26). The numbered survey recommendations were not presented in any particular order to participants and included both research and management recommendations. "*" indicates a tied ranking for that column (i.e., overall, manager, or scientist). References in ( ) refer to efforts that had previously identified the same or similar recommendations for the Chesapeake Bay.

Recommendation	Overall Ranking	Score Overall	Manager Ranking (Score)	Scientist Ranking (Score)
Strategic review and data-mining of all available current data to support forage quantification	*1*	*4.50*	*1 (4.33)*	*1 (4.64)*
Re-establish zooplankton monitoring to develop an index of feeding conditions for key forage (e.g., Bay Anchovy, Menhaden) and to develop abundance indices for key forage taxa (e.g., mysids); (Jasinski and Sellner 2011)	*2,3**	*4.04*	*2 (4.17)*	*5 (3.93)*
Develop a standard set of metrics and indicators (including proxies until direct information is available) to track forage abundance; use these to set targets and thresholds for triggering management actions	*2,3**	*4.04*	*4 (4.00)*	*4 (4.07)*
Relate forage trends to predator trends (CBFEAP 2006)	*4*	*3.88*	*8 (3.58)*	*2,3* (4.14)*

Improve understanding of forage dynamics & trends, especially those with limited or no current data (e.g., mysids, Bay Anchovy), both at a system-scale and at specific habitat-scale	*5*	*3.85*	*9 (3.50)*	*2,3 *(4.14)*
Establish shallow water monitoring in soft-bottom, marsh, and SAV habitats (to complement long-term seine and B-IBI monitoring surveys); including up-tributary habitats (Bonzek et al. 2007)	*6*	*3.81*	*5 (3.83)*	*6 (3.79)*
Expand diet studies that broadly cover predator ages and sizes	*7*	*3.73*	*3 (4.08)*	*8,9* (3.43)*
Estimate predator demand and forage supply by habitat. Utilize models as well as monitoring data	*8*	*3.58*	*6,7* (3.75)*	*8,9* (3.43)*
Determine (or summarize available information) prey nutritional quality; relate to nutritional needs of key predators (CBFEAP 2006)	*9,10**	*3.31*	*6,7* (3.75)*	*11 (2.93)*
Need for habitat-focused management to facilitate management of forage species; implicit in this need, is an understanding of habitat use by key forage groups	*9,10**	*3.31*	*11 (2.92)*	*7 (3.64)*
Need for educational video & web-based materials that show the importance of forage, i.e., change the view that "forage is just bait and it doesn't matter"	*11*	*3.15*	*10 (3.33)*	*10 (3.00)*

Twenty-six participants responded to the survey (93%). Of respondents, roughly half (46%) were managers and half (54%) scientists. The overall results (Table 5, columns 2, and 3) indicate the combined priorities of both groups. Given the general agreement during discussion of the need for habitat-focused management, it may be that habitat management was listed relatively low in the overall ranking (Table 5, column 2, tied rank urgency of 9|10) due to a perceived need to accomplish some of the higher-ranked tasks while planning and prioritizing habitats that can be managed to conserve forage begins. Rankings differed between managers and scientists (Table 5, columns 4, and 5, respectively). Both groups agreed that a strategic review of all available data, and subsequent data-mining to quantify our current knowledge of forage, was the most urgent priority. Ranked fourth for both groups was the need for a standard set of metrics and indicators that can be applied in quantifying forage trends. Participants (from both groups) stated that they ranked this recommendation lower than they may have otherwise because clear management objectives for forage are not yet in place. Both groups were in agreement on their second-lowest priority - to produce the educational materials (including a video) for constituents (stakeholders) - a somewhat surprising result, given the wide agreement on this recommendation during discussion at the workshop. Its ranking may be a reflection of the low degree of urgency perceived by participants. There was a high degree of variability in responses within each stakeholder group, and all mean values were greater than 3, reflecting the fact that some members of each group ranked all of the recommendations as urgent.

Next Steps

Workshop products and outcomes have provided a foundation to develop a practical guide needed for fishery managers to account for forage trends in the Chesapeake Bay. Key and important forage taxa and groups have been defined; limiting factors for forage have been recognized; a suite of potentially useful metrics and indicators to assess forage has been identified; research priorities -- that both managers and scientists agree on -- have been set. Additionally, existing literature has been collected and annotated, and existing data sources have been identified. Clear data gaps were identified. Furthermore, specific management recommendations are made and brought forward for the SFGIT to consider.

Fishery managers do need to set clear management objectives for forage which will serve to identify the specific metrics and indicators that are most appropriate for implementation. Once a suite of metrics and indicators has been chosen to assess the forage base and habitats that support it, key data gaps will be more clearly recognized and efficiently filled. In an adaptive approach, scientists and managers will be able to initiate activity to develop benchmarks for current forage levels and associated factors in the Bay. Through continued, adaptive re-evaluation of the performance of the indicators, and improvement of the indicators and benchmarks, scientists and managers can refine the forage targets and thresholds, adopt appropriate actions, and in turn, improve management of the fished species that depend on forage. Once clear management objectives are set and indicators chosen, managers can estimate the cost of investments and alternatives to accomplish their objectives, in both the near and long term.

References

Alden, R. W., III, D. M. Dauer, J. A. Ranasinghe, L. C. Scott, and R. J. Llansó. 2002. Statistical verification of the Chesapeake Bay Benthic Index of Biotic Integrity. Envirometrics13: 473–498.

Baird, D., and R.E. Ulanowicz. 1989. The seasonal dynamics of the Chesapeake Bay ecosystem. Ecological Monographs 59(4): 329-364.

Beverton, R.J.H. 1990. Small marine pelagic fish and the threat of fishing; are they endangered? Journal of Fish Biology 37 (Supplement A):5-16.

Bilkovic, D. 2011. Response of Tidal Creek Fish Communities to Dredging and Coastal Development Pressures in a Shallow-Water Estuary. Estuaries and Coasts 34(1): 129-147.

Bilkovic, D.M., and M.M. Mitchell. 2013. Ecological tradeoffs of stabilized salt marshes as a shoreline protection strategy: Effects of artificial structures on macrobenthic assemblages. Ecological Engineering 61, Part A:469-481.

Bilkovic, D.M., and M.M. Roggero. 2008. Effects of coastal development on nearshore estuarine nekton communities. Marine Ecology Progress Series 358: 27-39.

Bogstad, B., M. Pennington, and J.H. Vølstad. 1995. Cost-efficient survey designs for estimating food consumption by fish. Fisheries Research 23(1–2): 37-46.

Bozek, C.M., and D.M. Burdick. 2005. Impacts of Seawalls on Saltmarsh Plant Communities in the Great Bay Estuary, New Hampshire USA. Wetlands Ecology and Management 13(5): 553-568.

Bonzek, C., E. Houde, S. Giordano, R. Latour, T. Miller, and K.G. Sellner. 2007. Baywide and coordinated Chesapeake Bay fish stock monitoring. Chesapeake Research Consortium/ NOAA Chesapeake Bay Office, CRC Publication 07-163, Edgewater, MD, 70 p.

Bonzek, C.F., J. Gartland, D.J. Gauthier, and R.J. Latour. 2014. ChesMMAP Annual Report - Data collection and analysis in support of single and multispecies stock assessments in Chesapeake Bay: The Chesapeake Bay Multispecies Monitoring and Assessment Program. Virginia Institute of Marine Science, F-130-R-7, Gloucester Point, 171 p.

Brett, J.R., and T.D.D. Groves. 1979. Physiological energetics. Pages 279-352 *in:* W.S. Hoar, D. J. Randall, and J.R. Brett (eds), Fish Physiology, volume 8. Academic Press, New York.

Brinker, D.F., J.M. McCann, B. Williams, B.D. Watts. 2007. Colonial-nesting seabirds in the Chesapeake Bay region: where have we been and where are we going? Waterbirds 30: 93-104.

Buchheister, A., and R.J. Latour. 2015. Diets and trophic-guild structure of a diverse fish assemblage in Chesapeake Bay, U.S.A. Journal of Fish Biology 86: 967-992.

Buckel, J.A., D.O. Conover, N.D. Steinberg, and K.A. McKown. 1999. Impact of age-0 bluefish (Pomatomus saltatrix) predation on age-0 fishes in the Hudson River estuary: evidence for density-dependent loss of juvenile striped bass (Morone saxatilis). Canadian Journal of Fisheries and Aquatic Sciences 56(2): 275-287.

Cahoon, D.R., D.J. Reed, A.S. Kolker, M.M. Brinson, J.C. Stevenson, S. Riggs, R. Christian, E. Reyes, C. Voss, and D. Kunz. 2009. Coastal wetland sustainability, Chapter 4, *in* Coastal sensitivity to sea-level rise - A focus on the Mid-Atlantic region: A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. U.S. Environmental Protection Agency, Washington, D.C.

Chambers, R.M., L.A. Meyerson, and K. Saltonstall. 1999. Expansion of Phragmites australis into tidal wetlands of North America. Aquatic Botany 64(3–4): 261-273.

Chesapeake Bay Fisheries Ecosystem Advisory Panel. 2006. A Fisheries Ecosystem Plan for the Chesapeake Bay. American Fisheries Society, Trends in Fisheries Science and Management 3, Bethesda. 450 p.

Christensen, V., A. Beattie, C. Buchanan, H. Ma, S.J.D. Martell, R.J. Latour, D. Preikshot, M.B. Sigrist, J.H. Uphoff, C.J. Walters, R.J. Wood, and H. Townsend. 2009. Fisheries ecosystem model of the Chesapeake Bay: methodology, parameterization, and model exploration. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-F/SPO-106, 146 p.

Constable, A. J., W. K. de la Mare, D. J. Agnew, I. Everson, and D. Miller. 2000. Managing fisheries to conserve the Antarctic marine ecosystem: practical implementation of the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR). ICES Journal of Marine Science 57: 778-791.

Costanzo, G.R., and LJ. Hindman. 2007. Chesapeake Bay breeding waterfowl populations. Waterbirds 30: 17-24.

Currin, C., P. Delano, and L. Valdes-Weaver. 2008. Utilization of a citizen monitoring protocol to assess the structure and function of natural and stabilized fringing salt marshes in North Carolina. Wetlands Ecology and Management 16(2): 97-118.

Davis, J.L.D., R.L. Takacs, and R. Schnabel. 2006. Evaluating ecological impacts of living shorelines and shoreline habitat elements: an example from the upper western Chesapeake Bay. Pages 55-61 *in* S.Y. Erdle, J.L.D. Davis, and K.G. Sellner (eds), Management, Policy, Science, and Engineering of Nonstructural Erosion Control in the Chesapeake Bay. CRC Publication No. 08-164, Gloucester Point, VA.

Dalyander, P.S., and C.F. Cerco. 2010. Integration of a fish bioenergetics model into a spatially explicit water quality model: Application to menhaden in Chesapeake Bay. Ecological Modelling 221(16): 1922-1933.

Durbin, A.G., and E.G. Durbin. 1998. Effects of menhaden predation on plankton populations in Narragansett Bay, Rhode Island. Estuaries 21(3): 449-465.

Froese, R. 2006. Cube law, condition factor and weight–length relationships: history, meta-analysis and recommendations. Journal of Applied Ichthyology 22(4): 241-253.

Fulton, T. W. 1904. The rate of growth of fishes. Twenty-second Annual Report, Part III. Fisheries Board of Scotland, Edinburgh, pp. 141-241.

Funderburk, S.L., J.A. Mihursky, S.J. Jordan and D. Riley (eds). 1991. Habitat requirements for Chesapeake Bay living resources. Cheapeake Bay Research Consortium, Solomons, MD.

Garcia, S.M., A. Zerbi, C. Aliaume, T. DoChi, and G. Lasserre. 2003. The ecosystem approach to fisheries. Issues, terminology, principles, institutional foundations, implementation and outlook. FAO, Rome, 71 p.

Gottlieb, S.J. 1998. Ecological role of Atlantic Menhaden (*Brevoortia Tyrranus*) in Chesapeake Bay and implications for managementof the fishery. University of Maryland, College Park.

Hartman, K.J., and S.B. Brandt. 1995a. Estimating energy density of fish. Transactions of the American Fisheries Society 124(3): 347-355.

Hartman, K.J., and S.B. Brandt. 1995b. Predatory demand and impact of striped bass, bluefish, and weakfish in the Chesapeake Bay: applications of bioenergetics models. Canadian Journal of Fisheries and Aquatic Sciences 52(8): 1667-1687.

Hartman, K.J., B.A. Phelan, and J.E. Rosendale. 2011. Temperature effects on bioelectrical impedance analysis (BIA) used to estimate dry weight as a condition proxy in coastal Bluefish. Marine and Coastal Fisheries 3(1): 307-316.

Jasinski, P.H., and K.G. Sellner. 2011. Plankton Monitoring Design Workshop, Summary & Recommendations. NOAA Chesapeake Bay Office, 45 p.

Jung, S. and E.D. Houde. 2003. Spatial and temporal variabilities of pelagic fish community structure and distribution in Chesapeake Bay, USA. Estuarine, Coastal and Shelf Science 58: 335-351.

Jung, S. and E.D. Houde. 2004. Recruitment and spawning-stock biomass distribution of bay anchovy (*Anchoa mitchilli*) in Chesapeake Bay. Fishery Bulletin, US 102: 63-77.

Kemp, W.M., W.R. Boynton, J.E. Adolf, D.F. Boesch, W.C. Boicourt, G. Brush, J.C. Cornwell, T.R. Fisher, P.M. Glibert, J.D. Hagy, L.W. Harding, E.D. Houde, D.G. Kimmel, W.D. Miller, R.I.E. Newell, M.R. Roman, E.M. Smith, and J.C. Stevenson. 2005. Eutrophication of Chesapeake Bay: historical trends and ecological interactions. Marine Ecology Progress Series 303: 1-29.

Limburg, K.E. and J.R. Waldman. 2009. Dramatic declines in North Atlantic diadromous fishes. Bioscience 59: 955-965.

Link, J.S. 2010. Ecosystem-based fisheries management: Confronting tradeoffs. Cambridge University Press. 207 p.

Lynch, P.D., M.J. Brush, E.D. Condon, and R.J. Latour. 2010. Net removal of nitrogen through ingestion of phytoplankton by Atlantic menhaden Brevoortia tyrannus in Chesapeake Bay. Marine Ecology Progress Series 401: 195-209.

Martino, E.J. and E.D. Houde. 2010. Recruitment of striped bass in Chesapeake Bay: spatial and temporal environmental variability and availability of zooplankton prey. Marine Ecology Progress Series 409: 213-228.

Maryland Sea Grant. 2009. Ecosystem based fisheries management for Chesapeake Bay. Menhaden species team background and issues briefs. EBFM Menhaden Species Team. Maryland Sea Grant College UM-SG-TS-2009-08. 145 p.

Maryland Sea Grant. 2011. Ecosystem basee fisheries management for Chesapeake Bay. Alosine species team background and issues briefs. EBFM Alosine Species Team. Maryland Sea Grant College UM-SG-TS-2011-01. 136 p.

Maryland Task Force. 2015. Report of the Maryland Task Force to Study the Impact of Ocean Acidification on State Waters. Study in response to Maryland General Assembly House Bill 118. (http://bit.ly/MDOATF final report).

Moore, K.A., and J.C. Jarvis. 2008. Environmental Factors Affecting Recent Summertime Eelgrass Diebacks in the Lower Chesapeake Bay: Implications for Long-term Persistence. Journal of Coastal Research (Special Issue No. 55): 135-147.

Najjar, R.G., C.R. Pyke, M.B. Adams, D. Breitburg, C. Hershner, M. Kemp, R. Howarth, M.R. Mulholland, M. Paolisso, D. Secor, K. Sellner, D. Wardrop, and R. Wood. 2010. Potential climate-change impacts on the Chesapeake Bay. Estuarine, Coastal and Shelf Science 86(1): 1-20.

Northeast Fisheries Science Center. 2009. 48th Northeast Regional Stock Assessment Workshop (48th SAW): Assessment Summary Report, Appendix C. US Dept Commer., NOAA, NMFS, http://www.nefsc.noaa.gov/nefsc/saw/ Woods Hole, Massachusetts, 834 p.

NRC. 2007. Mitigating Shore Erosion along Sheltered Coasts. The National Academies Press, Washington, DC. 188 p.

Orth, R.J., S.R. Marion, K.A. Moore, and D.J. Wilcox. 2009. Eelgrass (Zostera marina L.) in the Chesapeake Bay Region of Mid-Atlantic Coast of the USA: Challenges in Conservation and Restoration. Estuaries and Coasts 33(1): 139-150.

Patrick, C., D. Weller, X. Li, and M. Ryder. 2014. Effects of Shoreline Alteration and Other Stressors on Submerged Aquatic Vegetation in Subestuaries of Chesapeake Bay and the Mid-Atlantic Coastal Bays. Estuaries and Coasts 37(6): 1516-1531.

Patterson, K. 1992. Fisheries for small pelagic species: an empirical approach to management targets. Reviews in Fish Biology and Fisheries 2(4): 321–338.

Peterson, M.S., B.H. Comyns, J.R. Hendon, P.J. Bond, and G.A. Duff. 2000. Habitat use by early life-history stages of fishes and crustaceans along a changing estuarine landscape: differences between natural and altered shoreline sites. Wetlands Ecology and Management 8(2-3): 209-219.

Peterson, M.S., and M.R. Lowe. 2009. Implications of Cumulative Impacts to Estuarine and Marine Habitat Quality for Fish and Invertebrate Resources. Reviews in Fisheries Science 17(4): 505-523.

Pikitch, E., P.D. Boersma, I.L. Boyd, D.O. Conover, P. Cury, T. Essington, S.S. Heppell, E.D. Houde, M. Mangel, D. Pauly, É. Plagányi, K. Sainsbury, and R.S. Steneck. 2012. Little fish, big impact: Managing a crucial link in ocean food webs. Lenfest Ocean Program, Washington, DC, 108 p.

Pothoven, S.A., and G.L. Fahnenstiel. 2014. Declines in the energy content of yearling non-native alewife associated with lower food web changes in Lake Michigan. Fisheries Management and Ecology 21(6): 439-447.

Pyke, C.R., R.G. Najjar, M.B. Adams, D. Breitburg, M. Kemp, C. Hershner, R. Howarth, M. Mulholland, M. Paolisso, D. Secor, K. Sellner, D. Wardrop, and R. Wood. 2008. Climate change and the Chesapeake Bay: State-of-the-science review and recommendations. A Report from the Chesapeake Bay Program Science and Technical Advisory Committee (STAC). Science and Technical Advisory Committee, Annapolis, MD, 59 p.

Rice, J.C., and M.J. Rochet. 2005. A framework for selecting a suite of indicators for fisheries management. ICES Journal of Marine Science: Journal du Conseil 62(3): 516-527.

Sainsbury, K.J., A.E. Punt, and A.D.M. Smith. 2000. Design of operational management strategies for achieving fishery ecosystem objectives. ICES Journal of Marine Science: Journal du Conseil 57(3): 731-741.

SEDAR. 2015. SEDAR 40 – Atlantic Menhaden Stock Assessment Report. SEDAR, http://www.sefsc.noaa.gov/sedar/Sedar_Workshops.jsp?WorkshopNum=40. Charleston, 643 p.

Seitz, R.D., R.N. Lipcius, N.H. Olmstead, M.S. Seebo, and D.M. Lambert. 2006. Influence of shallow-water habitats and shoreline development on abundance, biomass, and diversity of benthic prey and predators in Chesapeake Bay. Marine Ecology Progress Series 326: 11-27.

Smith, A.D., C.J. Brown, C.M. Bulman, E.A. Fulton, P. Johnson, I.C. Kaplan, H. Lozano-Montes, S. Mackinson, M. Marzloff, L.J. Shannon, Y.J. Shin, and J. Tam. 2011. Impacts of fishing low-trophic level species on marine ecosystems. Science 333(6046): 1147-50.

Smith, J. W. 1999. Distribution of Atlantic menhaden, *Brevoortia tyrannus*, purse-seine sets and catches from southern New England to North Carolina, 1985-96. NOAA Technical Report NMFS 144. 22 p.

Sturdivant, S.K., R. Díaz, R. Llansó, and D. Dauer. 2014. Relationship between Hypoxia and Macrobenthic Production in Chesapeake Bay. Estuaries and Coasts 37(5): 1219-1232.

Titus, J.G., D.E. Hudgens, D.L. Trescott, M. Craghan, W.H. Nuckols, C.H. Hershner, J.M. Kassakian, C.J. Linn, P.G. Merritt, T.M. McCue, J.F. O'Connell, J. Tanski, and J. Wang. 2009. State and local governments plan for development of most land vulnerable to rising sea level along the US Atlantic coast. Environmental Research Letters 4(4): 044008.

Weisberg, S. B., J.A. Ranasinghe, D.M. Dauer, L.C. Schaffner, R.J. Diaz, and J.B. Frithsen. 1997. An estuarine benthic index of biotic integrity (B-IBI) for the Chesapeake Bay. Estuaries 20: 149-158.

Williams, B., D.F. Brinker, B.D. Watts. 2007. The status of colonial nesting wading bird populations within the Chesapeake Bay and Atlantic barrier island-lagoon system. Waterbirds 30: 82-92.

Wuenschel, M.J., A.R. Jugovich, and J.A. Hare. 2006. Estimating the Energy Density of Fish: The Importance of Ontogeny. Transactions of the American Fisheries Society 135(2): 379-385.

Zhou, S., S. Yin, James T. Thorson, Anthony D.M. Smith, and M. Fuller. 2012. Linking fishing mortality reference points to life history traits: an empirical study. Canadian Journal of Fisheries and Aquatic Sciences 69(8): 1292-1301.

Appendix A: Workshop Participants

The steering committee assembled for this workshop (*denotes co-chair of workshop) ranged across jurisdictions and disciplines and included species experts, researchers, modelers, managers, and data experts. Steering committee members and invited workshop participants are listed (alphabetically) below, along with their institutional affiliation and their expertise as it pertains to this workshop. Lists are separated to denote each participant's primary role as either 'manager' or 'scientist'.

Steering Committee

<u>Managers:</u>

Nancy Butowski – Program Manager of Fishery Management Plans and Fish Passage at Maryland Department of Natural Resources (MDDNR); extensive knowledge and support of SFGIT work

Pat Campfield – Director of the Fisheries Science Program at the Atlantic States Marine Fisheries Commission (ASMFC) and SFGIT member; knowledge of Chesapeake Bay fisheries science needs and application of science to management

Jack Frye – Virginia Director of the Chesapeake Bay Commission (CBC) leading policy development and legislative outreach and SFGIT member; experience in conservation, recreation, and nutrient reduction

Joe Grist – Deputy Chief of the Fisheries Management Division of the Virginia Marine Resource Commission (VMRC); Chair of the Chesapeake Bay Stock Assessment Committee and applying science to management

Bill Goldsborough – Fisheries Director for the Chesapeake Bay Foundation (CBF) and SFGIT member; extensive background in policy and regional fisheries management

Earl Meredith – Manager, National Oceanic and Atmospheric Administration (NOAA) Chesapeake Bay Office's Ecosystem Science and Synthesis, Coordinator of the NOAA Fisheries' Cooperative Fisheries Program

Bruce Vogt – National Oceanic and Atmospheric Administration (NOAA) Chesapeake Bay Office's Ecosystem Science and Synthesis Manager, Coordinator for the SFGIT; background in benthic ecology and resource management

<u>Scientists:</u>

Chris Bonzek – Fisheries Data Analyst at the Virginia Institute of Marine Science (VIMS); extensive knowledge of the various Virginia and coastal surveys and leader of VIMS diet laboratory

Ed Houde* – Fisheries Scientist at University of Maryland - Chesapeake Biological Laboratory (UMCES-CBL); extensive expertise in fisheries oceanography, recruitment, population dynamics, ecosystem management, and a member of the Lenfest Forage Fish Task Force

Tom Ihde* – STAC Member, fisheries ecosystem modeler; background in fisheries stock assessment

Lee Karrh – Chief of Living Resource Assessment Division at MDDNR, former Chair of Chesapeake Bay Program's SAV Workgroup, and Habitat GIT member; background in biology

Rochelle Seitz – Runs the Community Ecology Laboratory at VIMS focused on benthic ecology; current research includes benthic predator-prey relationships and food web dynamics

Meeting Facilitator:

Alexander Wiker – Stakeholder Assessment, Sustainability Institute, Dickinson School of Law, Pennsylvania State University

NOAA Chesapeake Bay Office (NCBO) Staff:

Emilie Franke – Chesapeake Research Consortium, SFGIT Staffer; lead author and coordinator for the Literature Review (Appendix C) and Database Inventory (Appendix D)

Andrew Turner – SFGIT support at NCBO

STAC Staff:

Natalie Gardner – Chesapeake Research Consortium, STAC Coordinator, lead for all logistics of the workshop

Matthew Ellis – Chesapeake Research Consortium, STAC staff

Invited Workshop Participants

Invited participants comprised a relatively small group of individuals targeted for their previous system-level work, rather than any previous focus on any one particular species of the Bay, since the original workshop focus was to improve our understanding of the critical forage for the Chesapeake system to function.

Managers:

Yvone deReynier – NOAA; integral in development of the forage Fishery Ecosystem Plan for the Pacific Fisheries Management Council; experience with Ecosystem Based Fisheries Management (EBFM) issues in the Pacific Council; management/policy perspective

Lynn Fegley – Deputy Director, MDDNR Fisheries Service; benthic ecology

Martin Gary – Executive Secretary of the Potomac River Fisheries Commission (PRFC)

Robert O'Reilly – Chief of Fisheries Management for VMRC (Virginia Marine Resources Commission)

Deb Wilson-Vandenberg – PFMC; integral in development of the forage FEP for the Pacific Fisheries Management Council; experience with EBFM issues in the Pacific Council; management/policy perspective

Scientists:

Donna Bilkovic – VIMS; salt marsh expertise and habitat trends in the face of climate change

Denise Breitburg – SERC (Smithsonian Environmental Research Center); trophic ecology in shallow regions of Chesapeake Bay

Andre Buchheister – UMCES; structure, drivers & trophic interactions of demersal fish community in Chesapeake Bay (ChesMMAP data)

Daniel Day – USGS; resource utilization by avian species residing or over-wintering on the Chesapeake Bay

Sarah Gaichas – NOAA; fisheries ecology, forage, EBFM approaches, food web modeling

Thomas Miller – UMCES-CBL; Chesapeake Bay ecology; blue crab; juvenile fishes (CHESFIMS data)

Genny Nesslage – ASMFC, leads ASMFC analysis of multispecies models; predator-prey relationships for select forage species

Diann Prosser – USGS; avian diet analysis in the Chesapeake region

Howard Townsend – NOAA; expertise in ecosystem modeling; current member of the ASMFC multispecies modeling group, concerned with the development of quantitative biological ecosystem reference points

Jim Uphoff – MDDNR; fisheries biologist, stock assessment coordinator

Mike Wilberg – UMCES-CBL; fisheries stock assessment and population dynamics

Appendix B: Workshop Agenda

Assessing the Chesapeake Bay Forage Base:
Existing Data and Research Priorities
Scientific and Technical Advisory Committee Workshop
November 12-13th, 2014
Chesapeake Biological Lab, Solomons, MD

Workshop Goals: *Identify (1) forage groups of the Chesapeake Bay that are critical to assess for fisheries management; (2) existing data for these groups; (3) data gaps; and (4) strategies to improve the quantification of the forage base of this system. These strategies will both provide guidance in understanding and using current forage data, and allow for future integration of new research findings and enhanced approaches.*

Wednesday, November 12th

9:00 am **Light breakfast**

9:30 am **Welcome – Tom Miller (UMCES), Tom Ihde (NOAA), and Ed Houde (UMCES)**
- Introductions
- Review workshop agenda and objectives
- Facilitator introduction and ground rules
    - Alex Wiker – Pennsylvania State University, Sustainability Institute

9:45 am **Fisheries Management Panel**
- MD, VA, and PRFC managers will briefly discuss current efforts to manage, monitor, and protect forage species (5 min each)
- Panel questions for each: What is important to your jurisdictions concerning forage? What do you hope to get out of this workshop?
- Questions from workshop participants

Workshop Theme I: Chesapeake Bay Forage Base and Managed Predators

Outcomes: *Highlight pre-workshop products. Common understanding of the diets of managed predators and of the data currently available for Chesapeake Bay forage species.*

Product: *An organized list of Chesapeake Bay forage species/species groups to be considered throughout the workshop.*

10:15 am **Overview of Theme I**

10:20 am **What is considered "forage"? What managed predators do forage species support? – Chris Bonzek (VIMS) and Tom Ihde (NOAA)**

- Results of fish predator diet analyses based on fishery-independent survey data in the Chesapeake Bay
- Initial list of Chesapeake Bay forage species based on importance in fish predator diets

10:50 am **Full group discussion – List of forage species to focus the workshop**

- New insights and questions from workshop participants
- What are we missing from the list?
- List, categorize, and prioritize species

11:05 am **Data Review and Literature Review – Emilie Franke (Chesapeake Research Consortium)**

- 20 min. each for literature and data review
- Review of pre-workshop products and state of knowledge

11:45 am **Wrap-Up up discussion/questions**

12:00 pm **Lunch (provided)**

Workshop Theme II: Limiting Factors for Forage Species

<u>Outcome:</u> *Identification and understanding of the most significant stressors for forage species in the Chesapeake Bay.*

<u>Product:</u> *Organized and prioritized list of limiting factors and proposed actions or monitoring recommendations.*

12:30 pm **Overview of Theme II**

12:40 pm **Primary factors identified, current knowledge discussed (short presentations, 15 min each)**

- Habitat and Climate Change– Donna Bilkovic (VIMS)
- Land use/water quality/multiple stressors– Rochelle Seitz (VIMS) and Denise Breitburg (SERC)
- Seabird predation and trends – Diann Prosser (USGS)
- Harvest – Ed Houde (UMCES)

1:40 pm **Breakout groups**

- What are the most important limiting factors to consider?
- Proposed research or actions to address limiting factors?

2:40 pm **Full group discussion – Discuss research or management recommendations from breakout groups**

3:20 pm **Break (refreshments provided)**

Workshop Theme III: Forage Metric/Indicator Development

<u>Outcome/Product:</u> Proposed metrics to track the status of forage species in the Bay and strategies to develop those using currently available data.

<u>Chesapeake Bay Watershed Agreement Forage Outcome:</u>
"*By 2016, develop a strategy for assessing the forage fish base available as food for predatory species in the Chesapeake Bay.*"

3:40 pm **Overview of Theme III**

3:50 pm **Forage issues into management - tracking status, accounting for external forcings, and recognizing unknowns (15 min each):**
- North Atlantic – Sarah Gaichas (NOAA)
- Pacific Ecosystem – Yvonne deReynier (NOAA)
- Atlantic States Marine Fisheries Commission – Genny Nesslage (ASMFC)

4:35 pm **Chesapeake Bay metric/indicator needs – Mike Wilberg (UMCES)**
- Introduction of example indicators and/or approaches for Chesapeake Bay species

4:45 pm **Breakout groups**
- Proposals for Chesapeake Bay forage metrics/indicators
- Unique focus for each breakout group

5:30 pm **Recess**

<u>Thursday, November 13th</u>

8:00 am **Breakfast (provided)**

Workshop Theme III Continued: Forage Metric/Indicator Development

8:30 am **Breakout groups resume – Proposals for Chesapeake Bay forage metrics/indicators**
- Continue discussion (30 min) and summarize group ideas (10 min)

9:10 am **Full group discussion – Forage metric/indicators**
- Product: list of proposed metrics/indicators

10:10 am **Break (refreshments provided)**

Workshop Theme IV: Research Needs and Management Recommendations

<u>*Outcome/Product:*</u> *Prioritized list of research needs and management recommendations, including near-term actions to begin addressing the highest priority needs.*

10:25 am **Overview of Theme IV - Tom Ihde (Versar/NOAA) and Ed Houde (UMCES)**

- Summary of research needs, data gaps, and management recommendations that have been identified up to this point during the workshop

10:35 am **Breakout groups**

- Add to list of research needs - what has been missed so far?
- Prioritize research needs

11:15 am **Full group discussion – Prioritize research needs**

- Have we made progress on any of these needs already?
- Highest priority next steps?

12:00 pm **Lunch (provided)**

12:40 pm **Forage Management Needs**

- MD, VA, and PRFC fishery managers will briefly reflect on the workshop discussions and identify workshop outcomes that could address their jurisdictions' needs moving forward (10 min for each jurisdiction)
- Questions/comments from workshop participants

1:25 pm **Full group discussion – Refining prioritized management needs and actions**

- Refine indicator proposals and research & management recommendations for workshop report

2:00 pm **Break (refreshments provided)**

Workshop Wrap-Up

2:15 pm **What have we learned? What do we recommend? Planning for the near-term? Long-term?**

4:00 pm **Workshop Adjourns**

4:00-4:30 pm **Steering Committee Wrap-Up**

- Assign roles and commitments to compile notes for final report
- Report and summary for full Fisheries-GIT meeting in December

Appendix C: Collection of Literature on Chesapeake Bay Forage Species

Purpose:
This appendix compiles relevant literature and academic research on Chesapeake Bay forage species including: predator-prey dynamics; forage production; impacts of environmental factors; and research and theory on how ecosystem-based fisheries management (EBFM) could incorporate these aspects of the forage base. Relevant literature from outside the Chesapeake Bay region investigating predator-prey dynamics and EBFM are also included as valuable examples.

The workshop steering committee and supporting staff researched and submitted literature sources for inclusion in this collection. Workshop participants submitted additional literature sources for inclusion in this document during and after the workshop.

Introduction:
This document organizes relevant literature sources by major topic and provides a short summary for each topic area:

Some sources are stated in multiple categories. If a source is repeated under another heading, the source entry is followed by a reference number(s) indicating where the repeated entries are found; for example ***(I.A.3, III.B.5)*** indicates the entry is repeated in "Predator-Prey Interactions," section A, and is the 3rd entry" *and* again under "Forage Production, section B, and is the 5th entry".

I. Predator-Prey Interactions

A. *Modeling Approaches*

Various modeling approaches have been applied both to the Chesapeake Bay ecosystem and larger regional areas to evaluate predator-prey relationships between forage species and their predators. Most work in the Chesapeake Bay, including bioenergetics and population models, has focused on menhaden as the primary prey item with Striped Bass, Weakfish, and Bluefish as the major predators. Efforts in other coastal ecosystems have focused on how the forage base as a whole supports predators or species of interest.

Chesapeake Bay:

1. Baird, D. and R.E. Ulanowicz. 1989. The seasonal dynamics of the Chesapeake Bay ecosystem. Ecological Monographs 59(4): 329-364.

2. Christensen, V., A. Beattie, C. Buchanan, S. Martell, R.J. Latour, D. Preikshot, J.H. Uphoff, C.J. Walters, R.J. Wood, and H.M. Townsend. 2009. Fisheries ecosystem model of the Chesapeake Bay: methodology, parameterization and model exploration. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-F/SPO-106, 146 p.

3. Hartman, K.J. and S.B. Brandt. 1995a. Comparative energetics and the development of bioenergetics models for sympatric estuarine piscivores. Canadian Journal of Fisheries and Aquatic Sciences 52(8): 1647-1666.

4. Hartman, K.J. and S.B. Brandt. 1995b. Predatory demand and impact of striped bass, bluefish, and weakfish in the Chesapeake Bay: applications of bioenergetics models. Canadian Journal of Fishes and Aquatic Science 52(8): 1667-1687.

5. Sellner, K.G., N. Fisher, C.H. Hager, J.F. Walter and R.J. Latour. 2001. Ecopath with Ecosim Workshop, Patuxent Wildlife Center, October 22-24, 2001, Chesapeake Research Consortium, Edgewater, MD.

Other regions:

6. Garrison, L.P., J.S. Link, D.P. Kilduff, M.D. Cieri, B. Muffley, D.S. Vaughan, A. Sharov, B. Mahmoudi, and R.J. Latour. 2010. An expansion of the MSVPA approach for quantifying predator–prey interactions in exploited fish communities. ICES Journal of Marine Science 67(5): 856-870.

7. Link, J., C. Griswold, E. Methratta, and J. Gunnard (eds.). 2006. Documentation of the Energy Modeling and Analysis eXercise (EMAX). US Dep. Commerce, Northeast Fish. Sci. Cent. Ref. Doc. 06-15, Woods Hole, MA.

8. Link, J., W. Overholtz, J. O'Reilly, J. Green, D. Dow, D. Palka, C. Legault, J. Vitaliano, V. Guida, M. Fogarty, J. Brodziak, L. Methratta, W. Stockhausen, L. Col, and C. Griswold. 2008. The Northeast U.S. continental shelf Energy Modeling and Analysis exercise (EMAX): Ecological network model development and basic ecosystem metrics. Journal of Marine Systems 74: 453-474.

9. Luo, J., J.S. Ault, D.B. Olson, A. McCrea, K.J. Hartman, L. Kline, G. White, and P. Kilduff. 2005. A Spatial Ecosystem Model for Atlantic Coast Multispecies Fisheries Assessments of Menhaden and Bluefish. ASMFC.

10. Okey, T.A., A.M. Cisneros-Montemayor, R. Pugliese, and U.R. Sumaila. 2014. Exploring the Trophodynamic Signatures of Forage Species in the U.S. South Atlantic Bight Ecosystem to Maximize System-Wide Values. Fisheries Centre, University of British Columbia.

11. Tyrrell, M.C., J.S. Link, and H. Moustahfid. 2011. The importance of including predation in fish population models: Implications for biological reference points. Fisheries Research 108(1): 1-8.

B. *Trophic Dynamics of Multiple Predators and Prey*

Investigations of the trophic structures of the Chesapeake Bay and other estuarine environments have explored the differences in diet among major predators and the energy transfer up the food chain as well as the energy profitability of different prey items. Research has also studied the trophic guild structure of predators in the Bay and how they can be categorized by diet content, prey size, and habitat.

Chesapeake Bay:

1. Buchheister, A. 2013. Structure, Drivers, and Trophic Interactions of the Demersal Fish Community in Chesapeake Bay. College of William and Mary, Doctor of Philosophy Dissertation.

2. Buchheister, A. and R. Latour. 2015. Diets and trophic guild structure of a diverse fish assemblage in Chesapeake Bay, USA. Journal of Fish Biology 86(3): 967-992. doi :10.1111/jfb.12621

3. Hartman, K.J., and S.B. Brandt. 1995c. Trophic Resource Partitioning, Diets, and Growth of Sympatric Estuarine Predators. Transactions of the American Fisheries Society 124(4): 520-537.

4. Engelhard, G.H., M.A. Peck, A. Rindorf, S.C. Smout, M. van Deurs, K. Raab, K.H. Andersen, S. Garthe, R.A.M. Lauerburg, F. Scott, T. Brunel, G. Aarts, T. van Kooten, and M. Dickey-Collas. 2014. Forage fish, their fisheries, and their predators: who drives whom? ICES Journal of Marine Science 71: 90-104. ***(VI.11)***

5. Monaco, M.E. and R.E. Ulanowicz. 1997. Comparative ecosystem trophic structure of three U.S. mid-Atlantic estuaries. Marine Ecology Progress Series 161: 239-254.

6. Woodland, R.J. and D.H. Secor. 2011. Difference in juvenile trophic niche for two coastal fish species that use marine and estuarine nursery habitats. Marine Ecology Progress Series 439: 241-254. ***(II.20, III.18)***

Other regions:

7. Garrison, L.P. and J.S. Link. 2000. Dietary guild structure of the fish community in the Northeast United States continental shelf ecosystem. Marine Ecology Progress Series 202: 231-240.

8. Link, J.S. and F.P. Almeida. 2000. An Overview and History of the Food Web Dynamics Program of the Northeast Fisheries Science Center, Woods Hole, Massachusetts. Page 60. US Dep Commerce, NOAA Tech Memo NMFS NE 159.

9. Marancik, K.E. and J.A. Hare. 2007. Large scale patterns in fish trophodynamics of estuarine and shelf habitats of the southeast United States. Bulletin of Marine Science 80(1): 67-91.

10. Overholtz, W.J. and J.S. Link. 2007. Consumption impacts by marine mammals, fish, and seabirds on the Gulf of Maine–Georges Bank Atlantic herring (*Clupea harengus*) complex during the years 1977–2002. ICES Journal of Marine Science 64: 83-96.

11. Persson, A. and C. Bronmark. 2002. Foraging capacity and resource synchronization in an ontogenetic diet switcher, pikeperch (*Stizotedion lucioperca*). Ecology 83: 3014-3022.

12. Persson, L., A.V. Leeuwen, and A.M. DeRoos. 2014. The ecological foundation for ecosystem-based management of fisheries: mechanistic linkages between the individual-, population-, and community-level dynamics. ICES Journal of Marine Science 71(8): 2268-2280. ***(VI.18)***

13. Pethybridge, H., N. Bodin, E.J. Arsenault-Pernet, J.H. Bourdeix, B. Brisset, J.L. Bigot, D. Roos, and M. Peter. 2014. Temporal and inter-specific variations in forage fish feeding conditions in the NW Mediterranean: lipid content and fatty acid compositional changes. Marine Ecology Progress Series 512: 39-54. ***(III.4)***

14. Scharf, F.S., J.A. Buckel, P.A. McGinn, and F. Juanes. 2003. Vulnerability of marine forage fishes to piscivory: effects of prey behavior on susceptibility to attack and capture. Journal of Experimental Marine Biology and Ecology 294(1): 41-59.

15. Smith, B. and J. Link. 2010. The Trophic Dynamics of 50 Finfish and 2 Squid Species on the Northeast US Continental Shelf. NOAA Technical Memorandum NMFS NE 216 Page 640. National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543-1026.

16. Wuenschel, M.J., K.W. Able, J.M. Vasslides, D.M. Byrne. 2013. Habitat and diet overlap of 4 piscivorous fishes: variation on the inner continental shelf off New Jersey. Fisheries Bulletin 111: 352-369.

C. Benthic Community

Environmental stressors and predation effects have been studied in the Chesapeake Bay benthic community. While these data are not as extensive or specific as for predators, the studies emphasize the importance of energy availability and transfer up the food chain from the benthic community.

1. Long, W.C. and R.D. Seitz. 2008. Trophic interactions under stress: hypoxia enhances foraging in an estuarine food web. Marine Ecology Progress Series 362: 59-68.

2. Long, W.C., B.J. Brylawski, and R.D. Seitz. 2008. Behavioral effects of low dissolved oxygen on the bivalve *Macoma balthica*. Journal of Experimental Marine Biology and Ecology 359: 34-39. ***(IV.8)***

3. Orth, R.J., K.L. Heck, and J. van Montfrans. 1984. Faunal communities in seagrass beds: A review of the influence of plant structure and prey characteristics on predator-prey relationships. Estuaries 7(4): 339-350.

4. Posey, M.H. and A.H. Hines. 1991. Complex Predator-Prey Interactions within an Estuarine Benthic Community. Ecology 72(6): 2155-2169.

5. Seitz, R.D. 2011. Gradient effects on structuring of soft-bottom benthic infauna: Macoma balthica and predation, recruitment, and food availability. Journal of Experimental Marine Biology and Ecology 409(1-2): 114-122. ***(III.5)***

II. Predator Diet Studies

There have been extensive efforts in the Chesapeake Bay and Atlantic coastal region to characterize the diets of commercially and recreationally valuable predators. The diet preferences of Striped Bass are some of the most well-known in this region compared to other fish predators, and recent work has begun to develop nutritional reference points for Chesapeake Bay Striped Bass related to Atlantic Menhaden. The importance of forage fish in supporting seabirds is also recognized and highlighted by studies of specific bird species in the Chesapeake Bay. Offshore studies for the Atlantic include diet analyses for sea turtles, marine mammals, and offshore fish species.

<u>*Striped Bass:*</u>

1. Griffin, J.C. and F.J. Margraf. 2003. The diet of Chesapeake Bay Striped Bass in the late 1950s Fisheries Management and Ecology 10: 323-328.

2. Hartman, K.J. 2000a. The influence of size on striped bass foraging. Marine Ecology Progress Series 194: 263-268.

3. Hartman, K.J. 2000b. Variability in daily ration estimates of Age0 striped bass in the Chesapeake Bay. Transactions of the American Fisheries Society 129(5): 1181-1186.

4. Jacobs, J.M., M.R. Rhodes, A. Baya, R. Reimschuessel, H. Townsend, and R.M. Harrell. 2009. Influence of nutritional state on the progression and severity of mycobacteriosis in striped bass *Morone saxatilis*. Diseases of Aquatic Organisms 87: 183-197.

5. Jacobs, J.M., R.M. Harrell, J. Uphoff, H. Townsend, and K. Hartman. 2013. Biological reference points for the nutritional status of Chesapeake Bay striped bass. North American Journal of Fisheries Management 33:3: 468-481.

6. Markle, D.F. and G.C. Grant. 1970. The summer food habits of young-of-the year striped bass in three Virginia rivers. Chesapeake Science 11(1): 50-54.

7. Martino, E.J. and E.D. Houde. 2012. Density-dependent regulation of year-class strength in age-0 juvenile striped bass (*Morone saxatilis*). Canadian Journal of Fisheries and Aquatic Sciences 69(3): 430-446.

8. Maryland Department of Natural Resources Fisheries Service. 2013. Marine and estuarine finfish ecological and habitat investigations job 4: Development of ecosystem-based reference points for recreationally important Chesapeake Bay fishes of special concern: striped bass nutrition and forage availability benchmarks. Performance report for federal aid grant f-63-r, segment 4: 87-109. http://dnr2.maryland.gov/fisheries/Documents/2013_FHEP_Annual_Report.pdf

9. Nemerson, D.M. and K.W. Able. 2003. Spatial and temporal patterns in the distribution and feeding habits of *Morone saxatilis* in marsh creeks of Delaware Bay, USA. Fisheries Management and Ecology 10(5): 337-348.

10. Overton, A.S., C.S. Manooch, III, J.W. Smith, and K. Brennan. 2008. Interactions between adult migratory striped bass (*Morone saxatilis*) and their prey during winter off the Virginia and North Carolina Atlantic coast from 1994 through 2007. Fishery Bulletin 106(2): 174-182.

11. Overton, A.S., F.J. Margraf, and E.B. May. 2009. Spatial and temporal patterns in the diet of striped bass in Chesapeake Bay. Transactions of the American Fisheries Society 138(4): 915-926.

12. Pruell, R.J., B.K. Taplin, and K. Cicchelli. 2003. Stable isotope ratios in archived striped bass scales suggest changes in trophic structure. Fisheries Management and Ecology 10(5): 329-336.

13. Uphoff J.H., Jr. 2003. Predator-prey analysis of striped bass and Atlantic menhaden in upper Chesapeake Bay. Fisheries Management and Ecology 10: 313-322.

14. Walter III, J.F., A.S. Overton, K.H. Ferry, and M.E. Mather. 2003. Atlantic coast feeding habits of striped bass: a synthesis supporting a coast-wide understanding of trophic biology. Fisheries Management and Ecology 10: 349-360.

15. Walter III, J. F., and H.M. Austin. 2003. Diet composition of large striped bass (*Morone saxatilis*) in Chesapeake Bay. Fishery Bulletin 101(2): 414-423.

<u>*Bluefish:*</u>

16. Buckel, J.A., D.O. Conover, N.D. Steinberg, and K.A. McKown. 1999. Impact of age-0 bluefish (*Pomatomus saltatrix*) predation on age-0 fishes in the Hudson River estuary: evidence for density-dependent loss of juvenile striped bass (*Morone saxatilis*). Canadian Journal of Fisheries and Aquatic Sciences 56(2): 275-287.

17. Gartland, J., R.J. Latour, A.D. Halvorson, and H.M. Austin. 2006. Diet Composition of Young-of-the-Year Bluefish in the Lower Chesapeake Bay and the Coastal Ocean of Virginia. Transactions of the American Fisheries Society 135: 371-378.

18. Juanes, F., J.A. Buckel, F.S. Scharf. 2001. Predatory behaviour and selectivity of a primary piscivore: comparison of fish and non-fish prey. Marine Ecology Progress Series 217: 157-165.

19. Scharf, F.S., J.A. Buckel, F. Juanes, and D.O. Conover. 1998. Predation by juvenile piscivorous bluefish (*Pomatomus saltatrix*): the influence of prey to predator size ratio and prey type on predator capture success and prey profitability. Canadian Journal of Fisheries and Aquatic Sciences 55(7): 1695-1703.

20. Woodland, R.J. and D.H. Secor. 2011. Difference in juvenile trophic niche for two coastal fish species that use marine and estuarine nursery habitats. Marine Ecology Progress Series 439: 241-254. ***(I.B.6, III.18)***

<u>*Summer Flounder:*</u>

21. Buchheister, A. and R.J. Latour. 2011. Trophic ecology of summer flounder in lower Chesapeake Bay inferred from stomach content and stable isotope analyses. Transactions of the American Fisheries Society 140: 1240-1254.

22. Latour, R.J., J. Gartland, C.F. Bonzek, and R.A. Johnson. 2008. The trophic dynamics of summer flounder (*Paralichthys dentatus*) in Chesapeake Bay. Fishery Bulletin 106: 47-57.

<u>*Atlantic Croaker:*</u>

23. Nye, J. A., D.A. Loewensteiner, and T.J. Miller. 2011. Annual, seasonal, and regional variability in diet of Atlantic croaker (*Micropogonias undulatus*) in Chesapeake Bay. Estuaries and Coasts 34(4): 691-700.

Blue Crab:

24. Seitz, R.D., K.E. Knick, and M. Westphal. 2011. Diet selectivity of juvenile blue crabs (*Callinectes sapidus*) in Chesapeake Bay. Integrative and Comparative Biology 51(4): 598-607.

Atlantic Sturgeon:

25. Johnson, J.H., D.S. Dropkin, B.E. Warkentine, J.W. Rachlin, and W.D. Andrews. 1997. Food Habits of Atlantic Sturgeon off the Central New Jersey Coast. Transactions of the American Fisheries Society 126: 166-170.

26. Savoy, T. 2007. Prey eaten by Atlantic sturgeon in Connecticut waters. Pages 157-166 *in*: J. Munro, D. Hatin, J.E. Hightower, K. McKown, K.J. Sulak, A.W. Kahnle, and F. Caron (eds.), Anadromous sturgeons: habitats, threats, and management. American Fisheries Society, Symposium 56. American Fisheries Society, Bethesda, MD.

Birds:

27. Aygen, D. 2005. Royal tern (*Sterna maxima*) chick diet on Fisherman Island National Wildlife Refuge, Virginia. University of North Carolina Wilmington. Master of Science Thesis.

28. Barrett, R.T., C.J. Camphuysen, T. Anker-Nilssen, J.W. Chardine, R.W. Furness, S. Garthe, O. Hu¨ppop, M.F. Leopold, W.A. Montevecchi, and R.R. Veit. 2007. Diet studies of seabirds: a review and recommendations. ICES Journal of Marine Science 64(9): 1675-1691.

29. Cury, P.M., I.L. Boyd, S. Bonhommeau, T. Anker-Nilssen, R.J.M. Crawford, R.W. Furness, J.A. Mills, E.J. Murphy, H. Österblom, M. Paleczny, J.F. Piatt, J. Roux, L. Shannon, and W.J. Sydeman. 2011. Global seabird response to forage fish depletion – One-third for the birds. Science 334(6063): 1703-1706.

30. Erwin, R.M. 1996. Dependence of waterbirds and shorebirds on shallow-water habitats in the Mid-Atlantic coastal region: an ecological profile and management recommendations. Estuaries 19: 213-219.

31. Erwin, R.M., B.D. Watts, G.M. Haramis, M.C. Perry, and K.A. Hobson (eds.). 2007. Special Publication 1: Waterbirds of the Chesapeake Bay and Vicinity: Harbingers of Change?. Waterbirds: The International Journal of Waterbird Biology 30. 182p. http://www.jstor.org/stable/i25148269

32. Glass, K.A. and B.D. Watts. 2009. Osprey diet composition and quality in high- and low- salinity areas of lower Chesapeake Bay. Journal of Raptor Research 43(1): 27-36.

33. Hannesson, R. 2013. Strictly for the birds?: On ecosystem services of forage fish. Marine Policy 38: 109-115.

34. Kneib, R.T. 1982. The effects of predation by wading birds (Ardeidae) and blue crabs (*Callinectes sapidus*) on the population size structure of the common mummichog (*Fundulus heteroclitus*). Estuarine, Coastal and Shelf Science 14(2): 159-165.

35. Llansó, R.J., D.E. Strebel, and D.M. Dauer. 2007. Benthic feeding habitats of seaducks in Chesapeake Bay, USA. 22pp. Online: http://www.baybenthos.versar.com/Docs/Seaduck_feeding_habitats.pdf

36. Markham, A.C. and B.D. Watts. 2008. The influence of salinity on the diet of nesting bald eagles. Journal of Raptor Research 42: 99-109.

37. Safina, C. and J. Burger. 1985. Common tern foraging: seasonal trends in prey fish densities and competition with bluefish. Ecology 66(5): 1457-1463.

38. Schneider, D.C. and D.W. Heinemann. 1996. The state of marine bird populations from Cape Hatteras to the Gulf of Maine. Pages 197-216 *in* K. Sherman, N. A. Jaworski, and T. J. Smayda (eds.), The Northeast Shelf Ecosystem: Assessment, Sustainability, and Management. Blackwell Science Cambridge, MA.

39. Viverette, C.B., G.C. Garman, S. McIninch, A.C. Markham, B.D. Watts, and S.A. Macko. 2007. Finfish-waterbird trophic interactions in tidal freshwater tributaries of the Chesapeake Bay. Waterbirds 30: 50-62.

40. Watts, B.D. and B.J. Paxton. 2014. Status and distribution of colonial waterbirds in coastal Virginia: 2013 breeding season. CCBTR-14-03. Center for Conservation Biology, College of William and Mary/Virginia Commonwealth University, Williamsburg, VA 23 pp.

Sea Turtles:

41. Burke, V.T., S.J. Morreale, and E.A. Standora. 1994. Diet of the Kemp's Ridley sea turtle, *Lepidochelys kempii*, in New York waters. Fishery Bulletin 92: 26-32.

42. Burke, V.T., E.A. Standora, and S.J. Morreale. 1993. Diet of Juvenile Kemp's Ridley and Loggerhead Sea Turtles from Long Island, New York. Copeia 1993: 1176-1180.

43. Dodge, K.L., J.M. Logan, and M.E. Lutcavage. 2011. Foraging ecology of leatherback sea turtles in the Western North Atlantic determined through multi-tissue stable isotope analyses. Marine Biology 158: 2813-2824.

44. Montevecchi, W.A., A. Hedd, L. McFarlane Tranquilla, D.A. Fitfield, C.M. Burke, P.M. Regular, G.K. Davoren, S. Garthe, G.J. Robertson and R.A. Phillips. 2012. Tracking seabirds to identify ecologically important and high risk marine areas in the western North Atlantic. Biological Conservation 156: 62-71.

45. Seney, E.E. and J.A. Musick. 2007. Historical Diet Analysis of Loggerhead Sea Turtles (*Caretta caretta*) in Virginia. Copeia 2007: 478-489.

Marine Mammals:

46. Gannon, D.P. and D.M. Waples. 2004. Diets of coastal bottlenose dolphins from the U.S. Mid-Atlantic coast differ by habitat. Marine Mammal Science 20: 527-545.

47. Gavrilchuk, K., V. Lesage, C. Ramp, R. Sears, M. Bérubé, S. Bearhop, and G. Beauplet. 2014. Trophic niche partitioning among sympatric baleen whale species following the collapse of groundfish stocks in the Northwest Atlantic. Marine Ecology Progress Series 497: 285-301.

48. MacNiel, M.A., G.B. Skomal, and A.T. Fisk. 2005. Stable isotopes from multiple tissues reveal diet switching in sharks. Marine Ecology Progress Series 302: 199-206.

49. Smith, L.A., J.S. Link, S.X. Cadrin, and D.L. Palka. 2015. Consumption by marine mammals on the Northeast US continental shelf. Ecological Applications 25: 373-389.

Sharks:

50. Ellis, J.K. and J.A. Musick. 2006. Ontogenetic changes in the diet of the sandbar shark, *Carcharhinus plumbeus*, in lower Chesapeake Bay and Virginia (USA) coastal waters. Environmental Biology of Fishes 80: 51-67.

51. Gelsleichter, J., J.A. Musick, and S. Nichols. 1999. Food habits of the smooth dogfish, *Mustelus canis*, dusky shark, *Charcharhinus obscurus*, Atlantic sharpnose shark, *Rhizoprionodon terraenovae*, and the sand tiger, *Charcharias taurus*, from the northwest Atlantic Ocean. Environmental Biology of Fishes 54: 205-217.

52. Stillwell, C.E. and N.E. Kohler. 1982. Food, feeding habits, and estimates of daily ration of the shortfin mako (*Isurus oxyrinchus*) in the Northwest Atlantic. Canadian Journal of Fisheries and Aquatic Sciences 39: 407-414.

Offshore Fish Species:

53. Logan, J.M., R. Toppin, S. Smith, B. Galuardi, J. Porter, and M. Lutcavage. 2013. Contribution of cephalopod prey to the diet of large pelagic fish predators in the central North Atlantic Ocean. Deep Sea Research Part II: Topical Studies in Oceanography 95: 74-82.

54. Staudinger, M.D., F. Juanes, B. Salmon, and A.K. Teffer. 2013. The distribution, diversity, and importance of cephalopods in top predator diets from offshore habitats of the Northwest Atlantic Ocean. Deep Sea Research Part II: Topical Studies in Oceanography 95: 182-192.

III. Forage Production

Multiple studies have investigated the population dynamics and variability of forage species in the Chesapeake Bay. Seasonal, spatial, and environmental variability in these forage populations as well as availability of their prey influences the movements of the predators that depend on these forage populations. Many studies have focused specifically on Atlantic Menhaden or Bay Anchovy, particularly on recruitment/juveniles as well as the diets of these species.

1. Houde, E.D. and E.S. Rutherford. 1993. Recent Trends in Estuarine Fisheries: Predictions of Fish Production and Yield. Estuaries 16(2): 161-176.

2. Jung, S. and E.D. Houde. 2003. Spatial and temporal variabilities of pelagic fish community structure and distribution in Chesapeake Bay, USA. Estuarine, Coastal and Shelf Science 58(2): 335-351.

3. Llanso, R.J. 2002. Methods for Calculating the Chesapeake Bay Benthic Index of Biotic Integrity. Versar, Inc. Columbia, MD. http://www.baybenthos.versar.com/docs/ChesBayBIBI.PDF

4. Pethybridge, H., N. Bodin, E.J. Arsenault-Pernet, J.H. Bourdeix, B. Brisset, J.L. Bigot, D. Roos, and M. Peter. 2014. Temporal and inter-specific variations in forage fish feeding conditions in the NW Mediterranean: lipid content and fatty acid compositional changes. Marine Ecology Progress Series 512: 39-54. ***(I.B.13)***

5. Seitz, R.D. 2011. Gradient effects on structuring of soft-bottom benthic infauna: *Macoma balthica* and predation, recruitment, and food availability. Journal of Experimental Marine Biology and Ecology 409(1-2): 114-122. ***(I.C.5)***

6. Wood, R.J. and E.D. Houde. 2003. Variability in the dynamics of forage fish abundances in Chesapeake Bay: Retrospective Analysis, Models and Synthesis. University of Maryland Center for Environmental Sciences, Chesapeake Biological Laboratory. 18pp.

<u>*Atlantic Menhaden:*</u>

7. Annis, E.A., E.D. Houde, L.W. Harding, Jr., M.E. Mallonee, and M.J. Wilberg. 2011. Calibration of a bioenergetics model linking primary production to Atlantic menhaden *Brevoortia tyrannus* growth in Chesapeake Bay. Marine Ecology Progress Series 437: 253-267.

8. Humphrey, J., M.J. Wilberg, E.D. Houde and M.C. Fabrizio. 2014. Effects of temperature on age-0 Atlantic menhaden growth in Chesapeake Bay. Transactions of the American Fisheries Society 143: 1255-1265.

9. Jeffries, H.P. 1975. Diets of Juvenile Atlantic Menhaden (*Brevoortia tyrannus*) in Three Estuarine Habitats as Determined from Fatty Acid Composition of Gut Contents. Journal of the Fisheries Research Board of Canada 32(5): 587-592.

10. Lewis, V.P. and D.S. Peters. 1994. Diet of Juvenile and Adult Atlantic Menhaden in Estuarine and Coastal Habitats. Transactions of the American Fisheries Society 123(5): 803-810.

11. Luo, J., K.J. Hartman, S.B. Brandt, C.F. Cerco, and T.H. Rippetoe. 2001. A Spatially-Explicit Approach for Estimating Carrying Capacity: An application for the Atlantic menhaden (*Brevoortia tyrannus*) in Chesapeake Bay. Estuaries 24(4): 545-556.

12. Lynch, P.D. 2007. Feeding ecology of Atlantic menhaden (*Brevoortia tyrannus*) in Chesapeake Bay. The College of William and Mary in Virginia, MSc Thesis.

<u>*Bay Anchovy:*</u>

13. Jung, S. and E.D. Houde. 2004a. Production of bay anchovy *Anchoa mitchilli* in Chesapeake Bay: application of size-based theory. Marine Ecology Progress Series 281: 217-232.

14. Jung, S. and E.D. Houde. 2004b. Recruitment and spawning-stock biomass distribution of bay anchovy (*Anchoa mitchilli*) in Chesapeake Bay. Fishery Bulletin 102(1): 63-77.

15. Luo, J. and S.B. Brandt. 1993. Bay anchovy *Anchoa mitchilli* production and consumption in mid-Chesapeake Bay based on a bioenergetics model and acoustic measures of fish abundance. Marine Ecology Progress Series 98: 223-236.

16. Newberger, T.A. and E.D. Houde. 1995. Population Biology of Bay Anchovy *Anchoa mitchilli* in the Mid-Chesapeake Bay. Marine Ecology Progress Series 116: 25-37.

17. Wang, S. and E.D. Houde. 1995. Distribution, relative abundance, biomass and production of bay anchovy *Anchoa mitchilli* in the Chesapeake Bay. Marine Ecology Progress Series 121: 27-38.

18. Woodland, R.J. and D.H. Secor. 2011. Difference in juvenile trophic niche for two coastal fish species that use marine and estuarine nursery habitats. Marine Ecology Progress Series 439: 241-254. ***(I.B.6, II.20)***

IV. Environmental Impacts on Forage Species (Climate change, water quality, and habitat)

Recent studies in the Chesapeake Bay region have focused on water quality, eutrophication, and climate change impacts on forage species. These impacts as well as others are effecting forage production and leading to loss of important habitat required to support forage populations, especially as nursery areas in the Chesapeake Bay. Specific studies focus on water quality impacts on Atlantic Menhaden or Bay Anchovy and specific habitat analyses focus on the managed American Shad.

Species-specific:

1. Adamack, A.T. 2007. Predicting Water Quality Effects on Bay Anchovy (*Anchoa mitchilli*) Growth and Production in Chesapeake Bay: Linking Water Quality and Individual-Based Fish Models. Louisiana State University, Doctor of Philosophy Thesis.

2. Bilkovic, D.M., C.H. Hershner, and J.E. Olney. 2002. Macroscale assessment of American shad spawning and nursery habitats in the Mattaponi and Pamunkey rivers. North American Journal of Fisheries Management 22(4): 1176-1192.

3. Bilkovic, D.M., J.E. Olney, and C.H. Hershner. 2002. Spawning of American shad (*Alosa sapidissima*) and striped bass (*Morone saxatilis*) in the Mattaponi and Pamunkey Rivers, Virginia. Fishery Bulletin 100(3): 632-640.

4. Capossela, K.M. 2013. Maryland's American Shad Habitat Plan. ASMFC.

5. Dalyander, P.S. and C.F. Crecco. 2010. Integration of a fish bioenergetics model into a spatially explicit water quality model: Application to menhaden in Chesapeake Bay. Ecological Modelling 221: 1922-1933.

6. District of Columbia Department of the Environment. 2014. District of Columbia American Shad Habitat Plan. ASMFC.

7. Hilton, E.J., J. Cimino, and A. Weaver. 2014. Commonwealth of Virginia American Shad Habitat Plan. ASMFC.

8. Long, W.C., B.J. Brylawski, and R.D. Seitz. 2008. Behavioral effects of low dissolved oxygen on the bivalve *Macoma balthica*. Journal of Experimental Marine Biology and Ecology 359: 34-39. ***(I.C.2)***

9. Long, W.C., R.D. Seitz, B.J. Brylawski, and R.N. Lipcius. 2014. Individual, population, and ecosystem effects of hypoxia on a dominant benthic bivalve in Chesapeake Bay. Ecological Monographs 84: 303-327.

10. Lynch, P., M.J. Brush, E.D. Condon and R.J. Latour. 2010. Net removal of nitrogen through ingestion of phytoplankton by Atlantic menhaden *Brevoortia tyrannus* in Chesapeake Bay. Marine Ecology Progress Series 401: 195-209.

Fish and Benthic Communities:

11. Bilkovic, D.M. 2011. Response of tidal creek fish communities to dredging and coastal development pressures in a shallow water estuary. Estuaries & Coasts 34(1): 129-147.

12. Bilkovic, D.M. and M. Roggero. 2008. Effects of coastal development on nearshore estuarine nekton communities. Marine Ecology Progress Series 358: 27-39.

13. Bilkovic, D.M., M. Roggero, C.H. Hershner, and K. Havens. 2006. Influence of land use on macrobenthic communities in nearshore estuarine habitats. Estuaries and Coasts 29(6B): 1185-1195.

14. Funderburk, S.L., S.J. Jordan, J.A. Mihursky, and D.R. Riley. 1991. Habitat Requirements for Chesapeake Bay Living Resources: Second Edition. EPA Chesapeake Bay Program and Chesapeake Research Consortium.

15. Kemp, W.M., W.R. Boynton, J.E. Adolf, D.F. Boesch, W.C. Boicourt, G. Brush, J.C. Cornwell, T.R. Fisher, P.M. Glibert, J.D. Hagy, L.W. Harding, E.D. Houde, D.G. Kimmel, W.D. Miller, R.I.E. Newell, M.R. Roman, E.M. Smith, and J.C. Stevenson. 2005. Eutrophication of Chesapeake Bay: historical trends and ecological interactions. Marine Ecology Progress Series 303: 1-29.

16. Lawless, A.S. and R.D. Seitz. 2014. Effects of shoreline stabilization and environmental variables on benthic infaunal communities in the Lynnhaven River System of Chesapeake Bay. Journal of Experimental Marine Biology and Ecology 457: 41-50.

17. Long, W.C. and R.D. Seitz. 2009. Hypoxia in Chesapeake Bay Tributaries: Worsening effects on Macrobenthic Community Structure in the York River. Estuaries and Coasts 322: 287-297.

18. Najjar, R.G., C.R. Pyke, M.B. Adams, D. Breitburg, C. Hershner, M. Kemp, R. Howarth, M. Mulholland, M. Paolisso, D. Secor, K. Sellner, D. Wardrop, and R. Wood. 2010. Potential climate-change impacts on the Chesapeake Bay. Estuarine, Coastal and Shelf Science 86(1): 1-20.

19. Pyke, C.R., R.G. Najjar, M.B. Adams, D. Breitburg, M. Kemp, C. Hershner, R. Howarth, M. Mulholland, M. Paolisso, D. Secor, K. Sellner, D. Wardrop, and R. Wood. 2008. Living Resources, Fish and Shellfish Section in Climate Change and the Chesapeake Bay: State-of-the-Science Review and Recommendations. Scientific and Technical Advisory Committee (STAC): 39-45.

20. Sturdivant, S.K., M.J. Brush, and R.J. Diaz. 2014. Modeling the effect of hypoxia on macrobenthos production in the lower Rappahannock River, Chesapeake Bay, USA. PLoS One 8(12): 10.1371/journal.pone.0084140.

21. Sturdivant, S.K., R.D. Seitz, and R.J. Diaz. 2013. Effects of seasonal hypoxia on macrobenthic production and function in the Rappahannock River, Virginia, USA. Marine Ecology Progress Series 490: 53-68.

22. Uphoff, J.H., M. McGinty, R. Lukacovic, J. Mowrer, and B. Pyle. 2011. Impervious Surface, Summer Dissolved Oxygen, and Fish Distribution in Chesapeake Bay Subestuaries: Linking Watershed Development, Habitat Conditions, and Fisheries Management. North American Journal of Fisheries Management 31: 554-566.

V. Harvest and Managed Species

Regional stock assessments and ecosystem efforts in the Atlantic region are working to consider multispecies interactions between managed predators and primary prey species, many of which are not managed. Stock assessment models and ecosystem plans at a regional level for the Mid-Atlantic are investigating regional and species-specific interactions. These reports describe what types of data are used, how they are integrated to describe these species interactions and how these interactions are considered in stock assessments of managed species and/or in discussions of fishing mortality.

1. ASMFC. 2006. 2006 Weakfish Stock Assessment. ASMFC.

2. ASMFC. 2010. Atlantic Croaker 2010 Benchmark Stock Assessment. ASMFC.

3. ASMFC. 2010. Bluefish Assessment Summary. ASMFC.

4. ASMFC. 2011. Atlantic Menhaden Stock Assessment and Review Panel Report. ASMFC, Stock Assessment Report No. 10-02.

5. ASMFC. 2012a. 2012 Atlantic Menhaden Stock Assessment Update. ASMFC.

6. ASMFC. 2012b. River Herring Benchmark Stock Assessment Volumes I and II. ASMFC Stock Assessment Report No. 12-02.

7. ASMFC and NEFSC. 2012. Bluefish 2012 Stock Assessment Update. ASMFC.

8. ASMFC. 2013. Striped Bass Stock Assessment for 2013. ASMFC.

9. ASMFC. 2013. Update of the Striped Bass Stock Assessment using Final 2012 Data. ASMFC.

10. Barange, M., M. Bernal, M.C. Cergole, L.A. Cubillos, G.M. Daskalov, C.L. de Moor (formerly Cunningham), J.A.A. De Oliveira, M. Dickey-Collas, D.J. Gaughan, K. Hill, L.D. Jacobson, F.W. Köster, J. Massé, M. Ñiquen, H. Nishida, Y. Oozeki, I. Palomera, S.A. Saccardo, A. Santojanni, R. Serra, S. Somarakis, Y. Stratoudakis, A. Uriarte, C.D. van der Lingen, and A. Yatsu. 2009. Current trends in the assessment and management of stocks. Pages 191-255 *in*: Checkley, D., J. Alheit, Y. Oozeki and C. Roy (eds.), Climate change and small pelagic fish. Cambridge University Press.

11. Bonzek, C.F., J. Gartland, D.J. Gauthier and R.J. Latour. 2015. Data collection and analysis in support of single and multispecies stock assessments in the Mid-Atlantic: Northeast Area Monitoring and Assessment Program Near Shore Trawl Survey (NEAMAP). Award Number: NA14NMF4540004. Annual Data Report to the National Oceanographic and Atmospheric Administration, National Marine Fisheries Service - Northeast Fisheries Science Center and the Mid-Atlantic Fishery Management Council. Virginia Institute of Marine Science, Gloucester Point, VA. 329 p.

12. Bonzek, C.F., J. Gartland, D.J. Gauthier, and R.J. Latour. 2014. Data collection and analysis in support of single and multispecies stock assessments in Chesapeake Bay: The Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP). Project # F-130-R-7. Annual Progress Report to the Virginia Marine Resources Commission, and the United States Fish and Wildlife Service. Virginia Institute of Marine Science, Gloucester Point, VA. 171 p.

13. Houde, E., S. Gaichas, and R. Seagraves. 2014. Managing Forage Fishes in the Mid-Atlantic Region: A White Paper to Inform the Mid-Atlantic Fisheries Management Council. Mid-Atlantic Fisheries Management Council.

14. NEFSC. 2006. Stock Assessment Report Part B: Expanded Multispecies Virtual Population Analysis (MSVPA-X) Stock Assessment Model. US Department of Commerce, NOAA.

15. NEFSC. 2009. 48th Northeast Regional Stock Assessment Workshop: Assessment Summary Report-Weakfish. US Department of Commerce, NOAA.

16. Patterson, K. 1992. Fisheries for small pelagic species: an empirical approach to management targets. Reviews in Fish Biology and Fisheries 2: 321-338.

17. Terceiro, M. and NEFSC, 2011. Stock Assessment of Summer Flounder for 2011. US Dept. of Commerce, NOAA.

VI. Ecosystem-based Fisheries Management

There have been many synthesis documents developed discussing the importance of considering forage in ecosystem-based management approaches both within the Chesapeake Bay and in other regions. A majority of the publications begin by defining "forage" and then describing the economic value of these forage species, both from direct harvest and their support as prey for predator species. The Chesapeake Bay-specific publications have focused on ecosystem issues surrounding specific species. The general reports provide recommendations for incorporating forage species into ecosystem planning for multiple regions and/or take a comprehensive look at the role of forage in the ecosystem.

<u>*Chesapeake Bay:*</u>

1. Bonzek, C., E. Houde, S. Giordano, R. Latour, T. Miller, and K.G. Sellner. 2007. Baywide & Coordinated Chesapeake Fish Stock Monitoring. Chesapeake Research Consortium Publication 07-163. Edgewater, MD. 70 p.

2. Chesapeake Fisheries Ecosystem Plan Technical Advisory Panel, with support of the NOAA Chesapeake Bay Office. 2006. Fisheries ecosystem planning for the Chesapeake Bay. American Fisheries Society, Trends in Fisheries Science and Management Report 3. Bethesda, MD.

3. EBFM Alosine Species Team. 2009. Ecosystem-Based Fisheries Management for the Chesapeake Bay: Alosine Background and Issue Briefs. Maryland Sea Grant.

4. EBFM Menhaden Species Team. 2009. Ecosystem-Based Fisheries Management for the Chesapeake Bay: Menhaden Background and Issue Briefs. Maryland Sea Grant.

5. EBFM Striped Bass Species Team. 2009. Ecosystem-Based Fisheries Management for the Chesapeake Bay: Striped Bass Background and Issue Briefs. Maryland Sea Grant.

6. Latour, R.J., M.J. Brush, and C.F. Bonzek. 2003. Toward ecosystem-based fisheries management: Strategies for multispecies modeling and associated data requirements. Fisheries 28(9): 10-22.

<u>*General:*</u>

7. Bigford, T.E. 2014. Forage species and issues. Fisheries 39(8): 340.

8. Beverton, R.J.H. 1990. Small marine pelagic fish and the threat of fishing; are they endangered? Journal of Fish Biology 37(Supplement A): 5-16.

9. Brodziak, J. and J. Link. 2002. Ecosystem-based fishery management: What is it and how can we do it? Bulletin of Marine Science 70(2): 589-611.

10. Dickey-Collas, M., G. H. Engelhard, A. Rindorf, K. Raab, S. Smout, G. Aarts, M. van Deurs, T. Brunel, A. Hoff, R.A.M. Lauerburg, S. Garthe, K. Haste Andersen, F. Scott, T. van Kooten, D. Beare, and M. A. Peck. 2014. Ecosystem-based management objectives for the North Sea: riding the forage fish rollercoaster. ICSES Journal of Marine Science 71(1): 128-142.

11. Engelhard, G.H., M.A. Peck, A. Rindorf, S.C. Smout, M. van Deurs, K. Raab, K.H. Andersen, S. Garthe, R.A.M. Lauerburg, F. Scott, T. Brunel, G. Aarts, T. van Kooten, and M. Dickey-Collas.. 2014. Forage fish, their fisheries, and their predators: who drives whom? ICES Journal of Marine Science 71: 90-104. ***(I.B.4)***

12. Essington, T.E., and A.E. Punt. 2011. Implementing ecosystem-based fisheries management: advances, challenges and emerging tools. Fish and Fisheries 12(2): 123-124.

13. Essington, T.E., P.E. Moriarty, H.E. Froehlich, E.E. Hodgson, L.E. Koehn, K.L. Oken, M.C. Siple, and C.C. Stawitz. 2015. Fishing amplifies forage fish population collapse. PNAS 112(21): 6648-6652.

14. FAO. 2003. Fisheries Management – 2. The ecosystem approach to fisheries. FAO Technical Guidelines for Responsible Fisheries. Food and Agriculture Organization of the United Nations. Rome. http://www.fao.org/docrep/005/Y4470E/Y4470E00.HTM

15. Link, J.S. 2010. Ecosystem-based fisheries management: confronting tradeoffs. Cambridge University Press, New York. 207 pp.

16. Hall, S.J. and B. Mainprize. 2004. Towards ecosystem-based fisheries management. Fish and Fisheries 5(1): 1-20.

17. Peck, M.A., S. Neuenfeldt, T.E. Essington, V.M. Trenkel, A. Takasuka, H. Gislason, M. Dickey-Collas, K.H. Andersen, L. Ravn-Jonsen, N. Vestergaard, S.F. Kvamsdal, A. Gardmark, J. Link, and J.C. Rice. 2014. Forage Fish Interactions: a symposium on "Creating the tools for ecosystem-based management of marine resources. ICES Journal of Marine Science 71(1): 1-4.

18. Persson, L., A.V. Leeuwen, and A.M. DeRoos. 2014. The ecological foundation for ecosystem-based management of fisheries: mechanistic linkages between the individual-, population-, and community-level dynamics. ICES Journal of Marine Science 71(8): 2268-2280. ***(I.B.12)***

19. Pikitch, E.K., C. Santora, E.A. Babcock, A. Bakun, R. Bonfil, D. O. Conover, P. Dayton, P. Doukakis, D. Fluharty, B. Heneman, E.D. Houde, J. Link, P.A. Livingston, M. Mangel, M.K. McAllister, J. Pope, K. J. Sainsbury. 2004. Ecosystem-based fishery management. Science 305(5682): 346-347.

20. Pikitch, E., Boersma, P.D., Boyd, I.L., Conover, D.O., Cury, P., Essington, T., Heppell, S.S., Houde, E.D., Mangel, M., Pauly, D., Plagányi, É., Sainsbury, K., and Steneck, R.S. 2012. Little fish, big impact: Managing a crucial link in ocean food webs. Lenfest Ocean Program. Washington, DC. 108 pp.

21. Rice, J. and D. Duplisea. 2014. Management of fisheries on forage species: the test-bed for ecosystem approaches to fisheries. ICES Journal of Marine Science 71(1): 143-152.

22. Smith, A.D., C.J. Brown, C.M. Bulman, E.A. Fulton, P. Johnson, I.C. Kaplan, H. Lozano-Montes, S. Mackinson, M. Marzloff, L.J. Shannon, Y. Shin, and J. Tam. 2011. Impacts of fishing low-trophic level species on marine ecosystems. Science 333(6046): 1147-50.

23. Zhou, S., S. Yin, J.T. Thorson, A.D.M. Smith, and M. Fuller. 2012. Linking fishing mortality reference points to life history traits: an empirical study. Canadian Journal of Fisheries and Aquatic Sciences 69(8): 1292-1301.

VII. Management Case Studies in other regions

Outside the Mid-Atlantic region, regions including the South Atlantic and Pacific are developing management options and recommendations to manage the forage base as a whole in support of valuable predator species. These plans and management strategies aim to consider the status of the forage base in relation to predators within current management frameworks. The European case studies investigate the use of biological reference points and ecological indicators for forage species in specific regions.

1. Collie, J.S. and H. Gislason. 2001. Biological reference points for fish stocks in a multispecies context. Canadian Journal of Fisheries and Aquatic Sciences 58(11): 2167-2176.

2. Dettmers, J.M., C.I. Goddard, and K.D. Smith. 2012. Management of Alewife Using Pacific Salmon in The Great Lakes: Whether to Manage for Economics or the Ecosystem? Fisheries 37(11): 495-501.

3. Pacific Fishery Management Council. 2014. Ecosystem Initiative 1: Protecting unfished and unmanaged forage fish species. Draft. Pacific Fishery Management Council, Ecosystem Workgroup Report. 107 p.

4. Shephard, S., A. Rindorf, M. Dickey-Collas, N.T. Hintzen, K. Farnsworth, and D.G. Reid. 2014. Assessing the state of pelagic fish communities within an ecosystem approach and the European Marine Strategy Framework Directive. ICES Journal of Marine Science 71(7): 1572-1585.

5. South Atlantic Fishery Management Council. 2009. Fishery ecosystem plan of the South Atlantic region. South Atlantic Fishery Management Council. 46 p.

6. SEDAR. 2015. SEDAR 40 – Atlantic Menhaden Stock Assessment Report, Appendix E. SEDAR, http://www.sefsc.noaa.gov/sedar/Sedar_Workshops.jsp?WorkshopNum=40. Charleston, 643 p.

Appendix D: Available Data on Chesapeake Bay Forage Species

Purpose

The purpose of this appendix is to compile available data sources for forage species in the Chesapeake Bay including data from specific academic studies, regional/state/tributary surveys, and other sources. This document does not provide the actual datasets, but rather a description and summary of application for each data set.

The steering committee and supporting staff researched and submitted data sources for inclusion in this document. Workshop participants submitted additional data sources for inclusion during and after the workshop.

Introduction

This collection includes a summary chart with the title, list of parameters measured, and temporal/spatial coverage for each dataset followed by in-depth descriptions of each dataset, provided courtesy of the data collection organization and/or the data manager. The datasets are divided into three categories and listed alphabetically within each category:

Dataset	Parameters measured	Temporal and Spatial Coverage
I. Diet Data		
Chesapeake Bay Fishery-Independent Multispecies Survey (CHESFIMS) – UMCES CBL, UMD, Maryland DNR	Trawl: - Focus on juvenile, pelagic species - Oceanographic conditions (CTD profile) - Fish catches: species ID, individual length, total or individual weight, subsample of abundant species to estimate catch - Select subsamples: gut content, otolith aging, tissue density	2001-2006 April, July, September sampling 50 sites in Chesapeake Bay mainstem plus additional sites in Patuxent River
Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP) - VIMS	Trawl: - Aggregate weights, counts and individual length for each fish/invertebrate species size class - Species subsample includes length, weight, sex, maturity stage, ageing analysis, and stomach content analysis - Water quality - Atmospheric conditions - Hydrographic conditions - Habitat	2002-present March-November sampling Chesapeake Bay mainstem: 5 regions, each with 80 sites
Chesapeake Bay Trophic Interaction Laboratory Services (CTILS) - VIMS	- Gut content: prey species ID - Length, weight, sex determination - Spatial and habitat diet analyses	2004-2006 Samples from MD, VA, NC
Development of Striped Bass Nutrition and Forage Availability Benchmarks – Maryland DNR	Striped Bass samples from charter boats/gill nets: - Gut content (species, frequency, length) - Sex, length, % body fat, and weight - Presence of mycobacteriosis - Stage of development and spawning capability (observations of reproductive organs)	2005-present Year-round sampling - Choptank River and the Chesapeake Bay mainstem (north of the Patuxent River) - Mainstem from mid-Bay to Bay mouth (winter) - Coastal waters from Virginia Beach to Oregon Inlet)
Extended Multispecies Virtual Population Analysis (MSVPA-X) Model: Application to	Model outputs: - Menhaden natural mortality rates at age caused by Striped Bass, Weakfish, and Bluefish predation - Striped bass diet preference	1982-2012 Atlantic Coast

Dataset	**Parameters measured**	**Temporal and Spatial Coverage**
Atlantic menhaden and its predators – ASMFC	- Striped bass consumption rate estimates by age and by prey (Menhaden, Bay Anchovy, macro-zooplankton, Sciaenids, benthic invertebrates)	
Juvenile Blue Crab Diet Data	- Gut contents (species ID) for Blue Crabs 7-40 mm carapace	2006 York and Rappahannock Rivers (upriver and downriver sites)
Northeast Area Monitoring and Assessment Program (NEAMAP) – VIMS	<u>Trawl:</u> - Aggregate weights, counts and individual length for each fish/invertebrate species size class - Species subsample includes length, weight, sex, maturity stage, ageing analysis, and stomach content analysis - Water quality - Atmospheric conditions - Hydrographic conditions - Habitat	2008-present Spring and fall surveys Atlantic Coast from Cape Cod, MA to Cape Hatteras, NC
Northeast Fisheries Science Center Bottom Trawl Survey - Food Habits Data – NOAA	<u>Trawl:</u> - Prey identification, weight, volumetric measurement, number, percent composition - Total stomach weight - Lengths of fish prey	1973-present Continental shelf waters from Cape Hatteras, NC to Nova Scotia
Osprey and Bald Eagle Diet Studies in the Chesapeake Bay	<u>Osprey Study (Glass and Watts 2009)</u> - Salinity at nesting site (upper-estuarine=0-5ppt; lower-estuarine=>18ppt) - Micro-video monitoring to record prey taxonomy, energy content, and length and mass estimates <u>Bald Eagle Study (Markham and Watts 2008)</u> - Salinity at nesting site (tidal-fresh=0-0.5ppt; mesohlaine=5-18ppt)	<u>Osprey Study (Glass and Watts 2009)</u> - 2006 and 2007 breeding seasons - 29 nests at a total of 9 sites in the Rappahannock, York and James Rivers and Mobjack Bay (5 upper-estuarine and 4 lower-estuarine) <u>Bald Eagle Study (Markham and Watts 2008)</u> - 2002 and 2003 breeding seasons - 18 nests at sites in the Rappahannock, York, and James

Dataset	Parameters measured	Temporal and Spatial Coverage
	- Video monitoring of prey taxonomy, data, delivery time and prey size (length and biomass estimates) - Hatch date of eaglets	Rivers (9 tidal-fresh and 9 mesohaline)
VIMS Trammel Net Survey	- Diets of fish species in seagrass beds	2004-2005 Lower York River grass beds

Dataset	Parameters measured	Temporal and Spatial Coverage
II. Abundance Data		
ASMFC Species Stock Assessments	- Abundance and/or biomass estimates - Natural and fishing mortality estimates - Commercial and recreational harvest levels	Time span varies by species Atlantic coast including Chesapeake Bay
Baywide Chesapeake Bay Program Plankton Monitoring	- Phytoplankton composition and abundance - Picoplankton abundance - Primary production rates - Microzooplankton composition and abundance - Mesozooplakton composition, biomass and abundance	Varying coverage between 1984-present depending on plankton program Chesapeake Bay mainstem and tidal tributaries
Blue Crab Winter Dredge Survey – MD DNR and VIMS	- Blue crab density (# crabs/ 1000m^2) - Sex and size (age) - Survey allows estimates of abundance, overwintering mortality, etc. - Depth, water temperature, salinity, tow area for each station	1990-present ~1500 randomly selected sampling stations Baywide in waters >5ft in depth (Maryland and Virginia)
Chesapeake Bay Benthic Monitoring Program and Benthic Index of Biotic Integrity	- Species ID, biomass, and abundance of benthic species - Sediment analysis - Water quality - Benthic index of biotic integrity (B-IBI)	1984-present Chesapeake Bay and tidal tributaries
Juvenile Fish and Blue Crab Trawl Survey – VIMS	- Fish species identification, length, and count at each tow site - Habitat type (until 2012) - Invertebrates species (Horseshoe Crabs, Blue Crabs, and penaid shrimp as of 2012) - Hydrographic and station data including location, depth, tide, air/water temperature, weather conditions, salinity, and DO	1960s-present - 22 stations in the James (1964-present), York (1956-present), Rappahannock (1962-present) are sampled each month year-round - 39-45 stations in the Bay mainstem are sampled each month year-round except for Jan and March (1988-present) - 17 stations in Mobjack Bay are sampled each month

Dataset	Parameters measured	Temporal and Spatial Coverage
Juvenile Shad and Herring Survey – MD DNR	Beach seines: - Juvenile abundance: fish identification and count - Catch per unit effort (CPUE) - Relative year-class strength	2005-2012 Sampling occurred biweekly from June-September Susquehanna, Chester, Pocomoke Rivers (4-8 sites per river)
Juvenile Striped Bass Survey – VIMS	Beach seines: - Length of all Striped Bass and a subsample for all other species - Species counts - Atmospheric and station data: salinity, water temperature, pH, DO, sampling time, tidal stage, weather conditions	1967-1972; 1980-present Sampling occurs biweekly from July- mid-September 18 index stations 22 auxiliary sites among James, York, and Rappahannock rivers
Juvenile Striped Bass Survey – MD DNR	Beach seines: - Lengths - Age 1+ fishes identification and count - Time of first haul, maximum distance from shore, weather, maximum depth, surface water temp, tide, salinity, substrates, % of SAV -Water quality (since 1997) -Juvenile indices	1954-present Sampling occurs monthly during July, August, and September 22 fixed stations in MD portion of the Chesapeake Bay divided among the four major spawning and nursery areas: - 7 stations in the Potomac - 7 stations in Head of the Bay area - 4 stations in the Nanticoke - 4 stations in the Choptank
Maryland Adult Striped Bass Creel Survey and Spawning Stock Survey	Creel Survey: - samples from charter boats - size (total length and weight), age, sex composition of striped bass from recreational season Spawning Stock Survey: - drift gill net samples - total length, sex, age - tag and release	Creel Survey: 2002-present Spring during the trophy/spring recreational fishing season Spawning Stock Survey: 1985-present Spring in Upper Bay and Potomac
Maryland Blue Crab Summer Trawl Survey – MD DNR	Otter trawl: - Crab count - Carapace width - Weight	1977-present Samples collected once per month May-October

Dataset	Parameters measured	Temporal and Spatial Coverage
	- Sex, maturity, molt stage - Catch per unit effort (CPUE) calculated for each size category as an index of abundance	37 total sites in 6 rivers: Chester River, Patuxent River, Choptank River, Eastern Bay, Tangier Sound and Pocomoke Sound Auxiliary sites in Little Choptank River, Fishing Bay, and Nanticoke River added in 2002
Potomac River Fisheries Commission Menhaden Pound Net Index	<u>Fishery Dependent Data</u> Catch-per-unit-effort (CPUE – lbs/net-days fished)	1976-present Potomac River
Upper Bay Winter Trawl Survey – MD DNR	- Count and ID of fish species - Length of subsample of fish samples - Otoliths from non-random subsample of target species (White and Yellow Perch; White and Channel Catfish) taken for age	2001-present Sampling occurs in six biweekly rounds from December-February Middle Bay (4 stations), Upper Bay (6 stations), Sassafras River (4 stations), and Elk River (4 stations)
VIMS Bivalve Sampling	<u>Benthic suction:</u> - Bivalve (including *Macoma* and *Mya* spp.) species abundance/biomass - Water temperature, salinity, DO, water depth - Sediment grain size, sedimentary grain size for some years	2000-2014 Various tributaries, including intensive work in the York and Rappahannock River
VIMS Pushnet Survey	- Species ID and count for American Shad and river herring (survey data for other species is unavailable)	1979-1987 and 1991-2001 Weekly nighttime sampling during the summer Mattaponi and Pamunkey
VIMS Surface Trawl Survey	- Enumerate juvenile abundance of American Shad and river herring - Water temperature and salinity	2014-present Weekly nighttime sampling during summer and early fall Chickahominy (downstream of Walker's Dam)

Dataset	Parameters measured	Temporal and Spatial Coverage
Waterbirds and Predatory Bird Species Monitoring – The Center for Conservation Biology, USFWS, USGS, MD DNR	- Population distribution and abundance - Diet and feeding ecology - Habitat use	Long-term monitoring programs, annual surveys, short-term sampling

Dataset	Parameters measured	Temporal and Spatial Coverage
III. Habitat Data		
Chesapeake Bay Program Water Quality Database	- Hydrographic profile - WQ parameters (chlorophyll, nitrogen, DO, etc.)	1984-present Chesapeake Bay mainstem and tributaries
Chesapeake Bay Shoreline Inventories for Maryland and Virginia – VIMS	-Presence and condition of shoreline structures for shore protection and recreational purposes	Major tributary areas of Maryland and Virginia
National Wetlands Inventory (NWI) – USFWS	-Wetland and riparian area extent and classification	Baywide
Nearshore fish community and influence of upland land use/shoreline development –SERC	<u>Beach Seines (15 m and 60 m):</u> - Fish species and at sites along various shoreline types (natural marsh, rip rap, bulkhead) - Temperature, salinity, DO	2010-2012 2010 -Honga River -Langfored Creek (Patuxent) -Rhode River -South River -St. Leonard River -Stony Creek (Patapsco) 2011 -Corrotoman River (Rappahannock) -Harris Creek -Magothy River -Miles River -Monroe Bay (Potomac) -Rhode River 2012 -Little Choptank River -Main Creek (Patapsco) -Mill Creek (Patuxent) -Rhode River -Wye River -Yeocomico River (Potomac)
National Wetlands Inventory (NWI) and North Atlantic Landscape Conservation Cooperative (NALCC)	<u>NWI:</u> - Digitally mapped type, size, location, and classification of wetlands in the U.S. <u>NALCC:</u>	<u>NWI</u>: Coterminous U.S., conterminous 48 States, Hawaii, Puerto Rico, the Virgin Islands, Guam, the major Northern Mariana Islands and 35 % of Alaska

Dataset	Parameters measured	Temporal and Spatial Coverage
	- Updates to NWI mapping for selected coastal areas in the North Atlantic	NALCC: 162 coastal areas in ME, MD, MA, NJ, NY, PA, and VA
SAV in Chesapeake Bay and Delmarva Peninsula Coastal Bays - VIMS	Aerial photography: - SAV distribution and density class (%)	1978-present -Baywide: mainstem and tributaries - 93 segments grouped into four salinity zones
Shallow-water benthic infauna and influence of upland land use/shoreline development – VIMS/SERC	Sieve (0.5 and 3 mm mesh): - Benthic species at sites along various shoreline types (natural marsh, rip rap, bulkhead) - Temperature, salinity, DO - Sediment grain size - Sediment organic carbon and nitrogen	2010-2013 2010 -Occohannock -East River -Poquoson River 2011 -Stony Creek -Magothy River -Harris Creek -Miles River -Monroe Bay -Corrotoman River -Poquoson River 2012 -Yeocomico -Severn -Mill Creek -Poquoson River 2013 -Catlett Islands -Onancock -Poquoson River
Tidal Marsh Inventory for Virginia – Comprehensive Coastal Inventory Program/VIMS	-Tidal marsh extent and classification	Virginia tidal areas

Dataset Descriptions

I. Diet Data

Chesapeake Bay Fishery-Independent Multispecies Survey (CHESFIMS)
Data Manager: Tom Miller, UMCES-CBL, miller@umces.edu

The Chesapeake Bay Fishery-Independent Multispecies Survey (CHESFIMS) was a large fishery independent survey of fishes in the Chesapeake Bay supported through a research grant to the University of Maryland Center for Environmental Science Chesapeake Biological Laboratory from the National

Oceanic and Atmospheric Administration's Chesapeake Bay Office. The program was conducted co-operatively by researchers from the University of Maryland Center for Environmental Science Chesapeake Biological Laboratory, University of Maryland - College Park, and the Maryland Department of Natural Resources. Research cruises were conducted from 2001-2005. In 2006, a reduced subset of the CHESFIMS program was implemented.

Bay wide surveys were conducted three times a year during April, July, and September from 2001-2006. Sampling during the surveys employed an 18 m^2 midwater trawl that was deployed in a stepwise fashion at approximately 50 sites throughout the mainstem of the Chesapeake Bay. Researchers collected 110 different fish species. Analyses of these data indicated clear seasonal and spatial patterns of variability with temperature, salinity, and dissolved oxygen being implicated as important environmental drivers. Studies of the ecology of individual species based on specimens conducted during the Baywide surveys were also completed. These studies provide data on species-specific patterns of abundance, distribution, growth, and diet that provide important inputs to efforts to implement ecosystem-based management within the Chesapeake Bay.

CHESFIMS built on and expanded earlier research, the NSF-funded Trophic Interactions in Estuarine Systems (TIES) program. TIES conducted research into biological production potential and its temporal and spatial variability in the Chesapeake Bay ecosystem from 1995-2000. Thus TIES and CHESFIMS represent an 11-year survey of the abundances and key trophic interactions in the Chesapeake Bay fish community.

In 2004, Maryland Department of Natural Resources provided funds to expand the Baywide sampling program into the Patuxent River, a principal western shore tributary of the Chesapeake Bay. This sampling program (PAXFIMS) utilized the same midwater trawl in sampling the fish community, but complemented this with collections made with an otter trawl.

Overall, the program had three specific objectives:

- Conduct a Baywide survey of the bentho-pelagic fish community, focusing juvenile and young of year fishes in the mainstem of Chesapeake Bay;
- Conduct pilot surveys of the pelagic fish community in key tributaries and in the mainstem to generate sampling statistics that will of use in subsequent design improvements; and
- Determine trophic interactions among key components of the pelagic fish community, and examine the implication of the relationships uncovered in empirical studies using bioenergetic modeling.

Above information from the CHESFIMS website.

Chesapeake Bay Multispecies Monitoring and Assessment Program (ChesMMAP)
Data Manager: Chris Bonzek, VIMS, cfb@vims.edu

Led by the Virginia Institute of Marine Science (VIMS), ChesMMAP began in 2002 and was developed to assist in filling data gaps, and ultimately to support Bay-specific, stock-assessment modeling activities at both single and multispecies scales. ChesMMAP was designed to maximize the biological and ecological information collected for several recreationally, commercially, and ecologically important species in Chesapeake Bay.

The survey uses a large-mesh bottom trawl to sample juvenile-to-adult fishes from the head of Chesapeake Bay at Poole's Island, MD to the mouth of the Bay just outside the Chesapeake Bay Bridge Tunnel. The Chesapeake Bay has been broken down into 5 regions of approximately 30 latitudinal minutes each. Within these 5 regions, 80 samples sites are chosen for each cruise using a stratified random design.

The ChesMMAP Survey has several goals:

- To estimate population sizes for priority species;
- To quantify geographic and seasonal distribution of these species;
- To quantify major links in the Bay's food web by conducting stomach content analysis for all species sampled; and
- To define the seasonal length and age structure of the fish and elasmobranch populations by taking otolith (ear bone) or vertebrae samples from the individuals collected.

Above information from the Virginia Institute of Marine Science website.

Chesapeake Bay Trophic Interaction Laboratory Services (CTILS)
Data Manager: Rob Latour, VIMS, latour@vims.edu

The purpose of the Chesapeake Bay Trophic Interaction Laboratory Services (CTILS) project was to provide fisheries scientists and managers with diet data of the fishes of Chesapeake Bay integrated into a single database. This was made possible by analyzing fish stomach contents via cooperation with fish monitoring surveys throughout the Bay region, including those from Maryland, Virginia, and North Carolina. Stomach samples of whole fish were obtained from a network of up to eight participating fisheries surveys in the Chesapeake Bay area. Whole fish were processed for length, weight, and sex determination. Stomachs were removed and prey types determined. In support of ecosystem-based fisheries management, estimates of location-specific diet composition were produced for each species. Comparisons were made between dietary habits of each species among a range of habitats in the Bay and throughout various time frames.

Above information from the Virginia Institute of Marine Science website and CTILS reports.

Bonzek, C.F., R.J. Latour, and D.J. Parthree. 2006. Establishment of a Chesapeake Bay Trophic Interaction Laboratory Services Program (CTILS). Award Number: RF 05-12. Annual Data Report to the Virginia Marine Resources Commission and the Recreational Fishing Advisory Board. Virginia Institute of Marine Science, Gloucester Point, VA. 28 pages.

Development of Striped Bass Nutrition and Forage Availability Benchmarks
Data Manager: Jim Uphoff, Maryland DNR, jim.uphoff@maryland.gov

Maryland Department of Natural Resources' (DNR) Fisheries Service has been developing an approach that combines available information on nutritional status, diet, relative prey abundance, and prey-predator ratios to evaluate foraging success of Striped Bass in Maryland's portion of Chesapeake Bay as part of a Federal Aid to Sportfishing Grant. Collectors' permits have been issued to the Chesapeake Bay Ecological Foundation (CBEF) to sample Striped Bass diets nearly year-round since 2006. Jim Price of CBEF is assisted by a group of recreational fishermen that collect Striped Bass under a DNR permit, which can account for up to 50% of the total samples. The CBEF diet collections were made from hook-and-line samples in the mid-Bay region (mainstem Bay from Bay Bridge to mouth of Patuxent River, plus Choptank River), with samples currently ranging from 285-1092 mm so far. These collections have been aided and monitored by Jim Uphoff and Joe Boone, a DNR biologist and a retired DNR fisheries biologist, respectively. The Fish Habitat and Ecosystem Program (DNR) staff are entering CBEF data into an Excel spreadsheet data base. These data consist of general location of collection (approximate site), length, weight (when available), sex, body fat index, presence of nodules in the spleen (an indicator of Mycobacteriosis), identification of diet items, and length of some diet items. Provisional data sets are available for October-February, 2006-2012; remaining seasons and years (through 2014) to be entered and edited. Diet data from Striped Bass sampled for health monitoring by the Fish and Wildlife Health Program in Maryland's portion of Chesapeake Bay (May-June 2012 and September-November, 2014) have also been collected. Analysis of 2006-2012 data for October-November indicates that connecting feeding success (based on CBEF-based diet estimates) to attainment of proposed nutritional targets and thresholds was feasible.

Above information from the Chesapeake Bay Ecological Foundation and Maryland DNR.

Extended Multispecies Virtual Population Analysis (MSVPA-X) Model: Application to Atlantic menhaden and its predators
Data Manager: Pat Campfield, ASMFC, pcampfield@asmfc.org

The extended multispecies virtual population analysis (MSVPA-X) model has been developed as a tool to incorporate predator-prey interactions into fisheries management advice. An application of the MSVPA-X model has been developed by the Atlantic States Marine Fisheries Commission (ASMFC) focusing on the interactions between Atlantic Menhaden and its major fish predators: Striped Bass, Weakfish, and Bluefish. The recent dynamics of these stocks have raised management concerns and highlighted the need for multispecies considerations in fisheries management. The MSVPA-X produces annual estimates of natural mortality rates at age caused by predation for Atlantic Menhaden. These estimates are incorporated into the Atlantic Menhaden single-species model.

Above information from the Atlantic States Marine Fisheries Commission's website.

Juvenile Blue Crab Diet Data
Data Manager: Rochelle Seitz (seitz@vims.edu) and Katie Knick (keknick@vims.edu), VIMS

In 2006, the gut contents from Blue Crabs 7-40 mm carapace were examined from the York and Rappahannock Rivers, including both upriver and downriver sites. Sites were the Poropotank and Indian Field Creek in the York and Cat Point and Harry George Creek in the Rappahannock. Gut contents were compared to the benthic infaunal communities sampled at each site to determine the diet selectivity of Blue Crabs.

Above information from the Virginia Institute of Marine Science Community Ecology Lab.

Northeast Area Monitoring and Assessment Program (NEAMAP)
Data Manager: Chris Bonzek, VIMS, cfb@vims.edu

NEAMAP was developed to meet the needs of fisheries management and stock assessment activities in the northeastern United States. NEAMAP began in 2006 with a fall pilot survey and in 2008 began conducting both a spring and fall survey. NEAMAP samples from Cape Cod, MA south to Cape Hatteras, NC and targets both juvenile and adult fishes. NEAMAP is led by the Virginia Institute of Marine Science (VIMS).

NEAMAP is an integrated, cooperative state/federal data collection program. Its mission is to facilitate the collection and dissemination of fishery-independent information obtained in the Northeast for use by state and federal fisheries management agencies, the fishing industry (commercial and recreational), researchers, and others requesting such information. The intent of NEAMAP is not to change existing programs but to coordinate and standardize procedures and improve data quality and accessibility.

Above information from the Virginia Institute of Marine Science website.

Northeast Fisheries Science Center Bottom Trawl Survey - Food Habits Data
Data Manager: Stacy Rowe, NOAA, stacy.rowe@noaa.gov

The Food Web Dynamics Program has two major sources of data. The first, and most extensive, is the standard Northeast Fisheries Science Center (NEFSC) Bottom Trawl Survey Program. During these surveys, food habits data are collected for a variety of species. These multispecies surveys were designed to monitor trends in abundance and distribution and study the ecology of fishes and invertebrates inhabiting the northeast U.S. continental shelf.

Additionally, "process-oriented" cruises are conducted periodically to address specific questions related to feeding ecology of fishes in this ecosystem. Both sources provide primarily stomach content information; composition, total and individual prey weights or volumes, and length of prey. Additional information associated with each fish predator is also collected. Other databases have encompassed the prey fields of these fish, and include zooplankton, ichthyoplankton, and benthic surveys.

The broad scale trawl surveys cover continental shelf waters from Cape Hatteras, NC to Nova Scotia, and extend from 1963 to present; however, systematic fish diet sampling began in 1973 and has continued through today. The sampling program was initiated in the autumn of 1963; a spring survey was initiated in 1968; seasonal surveys have also been conducted in summer and winter on an intermittent basis. Process oriented cruises have been undertaken sporadically throughout this time series, and are geographically more focused (e.g. Georges Bank).

Above information from the NOAA Northeast Fisheries Science Center's website.

Osprey and Bald Eagle Diet Studies in the Chesapeake Bay
Data Managers: Bryan Watts, Center for Conservation Biology, College of William and Mary, bdwatt@wm.edu

Recent research has studied the diets of ospreys and bald eagles in different salinity zones in Virginia tributaries of the Chesapeake Bay. Glass and Watts (2009) and Markham and Watts (2008) studied the influence of salinity on the diets of nesting ospreys and bald eagles, respectively. Both studies used video monitoring to record the prey taxonomy and size delivered to the nests. The results show many forage fish species of interest and their contribution to the overall diet of these birds during the breeding season. The studies also reveal spatial differences in both osprey and bald eagle diets based on the salinity zones the nesting sites are in.

Glass, K.A. and B.D. Watts. 2009. Osprey diet composition and quality in high- and low- salinity areas of lower Chesapeake Bay. Journal of Raptor Research 43(1): 27-36.

Markham, A.C. and B.D. Watts. 2008. The influence of salinity on the diet of nesting bald eagles. Journal of Raptor Research 42: 99-109.

VIMS Trammel Net Survey
Data Manager: Rob Latour, VIMS, latour@vims.edu

The VIMS Trammel Net Survey was conducted in the lower York River grass beds in 2004 and 2005 to document Blue Crab predation in seagrass beds. It documented the diets from a variety of fish species including Striped Bass, Summer Flounder, Weakfish, Atlantic Croaker, Spot, Blue Catfish, and White Perch.

II. Abundance Data

ASMFC Species Stock Assessments
Data Manager: Pat Campfield, ASMFC, pcampfield@asmfc.org

Coordinating the efforts of the Atlantic coastal states in the development and implementation of interstate fisheries management programs is the Atlantic States Marine Fisheries Commission's (ASMFC) primary role, with stock assessments forming the basis of these programs. ASMFC assesses fish stocks to determine their status, to evaluate how they may be affected by potential management actions, and to forecast their future conditions. In fisheries, determining stock status means estimating one or more biological characteristics of the stock, such as abundance (numbers of fish) or biomass (weight), and comparing estimated values to reference values that define desirable conditions.

ASMFC conducts stock assessments on the majority of Commission-managed species in order to determine the health and status of the fish stock and to provide scientific advice to fisheries managers. ASMFC also works closely with the National Marine Fisheries Service's Science Centers and Regional Fishery Management Councils on the assessments for jointly or cooperatively managed species, such as Atlantic Herring, Summer Flounder, and Spanish Mackerel.

Generally, ASMFC conducts two types of stock assessments: (1) a benchmark stock assessment, and (2) a stock assessment update. A benchmark stock assessment is a full analysis and review of the stock condition, focusing on the consideration of new data sources and newer or improved assessment models. This assessment is generally conducted every three to five years and undergoes a formal peer review by a panel of independent fisheries scientists who evaluate whether the data and methods used to produce the assessment are scientifically sound and appropriate for management use (peer-reviewed stock assessment). A stock assessment update incorporates data from the most recent years into the peer-reviewed assessment model to determine current stock status (abundance and overfishing level).

Above information from the Atlantic States Marine Fisheries Commission website.

Baywide CBP Plankton Database
Data Manager: Mike Mallonee, Chesapeake Bay Program, mmallonee@chesapeakebay.net

The states of Maryland and Virginia, in cooperation with the US EPA Chesapeake Bay Program, have conducted baseline monitoring of the lower trophic levels in the Chesapeake Bay and its tidal tributaries since 1984. These programs are designed to give comprehensive spatial and temporal information on phytoplankton composition and abundance; picoplankton abundance; primary production rates; microzooplankton composition and abundance; and mesozooplakton composition, biomass, and abundance. All Maryland monitoring programs began in July of 1984. The Virginia Phytoplankton and mesozooplankton monitoring programs began in 1985, primary production and picoplankton monitoring began in 1989, and microzooplankton monitoring began in 1993. These monitoring programs are performed in conjunction with the water quality monitoring programs in both jurisdictions.

Above information from the Chesapeake Bay Program website.

Blue Crab Winter Dredge Survey
Data Manager: Glenn Davis, MD DNR, glenn.davis@maryland.gov and Rom Lipcius, VIMS, rom@vims.edu

The winter dredge survey is the only Bay-wide fishery independent effort to estimate the number of Blue Crabs living in the Chesapeake Bay. The winter dredge survey produces information that is essential for the management of the species, such as an estimate of the number of crabs over-wintering in the bay and the number of young crabs entering the population each year. Also calculated is the estimated number of females that could spawn within the year, which is an important indicator of future spawning potential. Estimating the total number of crabs living in the Bay allows us to calculate the percentage of the crab population that is removed by harvest each year.

The survey has been in operation since 1989-90 and Maryland and Virginia continue to sample each winter from December through March. Each year, a total of 1500 sites in waters deeper than 5 feet are randomly selected. The number of sites assigned in each region is proportional to its area. All crabs collected at each site are measured and weighed and are measured from point to point across the top shell, or carapace. Male and female crabs are divided into different categories based on age, size and maturity. Crabs that are smaller than 2.4 inches across the carapace are considered to be young-of-the-year crabs. Female crabs bigger than 2.4 inches across are the females that could spawn this year and all crabs bigger than 2.4 inches are considered to be the harvestable stock that will support the fishery throughout the summer.

Above information from the Maryland Department of Natural Resources website and the Virginia Institute of Marine Science website.

Chesapeake Bay Benthic Monitoring Program and Benthic Index of Biotic Integrity
Data Manager: Versar Inc., Dr. Robert Llanso, rllanso@versar.com

Since 1994, the Chesapeake Bay Benthic Monitoring Program has consisted of two elements: (1) a fixed-site monitoring sampling effort directed at identifying trends in benthic condition and (2) a probability-based sampling effort intended to estimate the area of the Maryland Chesapeake Bay with benthic communities meeting, and failing to meet, the Chesapeake Bay Program's Benthic Community Restoration Goals. A similar sampling effort has been used in Virginia since 1996. Benthic samples are collected using four kinds of gear depending on the program element and habitat type. Species-level identifications and ash-free dry weights are provided. Four types of raw Benthic Monitoring Program data are publically available online for both Maryland and Virginia: water quality, sediment parameters, abundance, and biomass.

In addition to the raw data, the Chesapeake Bay benthic index of biotic integrity (B-IBI) is also available. The B-IBI was developed to assess benthic community health and environmental quality in Chesapeake Bay. The B-IBI evaluates the ecological condition of a sample by comparing values of key benthic community attributes ("metrics") to reference values expected under non-degraded conditions in similar habitat types. It is therefore a measure of deviation from reference conditions.

The Chesapeake Bay B-IBI is calculated by scoring each of several attributes of benthic community structure and function (abundance, biomass, Shannon diversity, etc.) according to thresholds established from reference data distributions. The scores (on a 1 to 5 scale) are then averaged across attributes to calculate and index value. Samples with index values of 3.0 or more are considered to have good benthic condition indicative of good habitat quality.

Versar, under a Memorandum of Agreement with the Bay Program's Chesapeake Information Management System (CIMS), provides direct public access to up-to-date benthic information, monitoring results, reports, and data through their website.

Above information from the Versar Inc. website.

Juvenile Fish and Blue Crab Trawl Survey - VIMS
Data Manager: Troy Tuckey, VIMS, tuckey@vims.edu

The Virginia Institute of Marine Science (VIMS) Juvenile Fish and Blue Crab Trawl Survey has played an important role in researching and monitoring the Bay's fish populations since 1955. It tracks trends in seasonal distribution and abundance of commercially, recreationally, and ecologically important finfish, as well as invertebrates such as the Blue Crab.

The primary goal of the survey is to develop indices of abundance, which measure the relative size of each year class of a target species. These indices indicate annual recruitment success or failure and help predict the future abundance of the stock. The data generated by the survey are used by fishery managers and researchers.

Currently, 22 stations in the James, York, and Rappahannock River are sampled each month, year-round. Sampling in the Bay varies between 39 and 45 stations per month (depending on season) and does not occur in January or March. After each 5-minute tow, the catch is sorted and fishes are identified and measured, then quickly returned to the water (subsets of large catches are measured and the rest are counted). Invertebrates (Horseshoe Crabs, Blue Crabs, and penaid shrimp only) are identified and measured. Approximately 70 species are commonly caught, although more than 200 species have been identified during the last 50 years. In addition to animal lengths, hydrographic and station data are also collected.

Above information from the Virginia Institute of Marine Science website.

Juvenile Shad and Herring Survey - MD DNR
Data Manager: Genine Lipkey, MD DNR, genine.lipkey@maryland.gov

The Maryland Department of Natural Resources Juvenile Shad and Herring survey ran from 2005-2012 with the purpose of assessing relative young-of-the-year abundance of *Alosa* species in the Maryland portion of the Chesapeake Bay through estimates of catch per unit effort (CPUE), juvenile abundance, and relative year-class strength. Beach seine hauls were conducted at four to eight sites each in the Susquehanna, Chester, and Pocomoke Rivers. All fish were identified and counted.

Above information from:

Bonzek, C., E. Houde, S. Giordano, R. Latour, T. Miller, and K.G. Sellner. 2007. Baywide and Coordinated Chesapeake Bay Fish Stock Monitoring. CRC Publication 07-163, Edgewater, MD. 70 p.

Juvenile Striped Bass Survey (Virginia) - VIMS

Data Manager: Dr. Mary Fabrizio, mfabrizio@vims.edu

The Virginia Institute of Marine Science (VIMS) initiated the juvenile Striped Bass seine survey in 1967 to monitor the abundance of this important resource. The survey was terminated in 1973 when federal funding was discontinued. As population levels declined in the 1970s, concern about Striped Bass rose, and in 1980, funding was reinstated.

The primary objective of the survey is to monitor relative annual recruitment success of juvenile Striped Bass in the spawning and nursery areas of lower Chesapeake Bay by developing an annual index of abundance for each year class. Estimates of young-of-the-year abundance derived from catch data help evaluate the health of a stock, and are used in predicting future commercial and recreational fish abundance. The survey also generates indices of abundance for a number of other recreationally, commercially, and otherwise ecologically important species.

Currently, the survey samples waters from 18 historically sampled sites (index stations) and 22 auxiliary sites along the shores of the James, York, and Rappahannock rivers. Addition of the auxiliary sites was made to provide better geographic coverage and, once a sufficient time series of data is developed, to create larger sample sizes within river systems so that trends in juvenile abundance can be meaningfully monitored on a system-by-system basis.

In the case of index stations, all fish taken during the first tow are removed from the net and held until after the second tow. All Striped Bass and a sub-sample of at least 25 individuals of other species are measured to the nearest millimeter fork length (or total length if appropriate). All fishes captured, except those preserved for life-history studies, are returned to the water at the conclusion of sampling. Counts are taken of other species after 25 individuals are measured. Atmospheric and station data are recorded: salinity, water temperature, pH, dissolved oxygen, sampling time, tidal stage, and weather conditions.

Above information from the Virginia Institute of Marine Science website.

Juvenile Striped Bass Survey (Maryland) - MD DNR

Data Manager: Eric Durell, MD DNR, eric.durell@maryland.gov

The Maryland Department of Natural Resources (MD DNR) juvenile Striped Bass survey documents annual year-class success for young-of-the-year (YOY) Striped Bass (*Morone saxatilis*) and relative abundance of many other fish species in Chesapeake Bay. Over 100 fish species have been collected since 1954. Annual indices of relative abundance provide an early indicator of future adult stock recruitment and document annual variation and long-term trends in abundance and distribution.

Juvenile indices are derived annually from sampling at 22 fixed stations within Maryland's portion of the Chesapeake Bay. Stations have been sampled continuously since 1954, with changes in some station locations. They are divided among four of the major spawning and nursery areas: seven each in the Potomac River and Head of Bay areas and four each in the Nanticoke and Choptank Rivers. Sampling is monthly, with rounds (sampling excursions) occurring during July (Round I), August (Round II), and September (Round III). Replicate seine hauls, a minimum of thirty minutes apart, are taken at each site on each sample round. This produces a total of 132 samples from which Bay-wide means are calculated.

From 1954 to 1961, juvenile surveys included various stations and rounds. Sample sizes ranged from 34 to 46. Present indices derived for this period include only stations which are consistent with subsequent years. In 1962, stations were standardized and a second sample round was added for a total of 88 samples. A third sample round, added in 1966, increased sample size to 132. Auxiliary stations have been sampled on an inconsistent basis and are not included in survey indices. These data enhance geographical coverage in rivers with permanent stations or provide information from other river systems and are also useful for replacement of permanent stations when necessary.

Above information from the Maryland Department of Natural Resources website.

Maryland Adult Striped Bass Creel Survey and Spawning Stock Survey
Data Manager: Beth Versak, MD DNR, beth.versak@maryland.gov

The MD DNR Striped Bass Program began the Creel Survey in 2002 and it remains ongoing. The main objectives are to develop a time-series of relative abundance of the Chesapeake Bay spawning stock harvested during the spring trophy fishery; determine the sex ratio and spawning condition of harvested fish; characterize length and weight of harvested fish; characterize the age-distribution of harvested fish; and collect scales and otoliths to supplement MD DNR age-length keys and for an ongoing ageing validation study of older fish. The survey is conducted by interviewing fisherman and sampling fish from charter boats.

MD DNR has used drift gill nets to monitor the Chesapeake Bay Striped Bass since 1985 and also remains ongoing. The survey generates estimates of relative abundance-at-age for Striped Bass in Chesapeake Bay during the spring spawning season each year. The survey also characterizes the spawning population by looking at length distribution, age structure, average length-at-age, and percentage of Striped Bass older than age 8 present on the spawning grounds. Indices produced from this study are currently used to guide management decisions concerning recreational and commercial Striped Bass fisheries from North Carolina to Maine.

Above information from Maryland Department of Natural Resources

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Maryland Blue Crab Summer Trawl Survey - Maryland Department of Natural Resources (MD DNR)
Data Manager: Glenn Davis, MD DNR, glenn.davis@maryland.gov

The Maryland Blue Crab trawl survey is a DNR sampling program conducted from May through October. The trawl survey began in 1977 with data collected from six river systems in Maryland's Chesapeake Bay region. The summer trawl survey produces information on trends in Blue Crab abundance and carapace width and weight.

Samples are collected once a month; May through October. There are a total of 37 sites in 6 different river systems; Chester River, Patuxent River, Choptank River, Eastern Bay, Tangier Sound and Pocomoke Sound, each of which is sampled monthly. Auxiliary sites in 3 additional rivers were added in 2002. These include 8 sites in the Little Choptank River and 4 sites each in Fishing Bay and the Nanticoke River. Although information from these sites is not included in indices of abundance, these sites serve to validate observations and improve the coverage of the survey.

After the sample is removed from the trawl the crabs are sorted and counted. The crab's carapace is measured to the nearest millimeter to determine carapace width (CW) and the weight is measured to the nearest gram (missing claws are noted). The sex, maturity, and molt stage are recorded for each crab. Monthly catch per unit effort (CPUE) is considered to be an index of abundance and is calculated as crabs per tow for each size category. Monthly indices are compared to the previous year and to a base average calculated from abundance indices from 1990 to 1999. For annual indices of growth crab (male crabs 60-120mm and immature females) abundance, the samples from July and August are used. For annual indices of mature female abundance, samples from August through October are used.

Above information from the Maryland Department of Natural Resources website.

Potomac River Fisheries Commission Menhaden Pound Net Index
Data Manager: Ellen Cosby, PRFC, ellen.prfc@verizon.net

The Potomac River Fisheries Commission (PRFC) has been tracking catch-per-unit-effort (CPUE) data for the Atlantic Menhaden fishery in the Potomac River each year since 1976. CPUE is measured in pounds per net per days fished (lbs/net-days fished). This fishery-dependent CPUE data is currently used as proxy abundance index for relative coast-wide Menhaden abundance by the Atlantic States Marine Fisheries Commission (ASMFC).

Above information from PRFC's annual Atlantic Menhaden report to the Atlantic States Marine Fisheries Commission.

Upper Bay Winter Trawl Survey - MD DNR
Data Manager: Butch Webb, MD DNR, butch.webb@maryland.gov

The Maryland Department of Natural Resources Upper Bay Winter Trawl Survey began in 2001 to biologically characterize and monitor spawning stocks of resident species in the Middle Bay, Upper Bay, Sassafras River, and Elk River in terms of age, size, sex ratio, and relative abundance. The four target species are: White Perch, Yellow Perch, Channel Catfish, and White Catfish.

Single 10-minute tows are conducted at 18 sites in each river system. Sampling locations are randomized by depth strata (<6 m and >6 m). All fish specimens are identified and enumerated, with at least 30 specimens of each species measured. Otoliths from a non-random sub-sample of the target species are taken for development of age-length keys. The survey data generate growth and mortality rates, recruitment indices, length, and age characterization of spawning populations of the four target species.

Above information from:

Bonzek, C., E. Houde, S. Giordano, R. Latour, T. Miller, and K.G. Sellner. 2007. Baywide and Coordinated Chesapeake Bay Fish Stock Monitoring. CRC Publication 07-163, Edgewater, MD. 70 p.

VIMS Bivalve Sampling
Data Manager: Rochelle Seitz (seitz@vims.edu) and Katie Knick (keknick@vims.edu), VIMS

Rochelle Seitz's Community Ecology Laboratory at the Virginia Institute of Marine Science has done bivalve sampling, including *Macoma* and *Mya* species since 2000 in various tributaries in the Chesapeake Bay. The York and Rappahannock rives have been sites of intensive sampling from 2002-2006. Most years used benthic suction sampling, with the exception of the deepwater *Macoma* sampling in 2003-2004, which used box coring.

- 2000-2001 - York River suction sampling for bivalves including *Macoma* and *Mya* in York River, upriver to downriver. Sampling 0.17 m^2 area to 40 cm sediment depth; 1 mm sieve. Concurrently measured water temperature, salinity, DO. All sites <2 m water depth.

- 2002-2006 - Benthic suction sampling various tributaries Chesapeake Bay. Suction sampling 0.17 or 0.11 m^2 area; 1 mm sieve. Concurrently measured water temperature, salinity, DO. All sites <2 m water depth.
- 2003-2004 - Deep-water *Macoma* sampling (~3-7 m water depth). Box coring in York and Rappahannock Rivers. Concurrently measured water temperature, salinity, DO, sediment grain size, sedimentary carbon.
- 2010-2014 - Benthic suctioning along developed and undeveloped shorelines, including various locations on the Maryland Eastern and Western shore. Suction sampling 0.11 m^2 area; 3 mm or 0.5 mm sieve. Concurrently measured water temperature, salinity, DO, sediment grain size, sedimentary carbon. All sites < 2 m water depth.

Above information from the Virginia Institute of Marine Science Community Ecology Lab.

VIMS Pushnet Survey
Data Manager: Eric Hilton, VIMS, ehilton@vims.edu

The VIMS Pushnet Survey ran from 1979-1987, and then was re-instituted from 1991-2001. Sampling was done weekly at nighttime during the summer (varying durations) on the Mattaponi and Pamunkey rivers. Catches were identified and counted. Data are available for American Shad and river herring.

VIMS Surface Trawl Survey
Data Manager: Eric Hilton, VIMS, ehilton@vims.edu

The VIMS Surface Trawl survey began in 2014 to calculate a juvenile abundance index for American Shad and river herring in the Chickahominy River. The survey uses nighttime tows of a surface trawl net to capture and enumerate juvenile abundance of the two taxa. Sampling will take place once a week for approximately 16 weeks during the summer and early fall months in the Chickahominy River, downstream of Walker's Dam. Stations will be selected prior to each cruise following a random stratified design. During each cruise, three stations will be randomly chosen within each of four adjacent 9.3 river km long blocks, for a total of 12 stations sampled on each night of trawling. Stations will be designated at every 1.9 river km, beginning 2 miles below Walker's Dam and ending at the river mouth. All trawls will be conducted along the central axis of the river channel and performed with the prevailing current.

Waterbirds and Predatory Bird Species Monitoring
Data Manager: Multiple, see organization links below

Multiple organizations conduct regular monitoring as well as specific research studies on bird species in the Chesapeake Bay. These programs collect a variety of information including information on population distribution, species abundance, diet and feeding ecology, and habitat use. Many birds and waterfowl consume forage species in the Bay, especially fish species, and the abundance and diet of these bird species is an important component of the overall predatory demand for forage in the Bay. Birds that feed on forage fish during the breeding season include Terns, Cormorants, Pelicans, Osprey, Eagles, and Herons. In the winter, these species include Mergansers and Loons.

Many organizations work collaboratively to conduct research and monitoring of specific bird species in the Bay and include:

- The Center for Conservation Biology (CCB) is a research group shared by The College of William and Mary and Virginia Commonwealth University and conducts research and develops information to support science-based conservation and support management of bird species of concern. Each year CCB conducts a variety of field projects to research and monitor bird species of concern, including many in the Chesapeake Bay (e.g. Osprey, Bald Eagles, waterbirds). Their long-term monitoring efforts include annual surveys of colonial waterbird species in Virginia and breeding bald eagles in Virginia.
- USGS Patuxent Wildlife Research Center run by the U.S. Geological Survey (USGS) conducts research and monitoring programs on a variety of bird species. The Center manages multiple programs that provide information on the population trends of bird species throughout North America. Specific to the Chesapeake Bay, the Center is currently focused on research around the feeding ecology of seaducks, sea level rise impacts on bird species, contaminant exposure effects on waterbirds, and productivity of Tern populations on Poplar Island.
- U.S. Fish and Wildlife Service (USFWS) Chesapeake Bay Field Office works with partners to monitor migratory bird populations in the Chesapeake Bay. Together with USGS, USFWS hosts the Migratory Bird Data Center online which provides access to data from bird inventories, surveys, and monitoring programs for bird populations in North America, including the Chesapeake Bay Watershed.

A more comprehensive list and description of current waterbird monitoring programs in the Chesapeake Bay can be found in "Waterbirds of the Chesapeake: A Monitoring Plan" on pages 15-27. This report (Watts 2013) outlines monitoring needs for waterfowl in the Chesapeake Bay, existing monitoring programs and a plan for future programs to address remaining monitoring needs.

Watts, B.D. 2013. Waterbirds of the Chesapeake: A monitoring plan. Version 1.0. VirginiaDepartment of Game and Inland Fisheries, Richmond, VA. 95 p.

III. Habitat Data

Chesapeake Bay Program Water Quality Database
Data Manager: Chesapeake Bay Program, Mike Mallonee, mmallone@chesapeakebay.net

The Chesapeake Bay Program (CBP) provides funding to Maryland and Virginia to routinely monitor 19 directly measured water quality parameters at 49 stations in the Bay's mainstem. The Water Quality Monitoring Program began in June 1984, with stations sampled twice each month in June, July, and August and once each month the rest of the year. "Special" sampling events - called cruises - may be added to record unique weather events.

The collecting organizations coordinate the sampling times of their respective stations so that data for each cruise represents a synoptic picture of the Bay at that point in time. At each station, a hydrographic profile (including water temperature, salinity, and dissolved oxygen) is made at approximately 1- to 2-meter intervals. Water samples for chemical analysis (such as nutrients and chlorophyll) are collected at the surface and bottom and at two additional depths depending on the presence and location of a pycnocline. Correlative data on sea state and climate are also collected.

Above information from the Chesapeake Bay Program website.

Chesapeake Bay Shoreline Inventories
Data Manager: Center for Coastal Resources Management, Virginia Institute for Marine Science

Shoreline inventories divide the shore zone into three regions: 1) the immediate **riparian zone**, evaluated for land use; 2) the **bank**, evaluated for height, stability, cover, and natural protection; and 3) the **shoreline**, describing the presence of shoreline structures for shore protection and recreational purposes. Data are available for major tributary areas of Maryland and Virginia, as well as for Delaware Bay.

Above information from the Virginia Institute of Science Center for Coastal Resources Management website.

National Wetlands Inventory (NWI) from USFWS
Data Manager: USFWS

The National Wetlands Inventory (NWI) was established by the US Fish and Wildlife Service (FWS) to conduct a nationwide inventory of U.S. wetlands to provide biologists and others with information on the distribution and type of wetlands to aid in conservation efforts. To do this, the NWI developed a wetland classification system (Cowardin et al. 1979) that is now the official FWS wetland classification system and the Federal standard for wetland classification (adopted by the Federal Geographic Data Committee on July 29, 1996: 61 Federal Register 39465). The NWI also developed techniques for mapping and recording the inventory findings. The NWI relies on trained image analysts to identify and classify wetlands and deep water habitats from aerial imagery. Currently, FWS serves its data via an on-line data discovery "Wetlands Mapper". GIS users can access wetlands data through an online wetland mapping service or download data for various applications (maps, data analyses, and reports). The techniques used by NWI have recently been adopted by the Federal Geographic Data Committee as the federal wetland mapping standard (FGDC Wetlands Subcommittee 2009). This standard applies to all federal grants involving wetland mapping to insure the data can be added to the Wetlands Layer of the National Spatial Data Infrastructure. NWI also produces national wetlands status and trends reports required by Congress.

Above information from the US Fish and Wildlife Service website.

Nearshore fish community and influence of upland land use/shoreline development
Data Manager: Denise Breitburg, SERC, breitburgd@si.edu

This data collection is part of a multi-year, project funded by NOAA to investigate the impacts of stressors at the land-water interface in Chesapeake Bay and Delmarva Coastal Bays. The project includes seventeen principal investigators from 8 institutions led by the Smithsonian Environmental Research Center (SERC). The project includes a focus on the impacts of land use and shoreline development on fish species. Fish species abundance and community composition were observed using beach seines at sites adjacent to various shoreline types (e.g. natural marsh, rip rap, bulkhead) and various upland usage types (forested, developed, agricultural) from 2010-2012 in Maryland tributaries.

National Wetlands Inventory (NWI) and North Atlantic Landscape Conservation Cooperative (NALCC)
Data Manager: Scott Klopfer, NALCC Project Lead, sklopfer@vt.edu

NWI data is viewable and downloadable from the online Wetlands Mapper tool which houses the NWI's digital wetland coverage, and includes the Chesapeake Bay watershed. The Wetlands Mapper tool shows the current type, size, and location of wetlands in the US. It also shows the associated wetland classification based on the NWI codes.

The NALCC has been working to update parts of the NWI for selected areas of intertidal wetlands in the North Atlantic. This project completed a rapid update for wetland mapping in 162 coastal areas (1:24,000 topographic quadrangles in ME, MD, MA, NY, NJ, PA, and VA) that were last updated prior to 2000. The updates, which will be incorporated into the National Wetlands Inventory, will have many applications in conservation analysis and coastal planning. That data can be downloaded from the project webpage.

Above information from the NWI website and the NALCC website.

SAV in Chesapeake Bay and Delmarva Peninsula Coastal Bays
Data Manager: Robert J. Orth, VIMS, jjorth@vims.edu

Black-and-white aerial photography at a scale of 1:24,000 was the principal source of information used to assess distribution and abundance of SAV in Chesapeake Bay, its tributaries, and the Delmarva Peninsula coastal bays from Assawoman Bay to Magothy Bay in 2013. There were 167 flight lines that yielded aerial photography negatives that were scanned and orthorectified to create orthophoto mosaics. These mosaics were carefully examined on-screen and outlines were drawn to identify all SAV beds visible on the photography, providing a geographic information system (GIS) digital database for analysis of bed areas and locations. Ground survey information collected in 2013 was tabulated and entered into the VIMS SAV GIS digital database.

SAV distribution data are presented and discussed based on the 2003 revised Chesapeake Bay Program (CBP) segmentation and zonation scheme (DAWG 1997). This segmentation scheme is mapped and listed by salinity regime.

The CBP Segmentation scheme defines 93 segments that are grouped into four salinity zones to reflect the communities of SAV species found in the Chesapeake Bay: Tidal Fresh (less than 0.5 ppt); Oligohaline (0.5-5 ppt); Mesohaline (5-18 ppt); and Polyhaline (18-25 ppt).

Above information from the Virginia Institute of Marine Science website.

Shallow-water benthic infauna and influence of upland land use/shoreline development
Data Manager: Rochelle Seitz, VIMS, seitz@vims.edu

This data collection is part of a multi-year project funded by NOAA to investigate the impacts of stressors at the land-water interface in Chesapeake Bay and Delmarva Coastal Bays. The project includes seventeen principal investigators from 8 institutions led by the Smithsonian Environmental Research Center (SERC). The project includes a focus on the impacts of land use and shoreline development on benthic infauna. Benthic data was observed for 6 replicate sites adjacent to various shoreline types (e.g., natural marsh, rip rap, bulkhead) and various upland usage types (forested, developed, agricultural) from 2010-2013 in tributaries across the watershed. Benthic infauna was sieved on 0.5 mm mesh and water quality parameters were also recorded.

Tidal Marsh Inventory for Virginia
Data Manager: Center for Coastal Resources Management, Comprehensive Coastal Inventory Program, Virginia Institute of Marine Science

Beginning in the 1970s, the VIMS Wetlands Advisory Program started mapping all tidal wetlands in support of the Virginia Wetlands Act (1972). USGS 7.5 minute topographic maps and aerial photography provided geographic boundaries for the wetlands. Each wetland site was visited in the field, and analyzed for community composition. Composition was based on estimated percent cover of wetland species observed during site visits. Each wetland was also assigned one of the 17 community types outlined in the Virginia Marine Resources Commission, Wetlands Guidelines (VMRC 1993), prepared by VIMS.

Work on developing the Tidal Marsh Inventories (TMIs) continued through the 1990s, with publications on a county by county basis. Most of these reports can now be downloaded from the web. In 1990, a large scale effort within the Comprehensive Coastal Inventory Program (CCI) digitized all marshes delineated in the Tidal Marsh Inventory Series. Marsh boundaries were drafted to stable-base mylar, 1:24,000 scale, USGS topographic quadrangles.

Starting in 2009, the Center for Coastal Resources Management (CCRM) at VIMS has begun the effort to update Tidal Marsh Inventories for Virginia localities. The program is using high resolution imagery and photo interpretation techniques to define the marsh boundaries. Heads-up, onscreen digitizing is used to map the boundaries from the imagery at a scale of 1:1,000 or better depending on the image resolution. Ground-truthing corrects for any interpretation errors and collects information on marsh community type. The data are available in shapefile format for download here.

Above information from the Virginia Institute of Marine Science Center for Coastal Resources Management website.

Appendix E: Monitoring Survey Data

Introduction:

This Appendix presents numerous summaries of food habit data from five major monitoring surveys conducted in Chesapeake Bay and/or its tributaries. Data from all species for which at least several tens (and up to several thousands) of stomachs were analyzed are included. None of these surveys, either individually or collectively, collect fishes from all habitats during all seasons. Fish food habits change and vary temporally, geographically, and ontogenetically so even though sample sizes for some species are very high these results must be reviewed in context. The overarching purpose of this document is to provide a data-driven basis on which to make recommendations on future progress towards monitoring and managing the forage base in the Chesapeake Bay region.

Predator species are grouped according to general life history traits (e.g., major predators, benthic feeders) and alphabetically within each group. Some species may qualify for inclusion in more than one group but are listed only once.

The Surveys:

Following is a very brief description of each survey from which data were analyzed. Additional details are available either online, in project reports, or from survey investigators.

ChesMMAP (Chesapeake Multispecies Monitoring and Assessment Program)

Most of the data included in this document come from this survey. ChesMMAP, conducted at VIMS, has been collecting data using a 45 ft. headrope length bottom trawl since 2002. The net is designed and utilized in a manner to maximize catches of late-juvenile-to-adult fishes. Up to 80 stations are sampled in a stratified random design during each of five (March, May, July, September, and November) annual cruises. Survey tows are conducted in the main stem Chesapeake Bay between Baltimore and the Bay mouth. In addition to collecting data on numbers, biomass, and lengths, at each station a subsample of fish are processed for individual length/weight/sex/maturity/age/diet.

Due to the relatively long time series now available and to the large numbers of specimens processed, for many species food habits are shown for various temporal and geographic subsets (e.g., by year, by month pooled over years, upper bay v. lower bay, etc.). Where appropriate, figures for sample sizes, length frequency histograms, and capture locations are included, as well as a figure which tracks the amount of 'unidentified material' in predator stomachs.

Diet summaries for ChesMMAP data are calculated based on cluster sampling theory. In short, this means that fish are assumed to be non-randomly distributed throughout their habitat, but rather they exist (and are captured) in clusters. Within-cluster variability is assumed to be smaller than between-cluster variability. Most importantly, the size of clusters (i.e., the total catch of each species at a station) is accounted for when analyzing the food habits. For example, for species X, at Station 1 a total of 5 specimens are captured and at Station 2 100 fish are taken. Survey protocols dictate that stomachs from 5 fish from each station will be preserved and analyzed. Simple-random sampling theory would dictate that each of the 10 fish sampled would be treated as equally representative of the population. However, using cluster sampling theory, the food habits proportions at each station are weighted by the number captured at each station, so the fish taken at Station 2 contribute 20-times (100/5) more to the final diet estimates (for the sampled population) than those at Station 1. This process can have a profound impact (up to an order of magnitude in some circumstances) on the food habits proportions that result. In general, this method will decrease the contribution of the smaller number of large predators with large prey items in their stomachs if most of the specimens captured for that species tend to be smaller and with different typical prey types.

While the data should exist to treat all of the surveys analyzed here using cluster theory, time constraints dictated that data from other surveys would be analyzed using simple-random-sampling techniques. Care should be taken in comparing across-survey results.

CHESFIMS (Chesapeake Fishery Independent Monitoring Survey)

This survey was conducted between 2001 and 2006 by UMCES/CBL. The objectives (taken from the CHESFIMS website) were to:

- *Conduct a baywide survey of the bentho-pelagic fish community, focusing juvenile and young-of-year fishes in the mainstem of Chesapeake Bay;*
- *Conduct pilot surveys of the pelagic fish community in key tributaries and in the mainstem to generate sampling statistics that will of use in subsequent design improvements; and*
- *Determine trophic interactions among key components of the pelagic fish community, and examine the implication of the relationships uncovered in empirical studies using bioenergetic modeling.*

Surveys were conducted three times yearly (spring, summer, fall) at approximately 40 stations in the mainstem Chesapeake Bay. Each tow of the 18m^2 6mm (cod end opening) mesh net was conducted during nighttime hours for 20 minutes. The net was fished for 2 minutes at each of 10 different depth zones in an oblique tow.

CHESFIMS food habits data are shown for Striped Bass, Weakfish, Atlantic Croaker, Spot, Spotted Hake, White Perch, and Silver Perch.

Note that only the ChesMMAP and CHESFIMS surveys have/had food habits enumeration protocols as parts of their routine sampling.

CTILS (Chesapeake Trophic Interactions Laboratory Services)

Diet data exist for the other surveys described below for relatively short time periods during the early 2000's. During that time, a VIMS program called CTILS encouraged other researchers in the region to collect fish stomachs and to have them analyzed at no cost. CTILS was disbanded in 2007 for lack of continued funding.

CTILS samples included in this report include:

VIMS Trawl Survey

The VIMS Juvenile Fishes and Blue Crab Trawl Survey sampled about 100 stations per month, 12 months per year, in the Virginia portion of the Bay and in the three major Virginia tributaries (Rappahannock, York, James Rivers). The primary data product is counts-based juvenile indices for a number of species. Both the CHESFIMS and VIMS Trawl Survey data supply information on smaller specimens which are not as abundant in ChesMMAP samples.

Data included in this report include: Years: 2005-2007; Species: Striped Bass, Summer Flounder, Weakfish, Atlantic Croaker, and Silver Perch.

Maryland Striped Bass Beach Seine Survey

This survey sampled at 40 fixed shallow water sites distributed among known Striped Bass nursery areas in the Maryland portion of Chesapeake Bay and its tributaries. Specimens were captured using a 100 ft. beach seine. Sites were sampled once per two-week period during July, August, and early September.

Data included in this report include: Years: 2003-2004; Species: Striped Bass.

Virginia Striped Bass Beach Seine Survey

This survey sampled at 22 fixed shallow water sites distributed among known Striped Bass nursery areas in the Virginia portion of Chesapeake Bay and its tributaries. Specimens were captured using a 100 ft. beach seine. Sites were sampled once per month during July, August, and September.

Data included in this report include: Years: 2003-2004; Species: Striped Bass, Blue Catfish, and White Perch.

Maryland Adult Striped Bass Monitoring Survey

This survey sampled primarily during spring months, concentrating on spawning-age fish. Gears included in the specimens made available to CTILS were captured with gill nets, hook & line, and trolling gear. Year: 2003-2005; Species: Striped Bass.

VIMS Trammel Net Survey

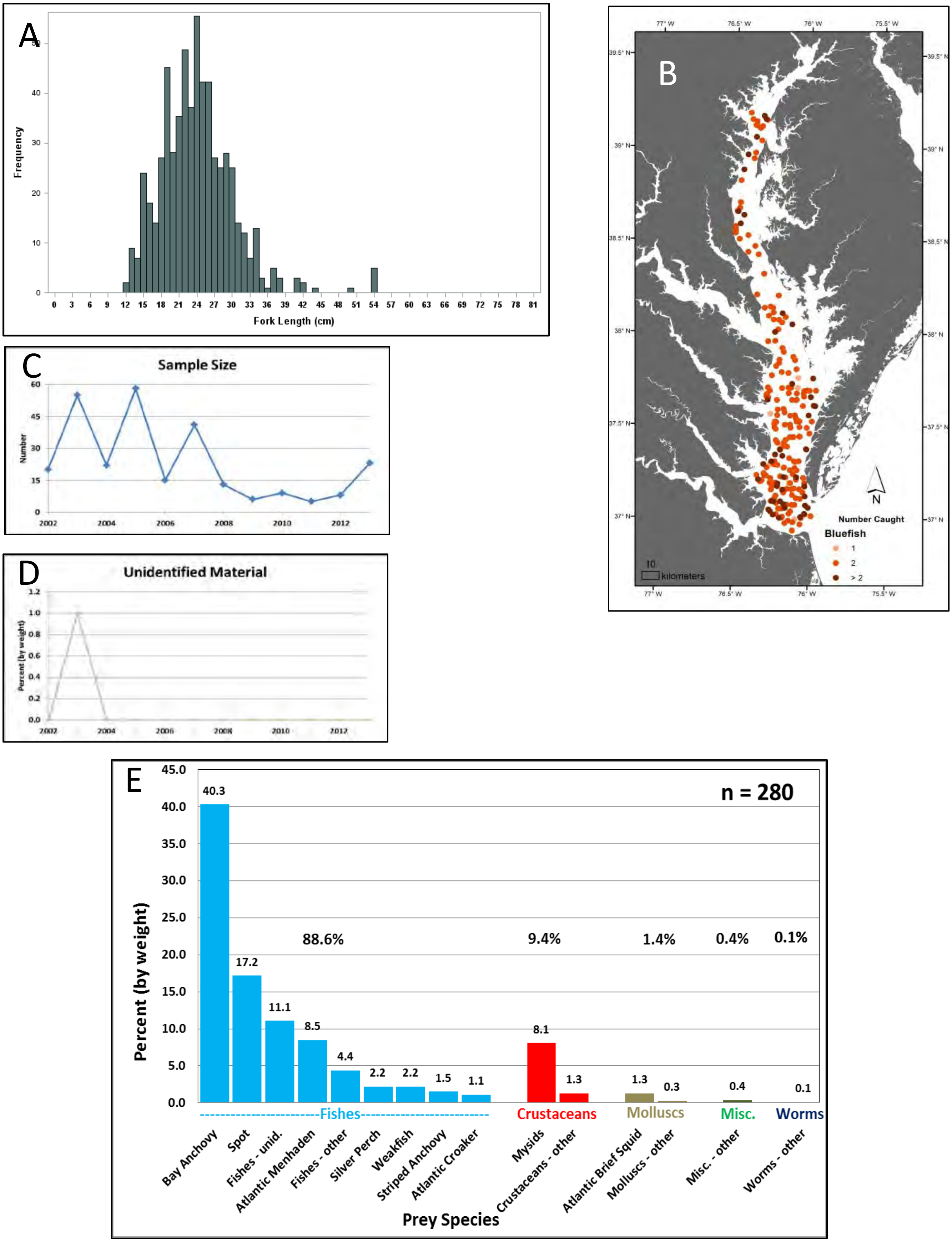
This survey was conducted in the lower York River grass beds only in 2004 and 2005. Species reported here: Striped Bass, Summer Flounder, Weakfish, Atlantic Croaker, Spot, Blue Catfish, and White Perch.

Appendix E: Table of Contents

Highly Piscivorous Fishes

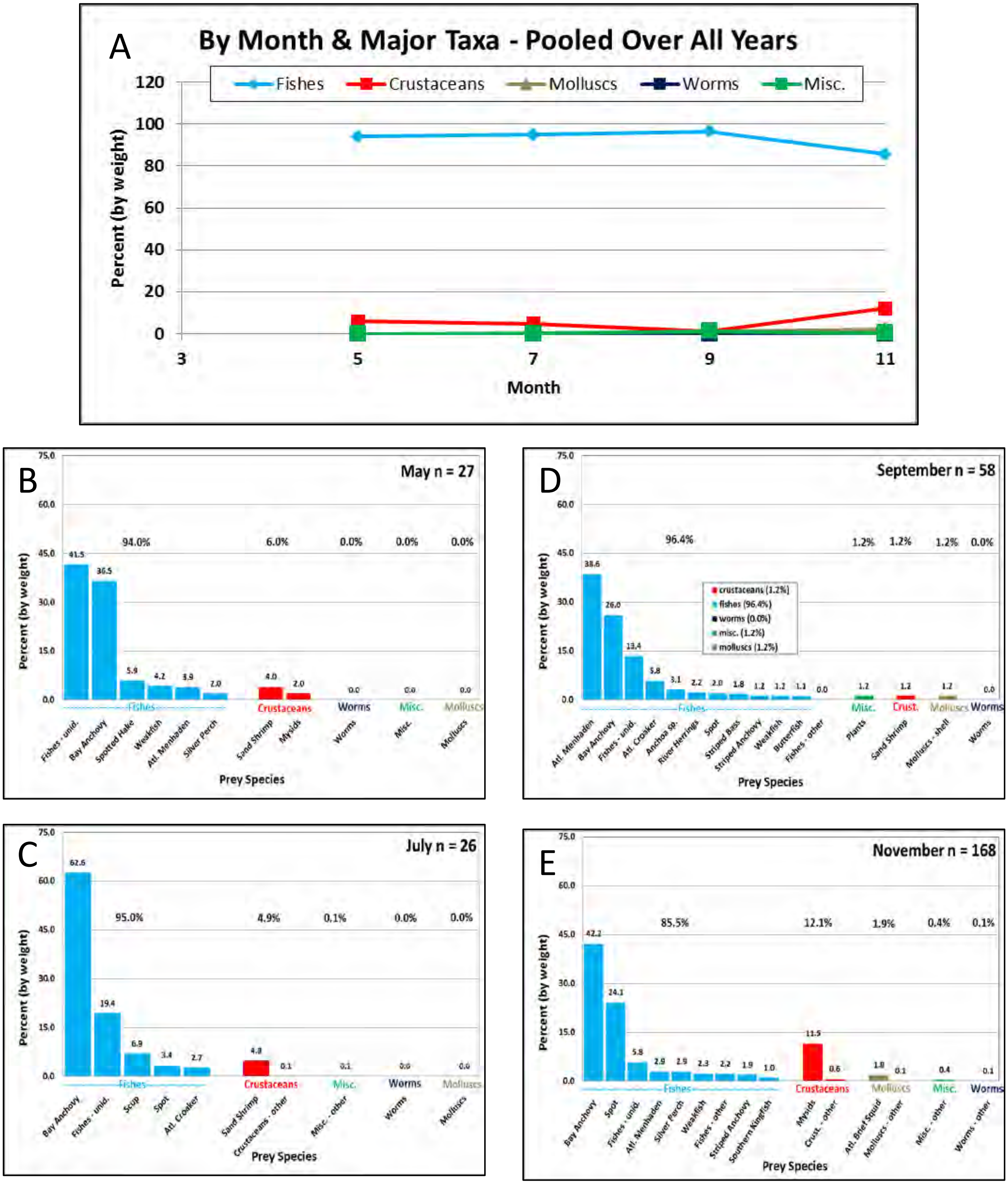
Bluefish

Figure E1. ChesMMAP Bluefish length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), yearly percentage of unidentifiable matter in stomachs (D), and food habits percentages for all data combined for years 2002-2013 (E).



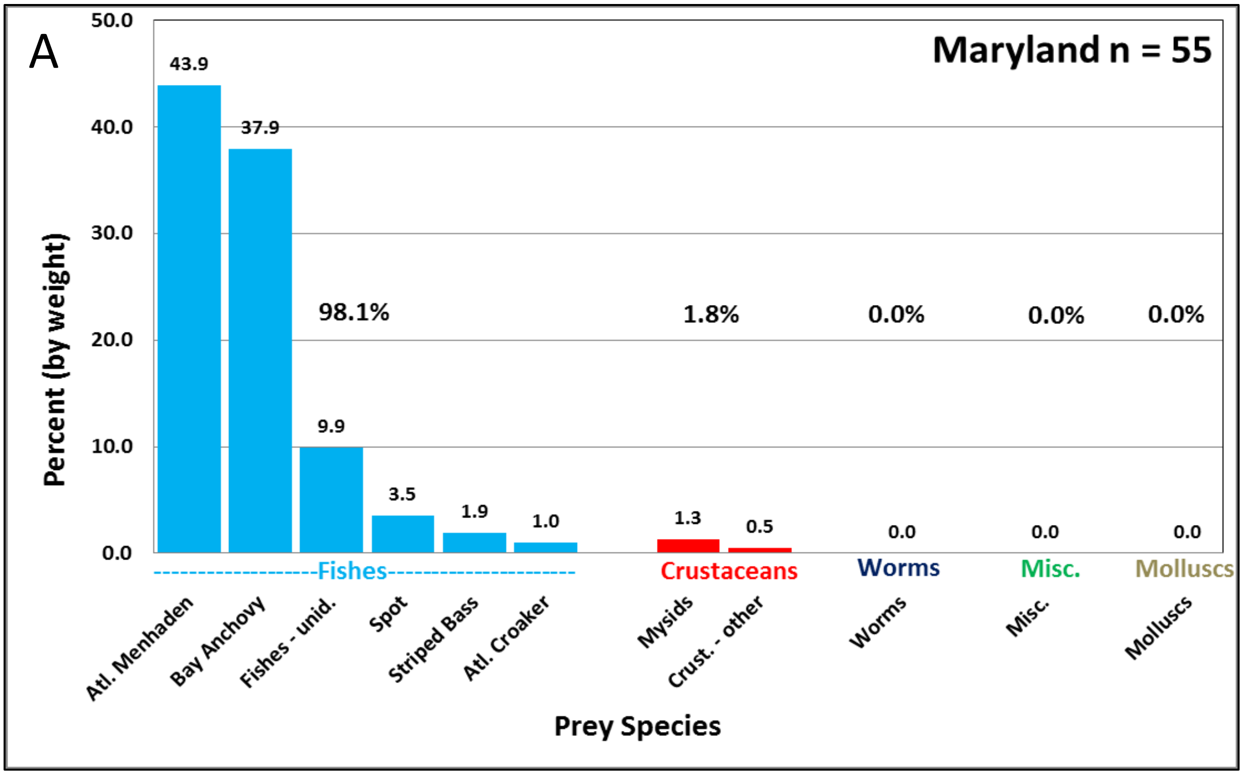
Bluefish

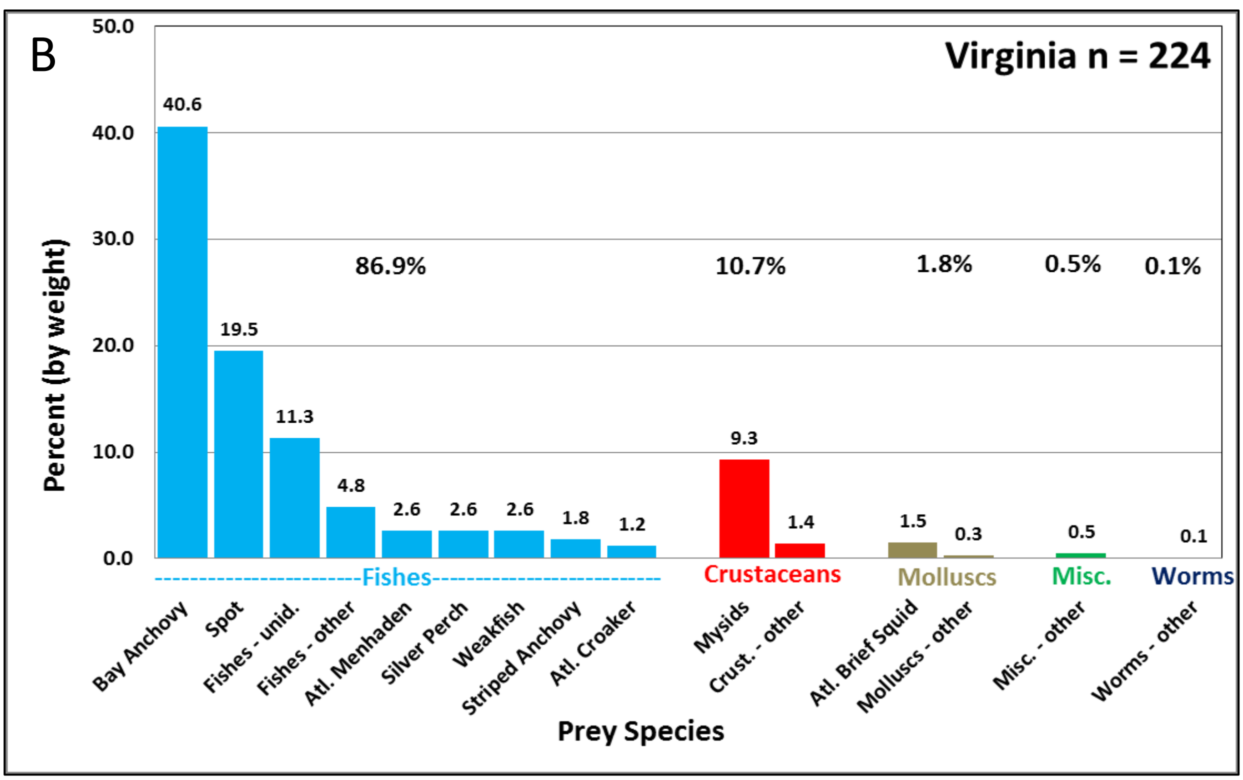
Figure E2. ChesMMAP Bluefish diet summaries by month, with data pooled over all sample years (2002-2013) and areas, for prey types summed over major taxa (A), and by species within major taxa for May (B), July (C), September (D), and November (E).



Bluefish

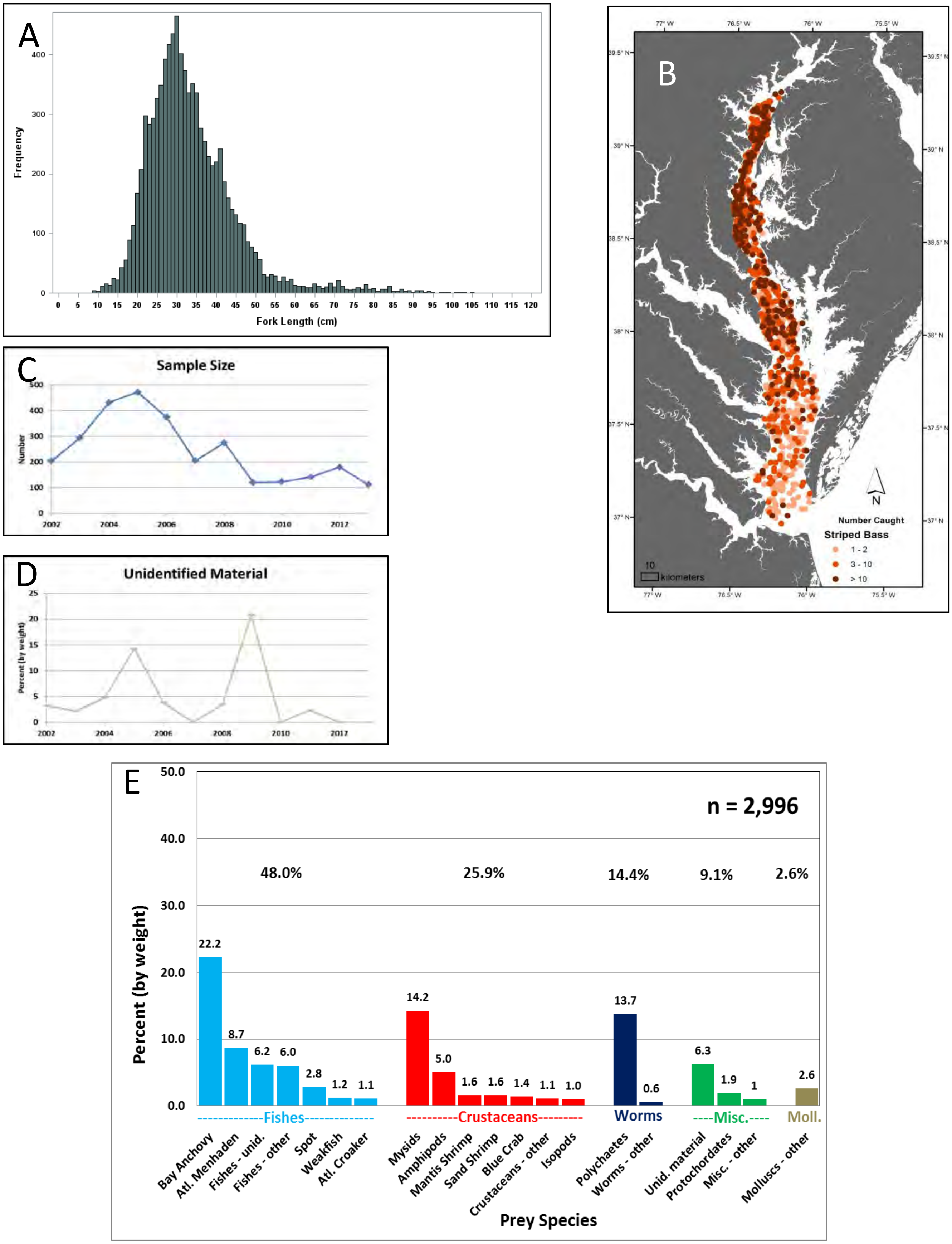
Figure E3. ChesMMAP Bluefish diet summaries by state, with data pooled over all sample years (2002-2013) and months, for Maryland (A), and Virginia (B).





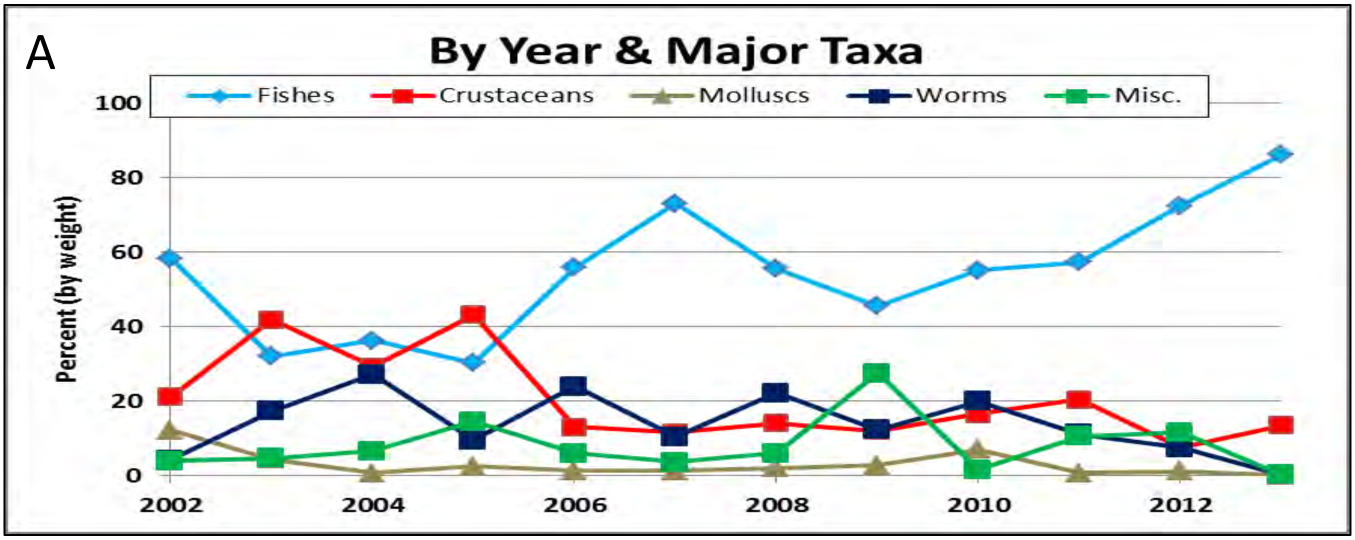
Striped Bass

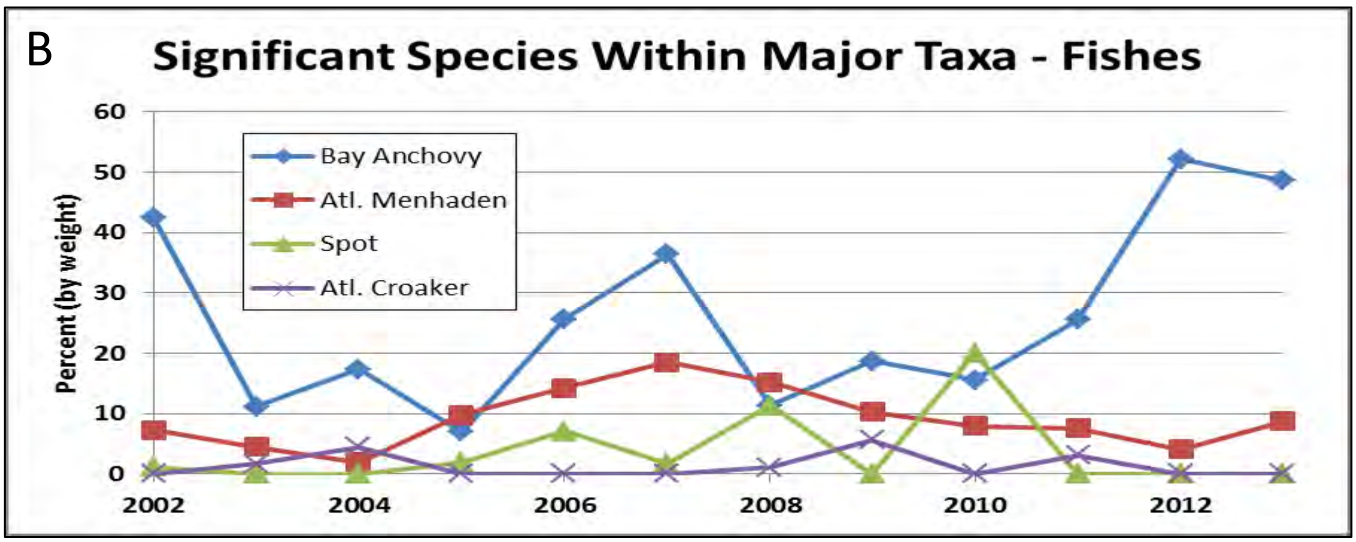
Figure E4. ChesMMAP Striped Bass length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), yearly percentage of unidentifiable matter in stomachs (D), and food habits percentages for all data combined for years 2002-2013 (E).

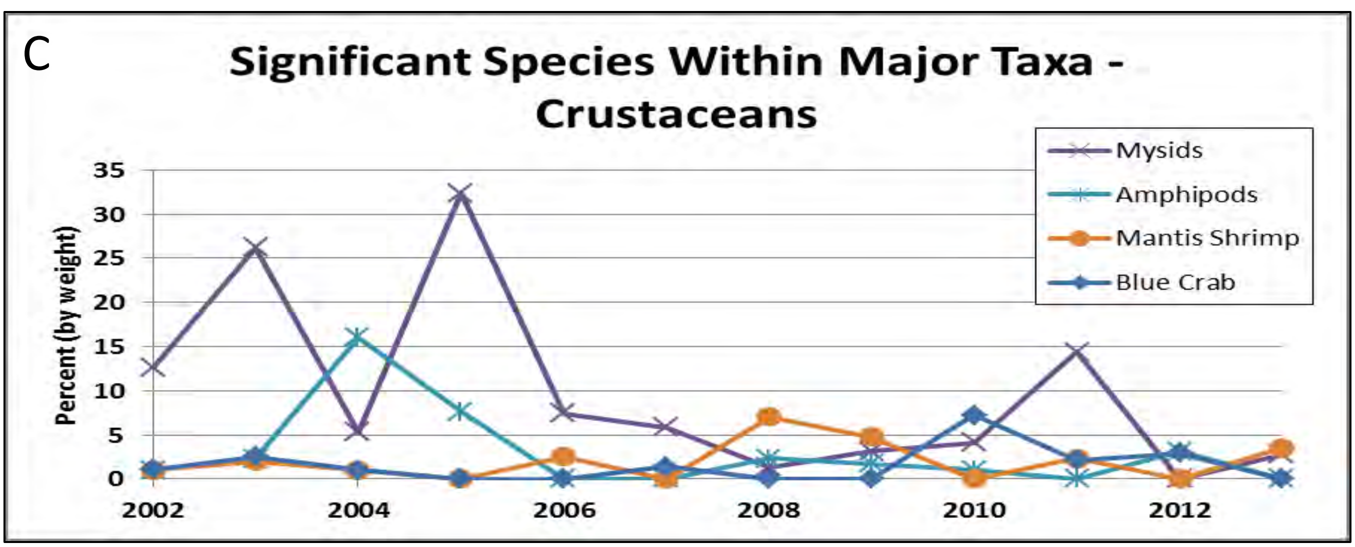


Striped Bass

Figure E5. ChesMMAP Striped Bass diet summaries by year, with data pooled over all sample months and areas, for all species combined within major taxa (A), and for selected species within the fish (B) and crustacean (C) taxa.

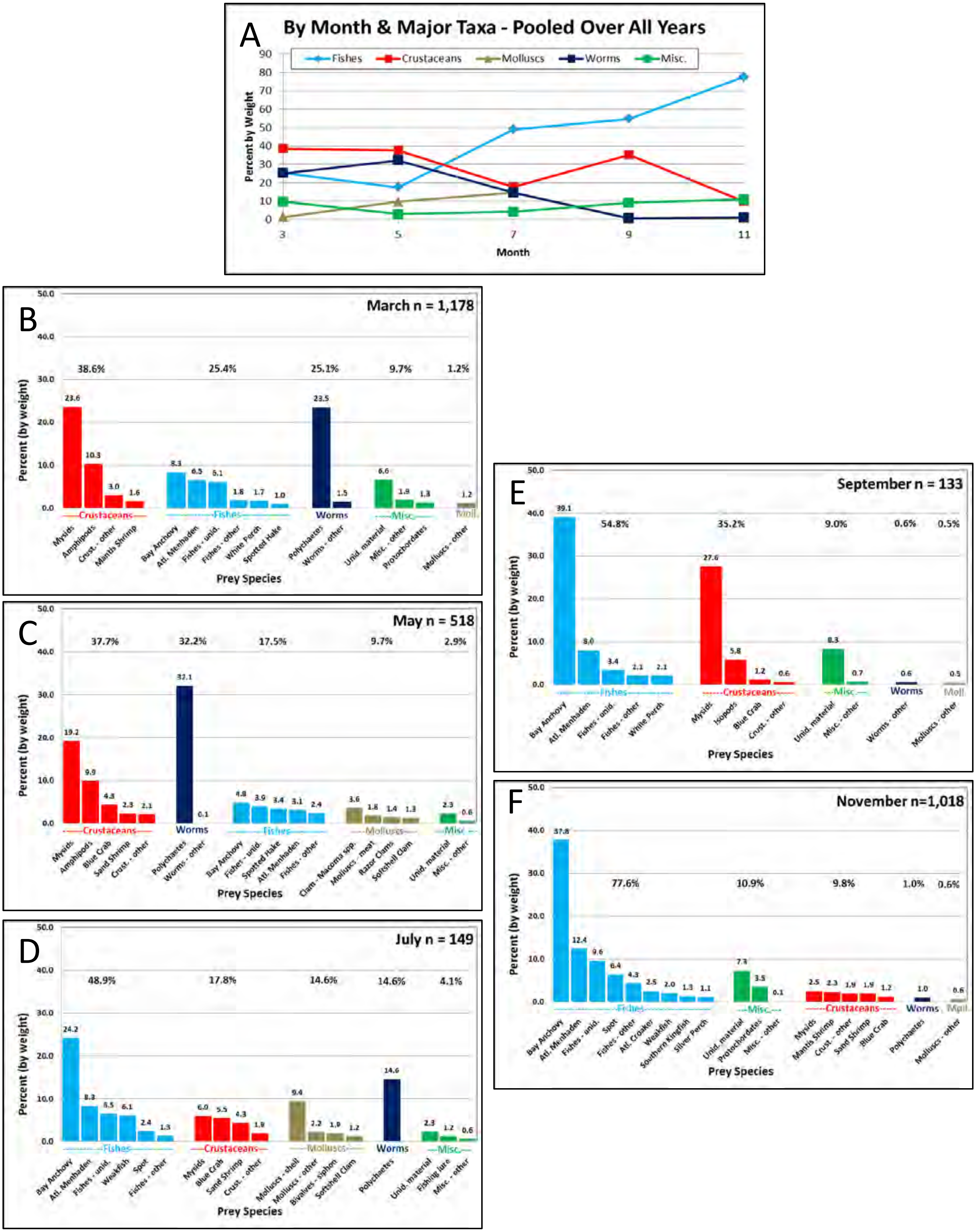






Striped Bass

Figure E6. ChesMMAP Striped Bass diet summaries by month, with data pooled over all sample years (2002-2013), for prey types summed over major taxa (A), and by species within major taxa for March (B), May (C), July (D), September (E), and November (F).

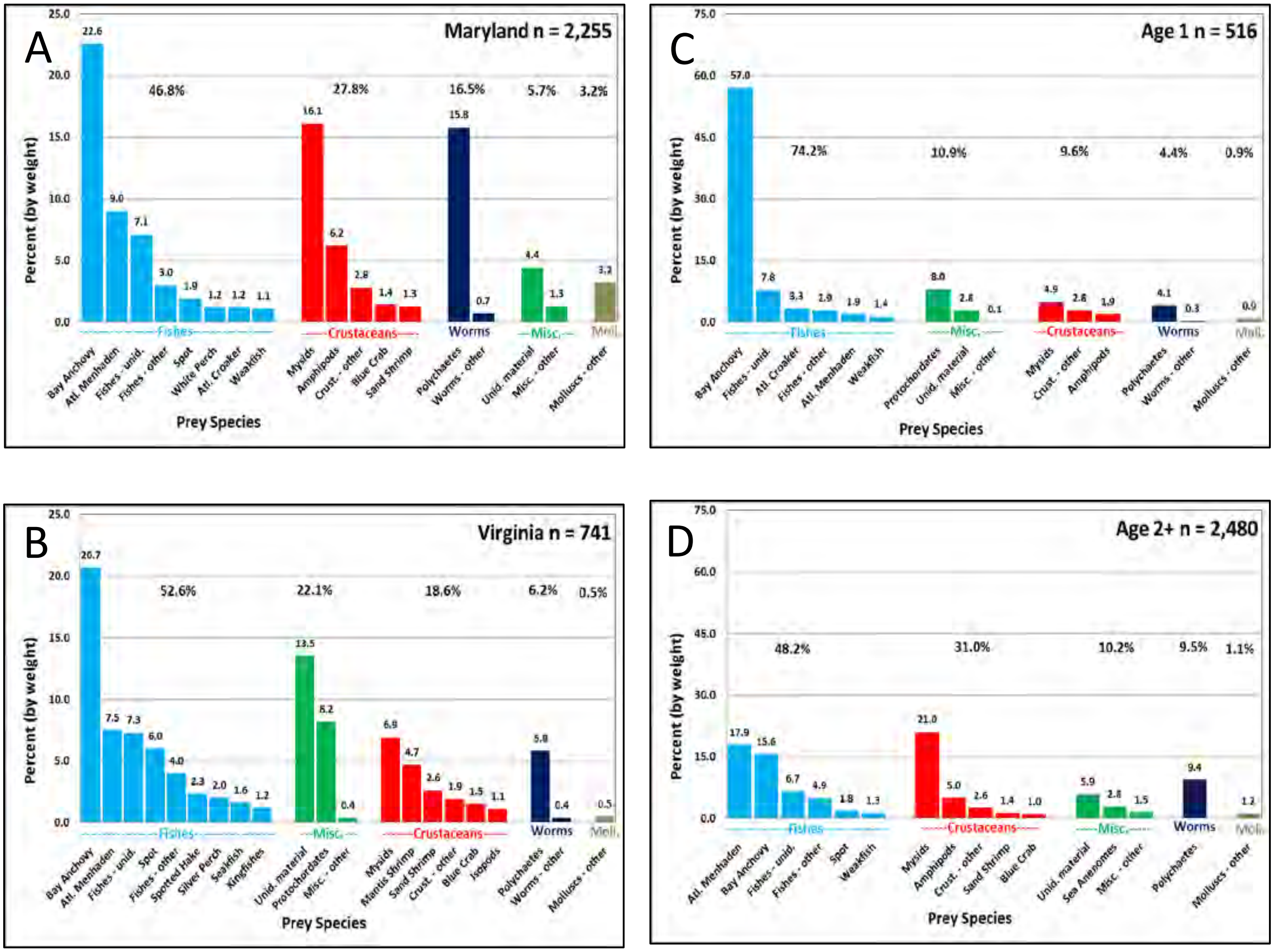


Striped Bass

Figure E7. ChesMMAP Striped Bass diet summaries by state with data pooled over all sample years (2002-2013) and months for Maryland (A) and Virginia (B); and by age group with data pooled over all years, months, and areas for age-1 (C) and ages-2 and older (D).

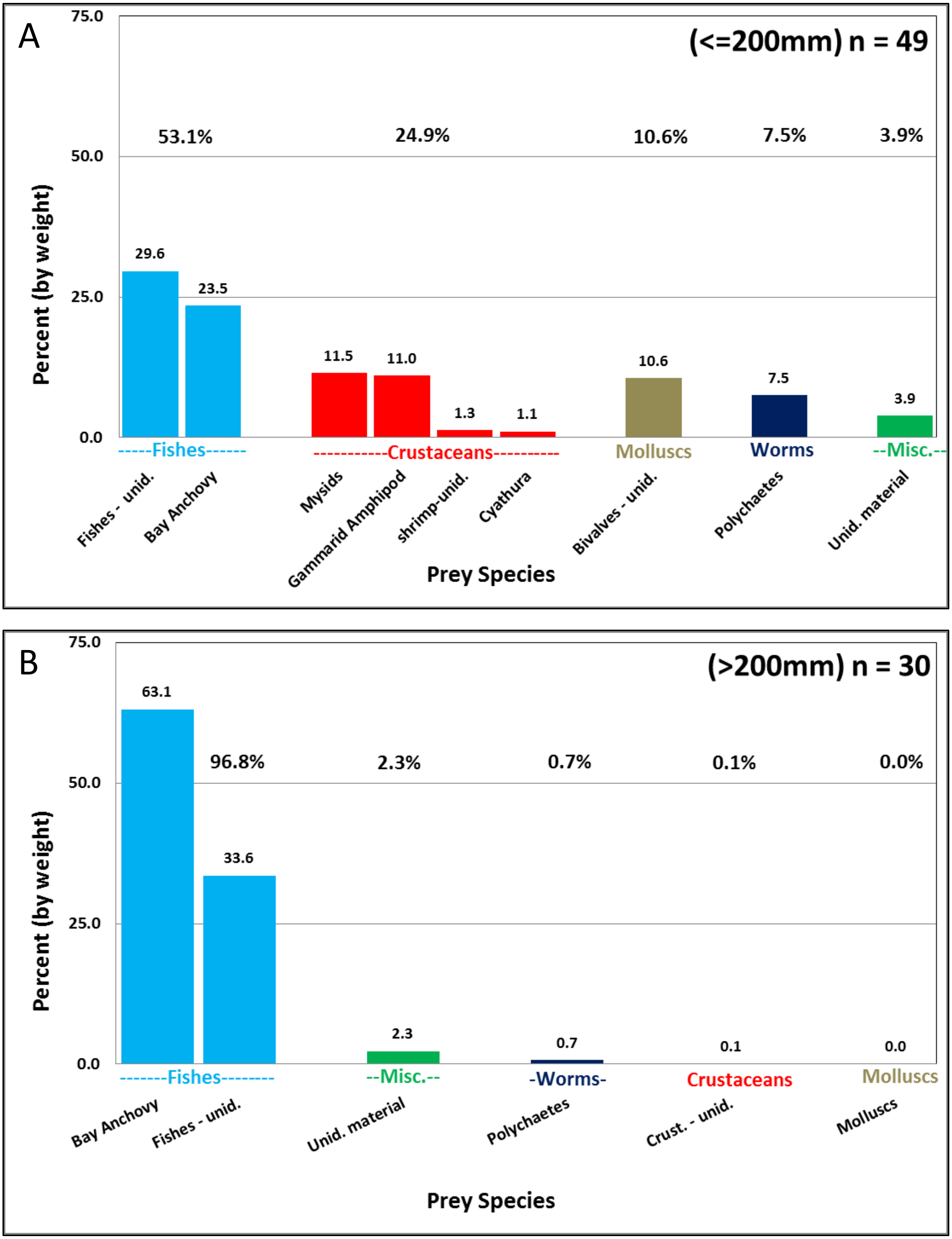
By State

By Age Group



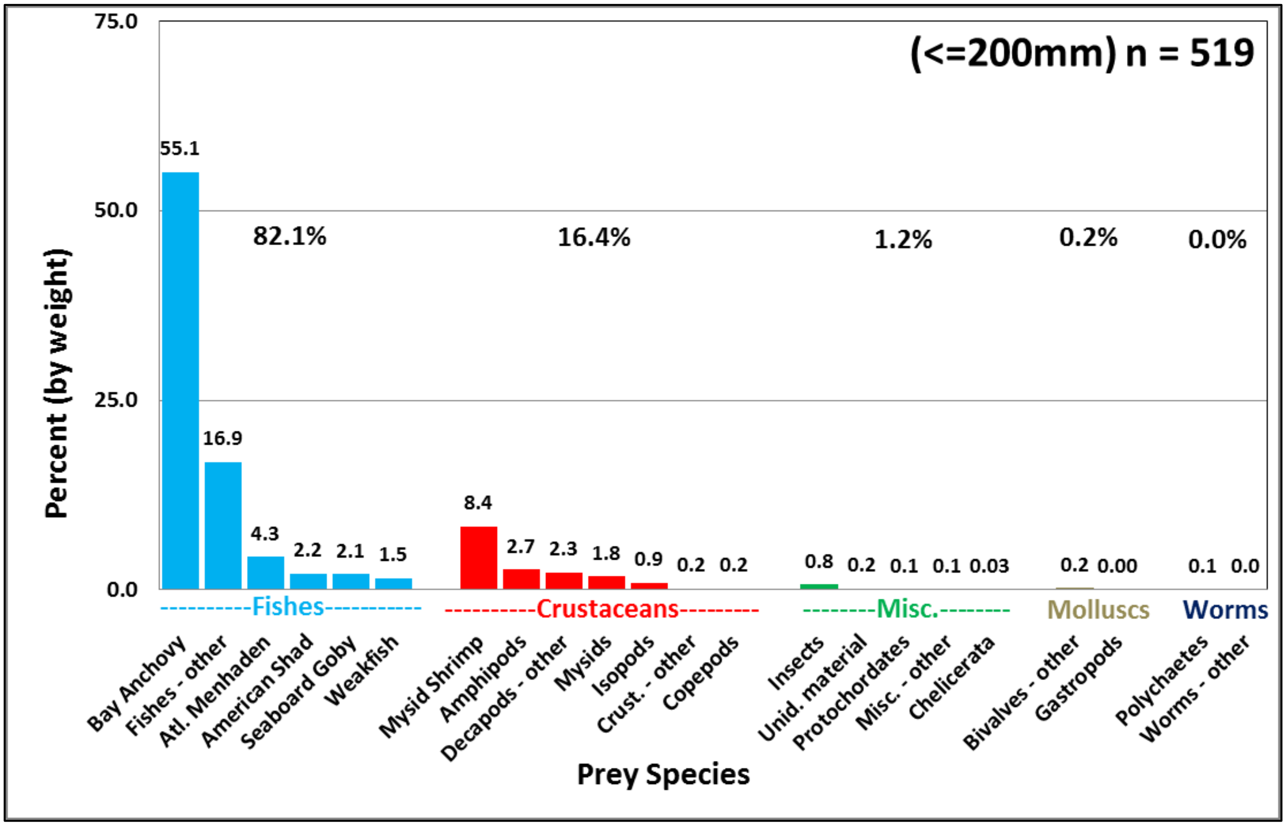
Striped Bass

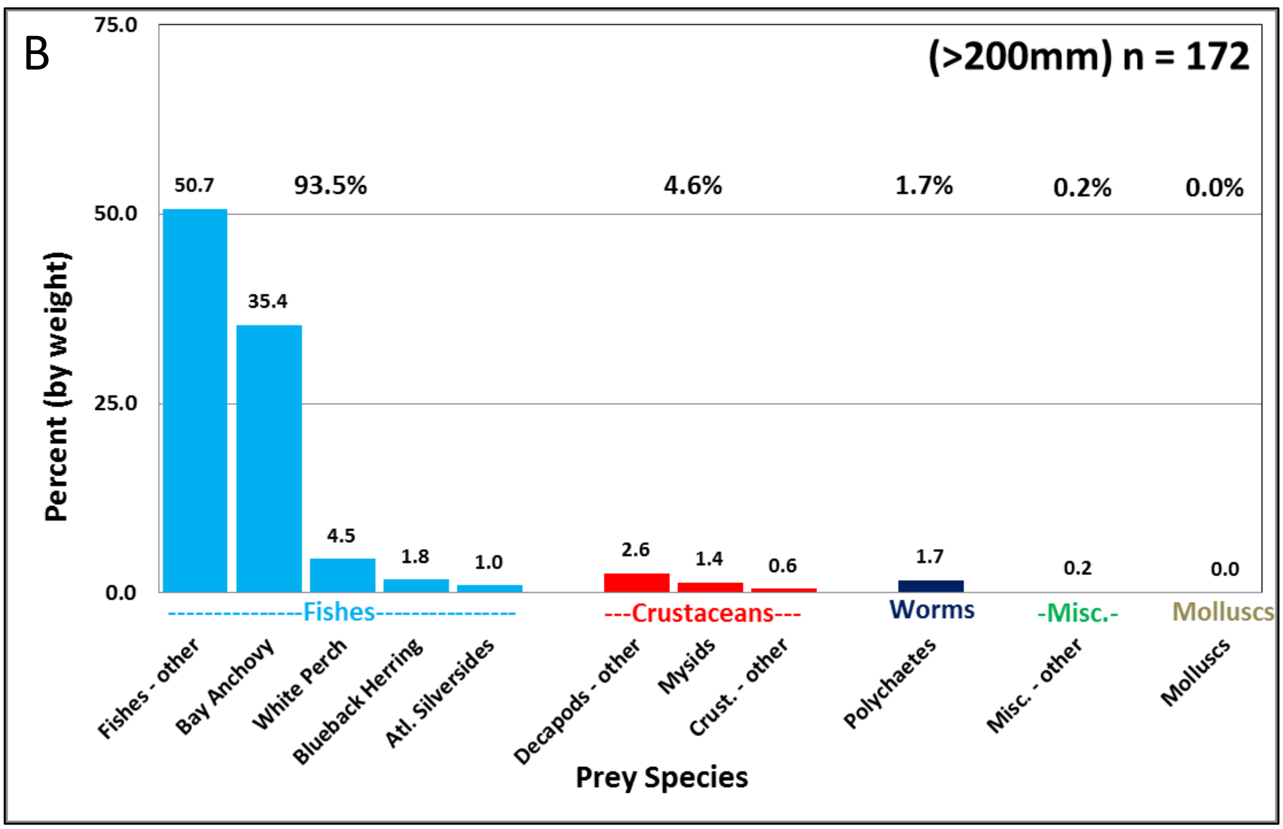
Figure E8. CHESFIMS Striped Bass diet summaries by size group with data pooled over all sample years and months for specimens 200mm and smaller (A) and 201mm and larger (B)



Striped Bass

Figure E9. VIMS Juvenile Fishes Trawl Survey Striped Bass diet summaries by size group with data pooled over all sample years and months for specimens 200mm and smaller (A) and 201mm and larger (B)





Striped Bass

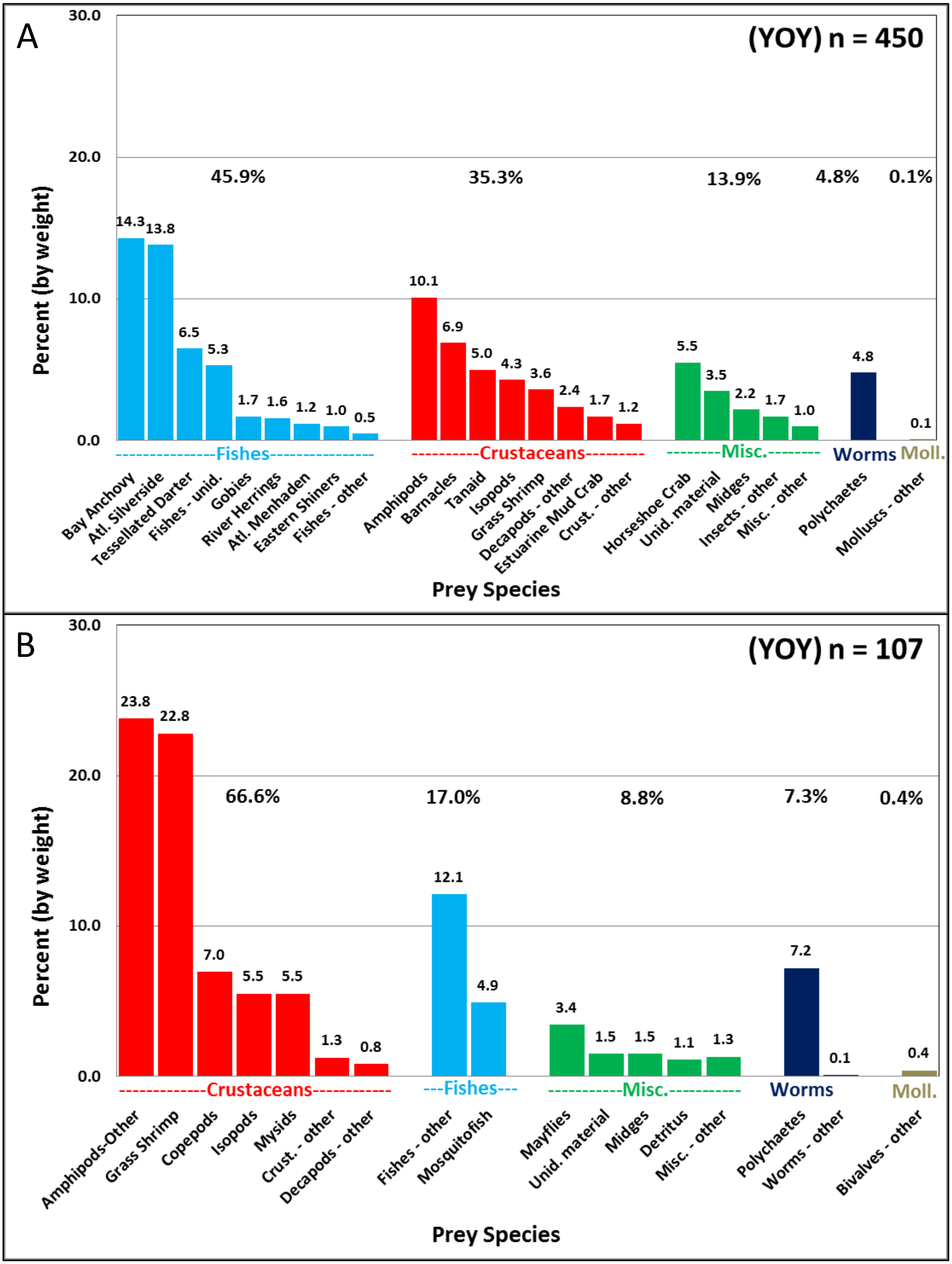


Figure E10. Maryland (A – 2003-2004) and Virginia (B – 2004-2006) Juvenile Fishes Seine Surveys Striped Bass young-of-year diet summaries.

Striped Bass

Figure E11. VIMS Trammel Net Survey Striped Bass diet summary (2004-2005).

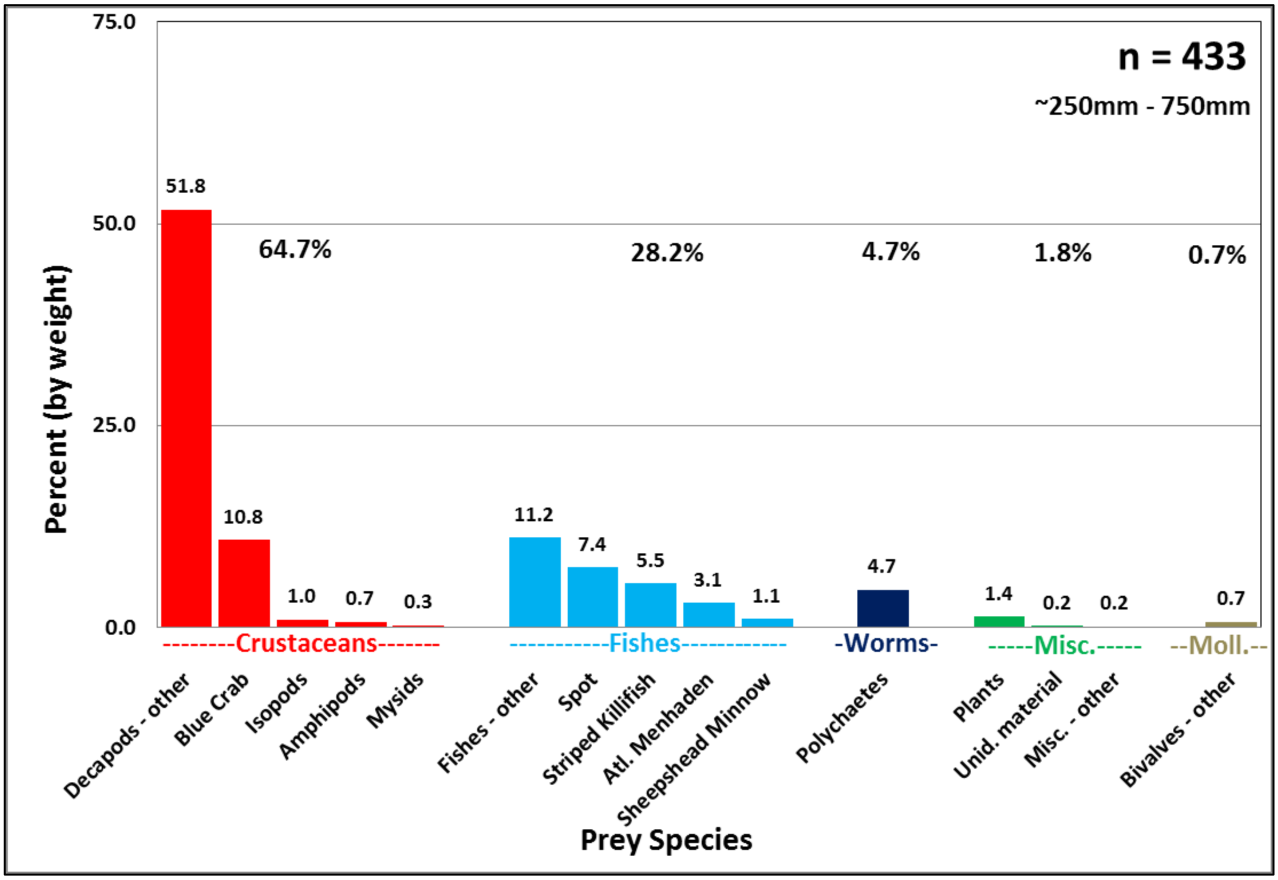
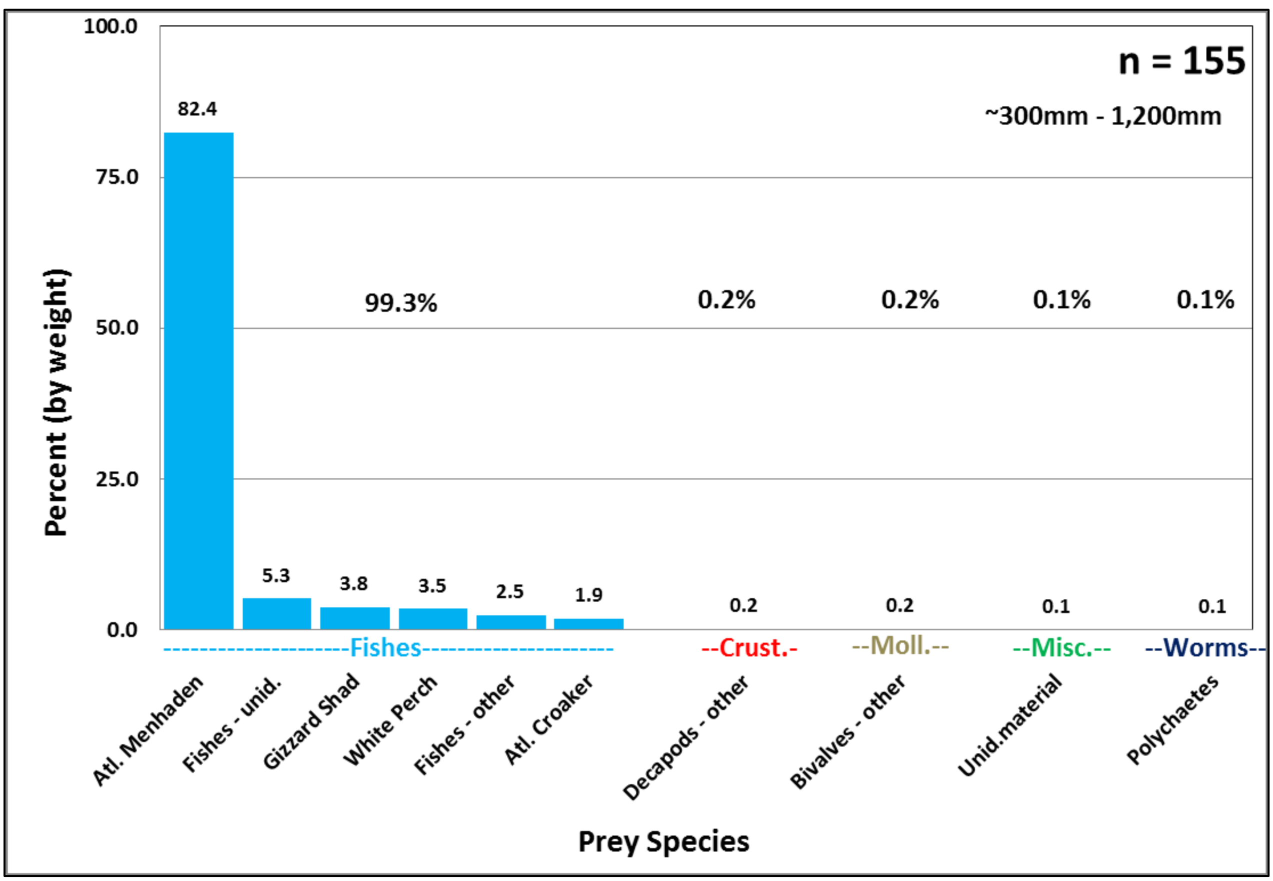
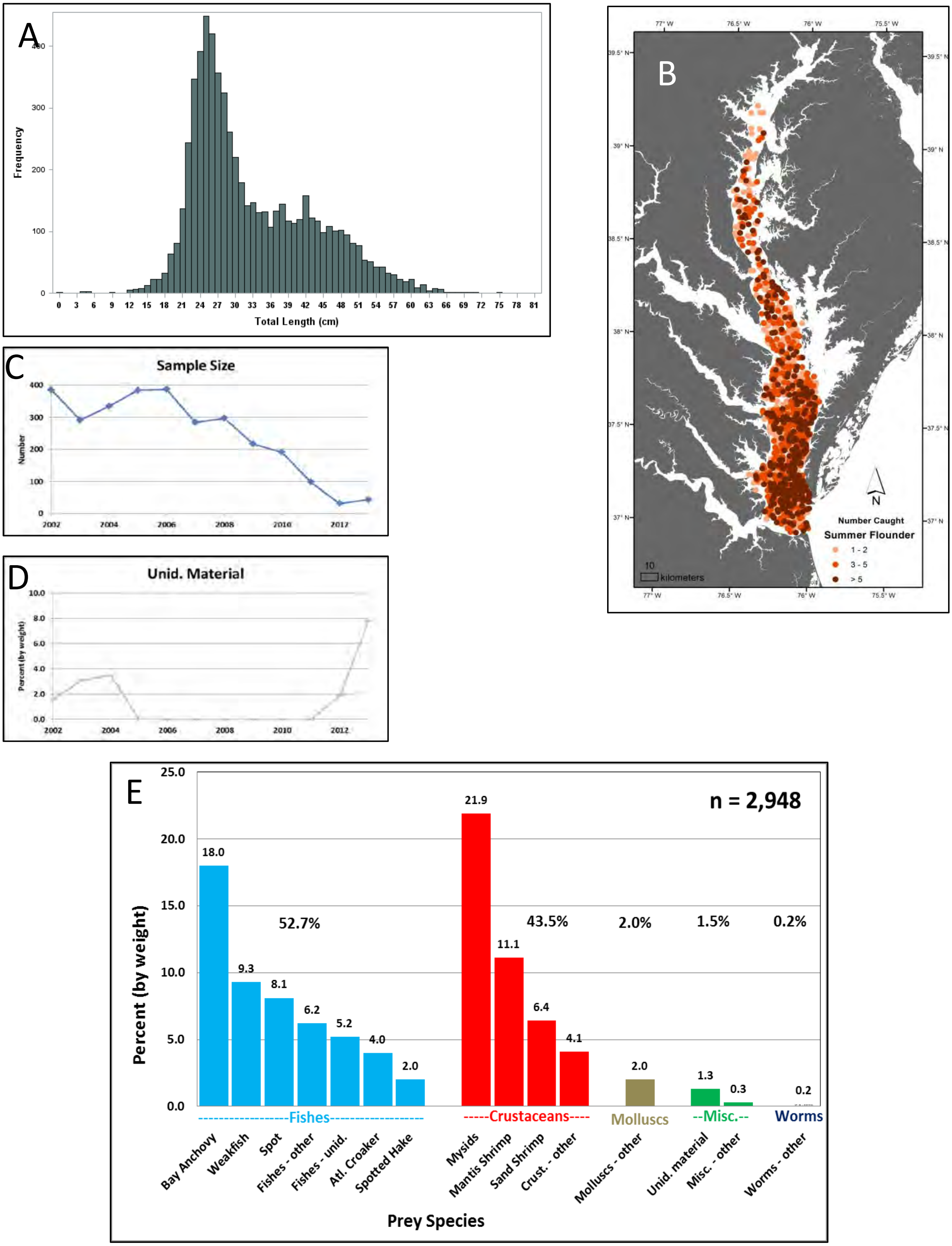


Figure E12. Maryland Adult Striped Bass Survey diet summary (2003-2005).



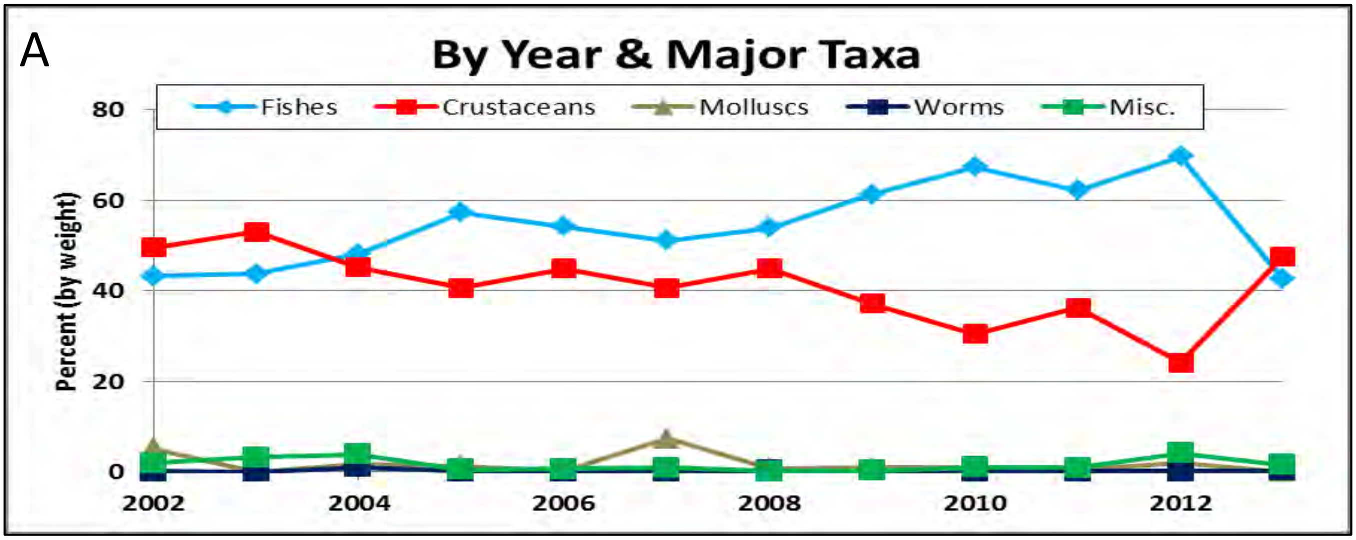
Summer Flounder

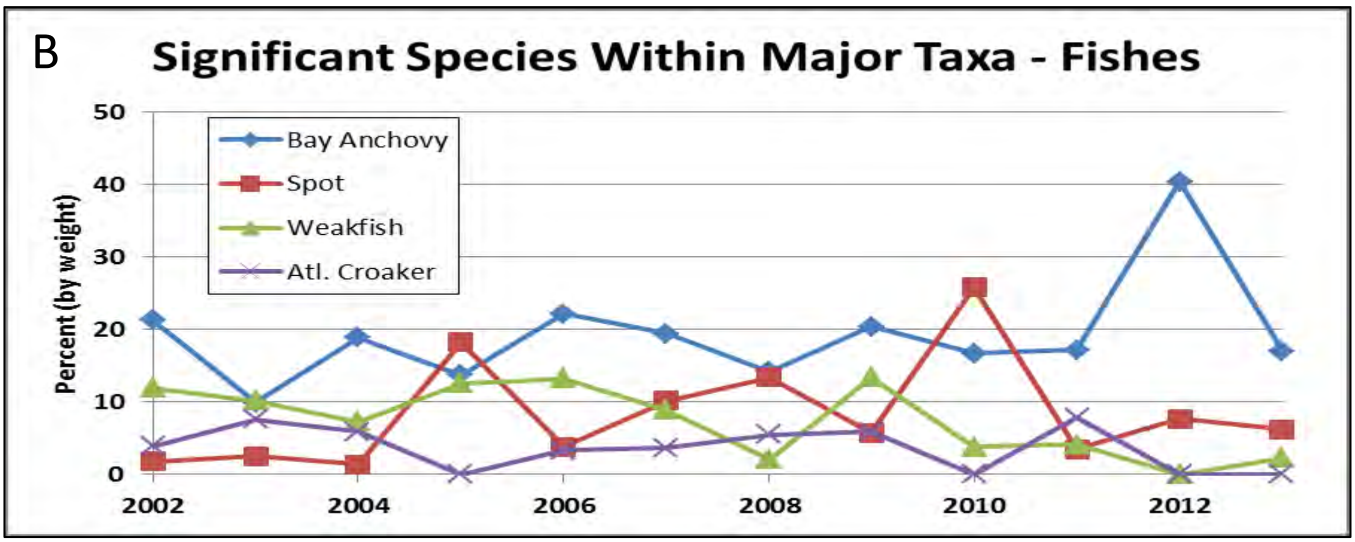
Figure E13. ChesMMAP Summer Flounder length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), yearly percentage of unidentifiable matter in stomachs (D), and food habits percentages for all data combined for years 2002-2013 (E).

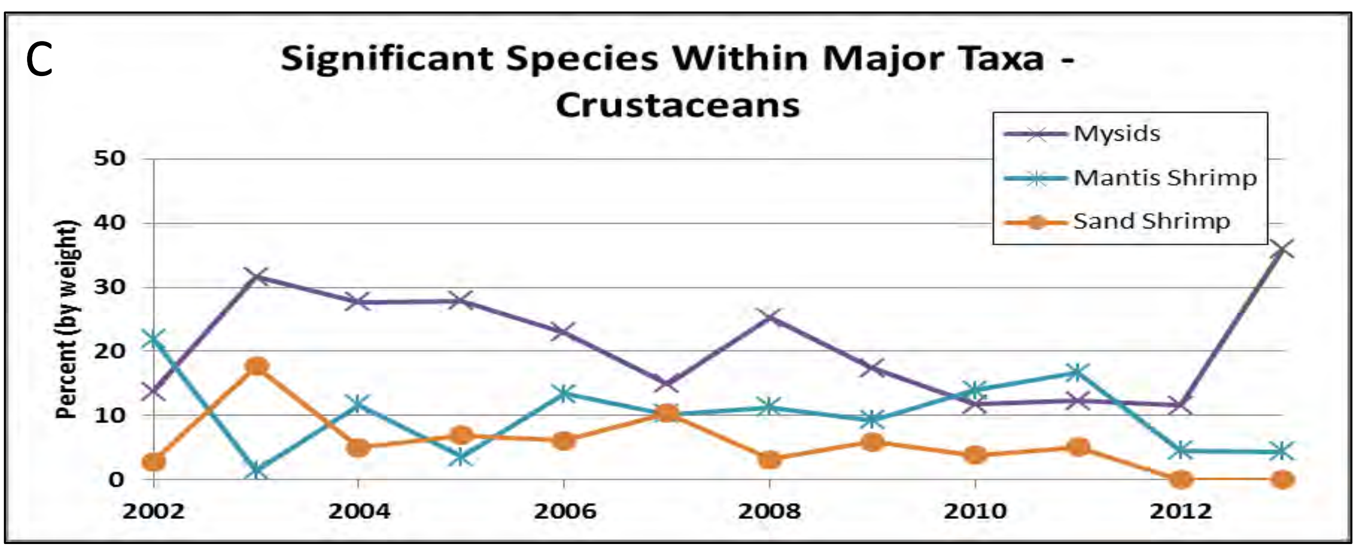


Summer Flounder

Figure E14. ChesMMAP Summer Flounder diet summaries by year, with data pooled over all sample months and areas, for all species combined within major taxa (A), and for selected species within the fish (B) and crustacean (C) taxa.

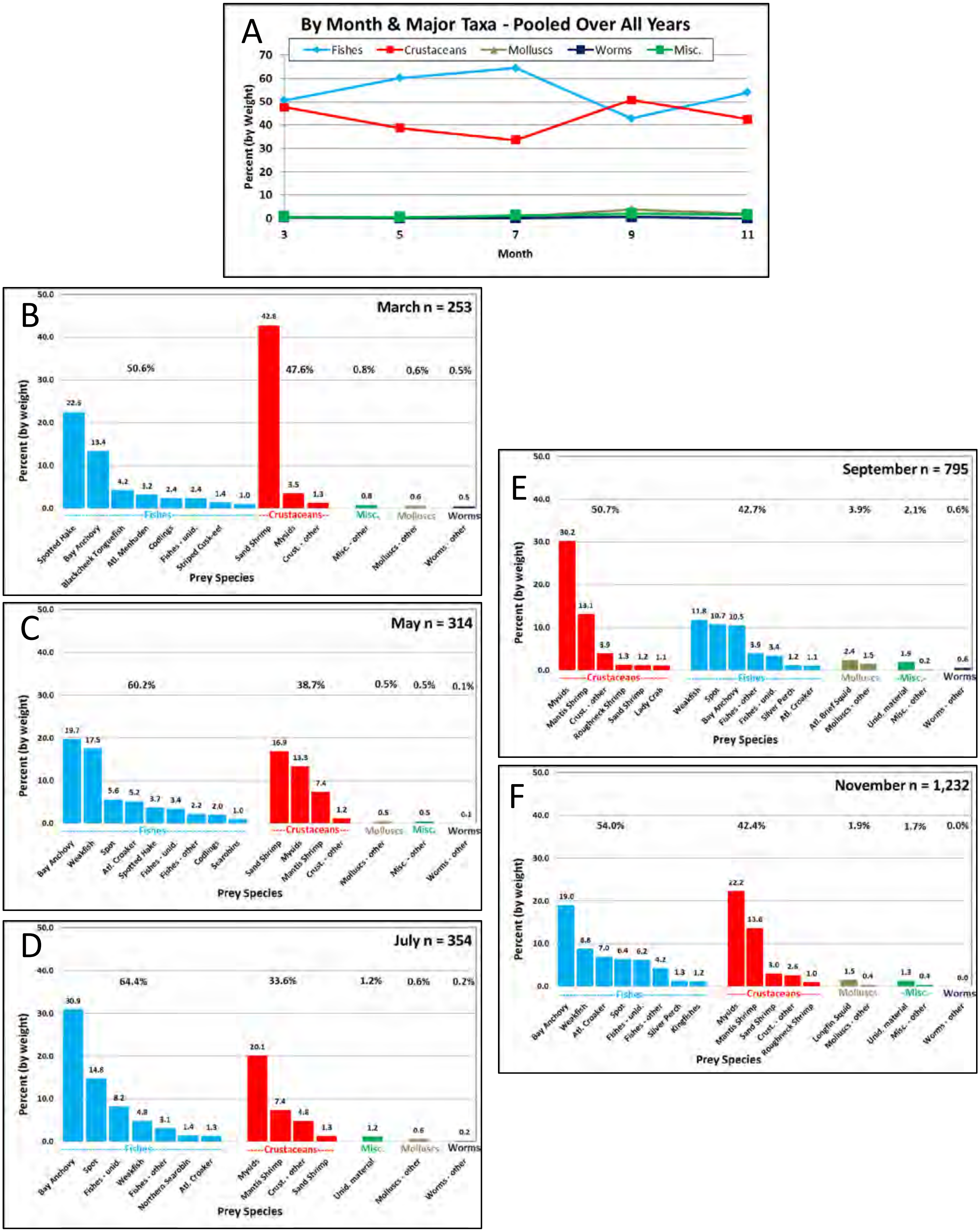






Summer Flounder

Figure E15. ChesMMAP Summer Flounder diet summaries by month, with data pooled over all sample years (2002-2013), for prey types summed over major taxa (A), and by species within major taxa for March (B), May (C), July (D), September (E), and November (F).

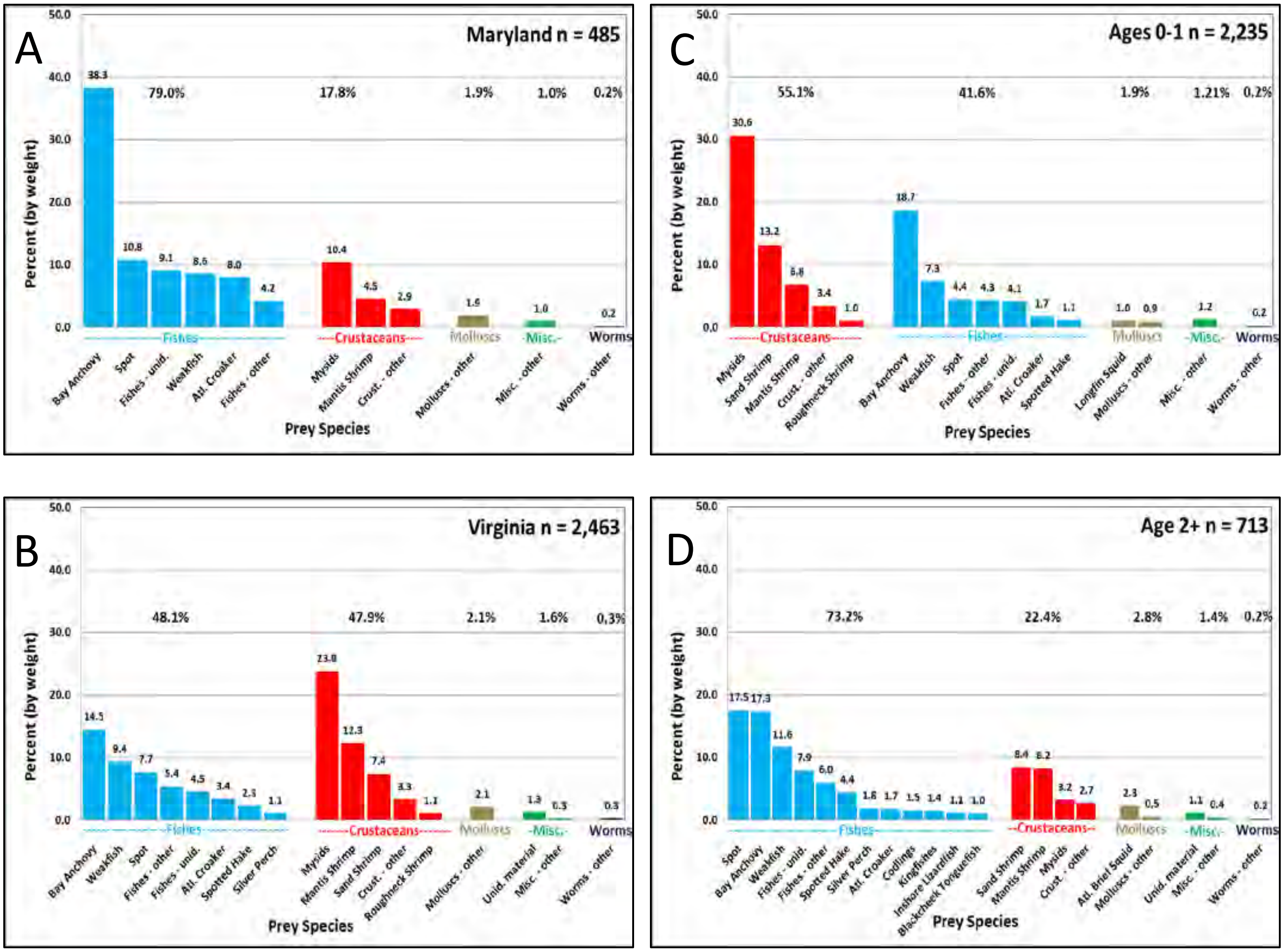


Summer Flounder

Figure E16. ChesMMAP Summer Flounder diet summaries by state with data pooled over all sample years (2002-2013) and months for Maryland (A) and Virginia (B); and by age group with data pooled over all years, months, and areas for ages0-1 (C) and ages-2 and older (D).

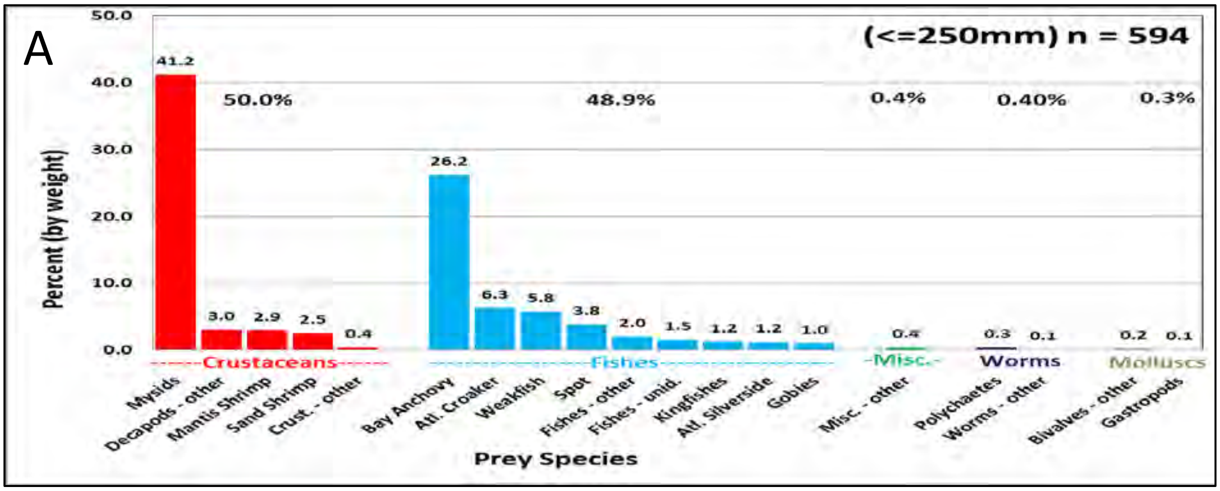
By State

By Age Group



Summer Flounder

Figure E17. VIMS Juvenile Fishes Trawl Survey Summer Flounder diet summaries by size group with data pooled over all sample years and months for specimens 250mm and smaller (A) and 251mm and larger (B).



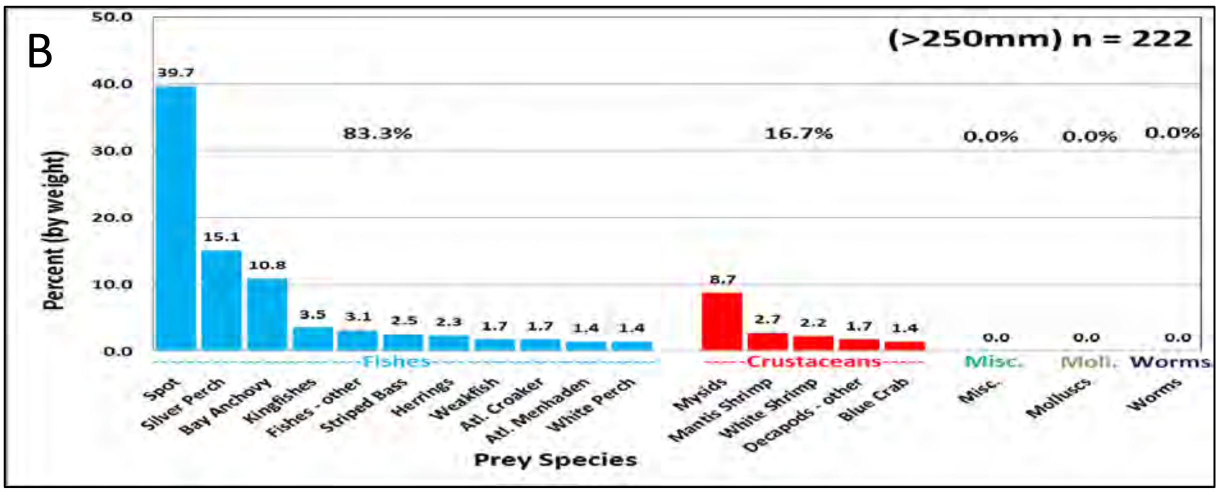
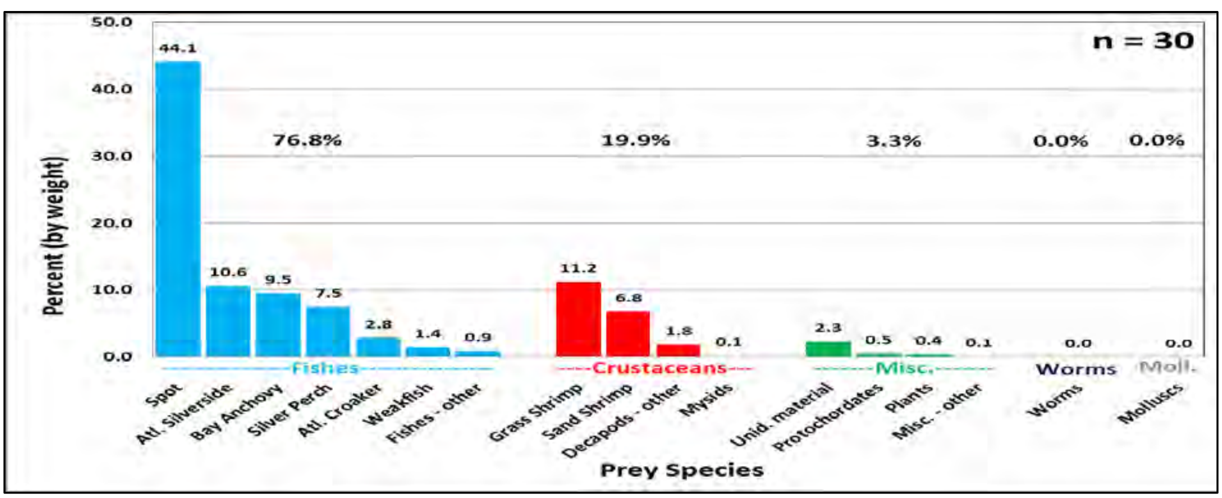
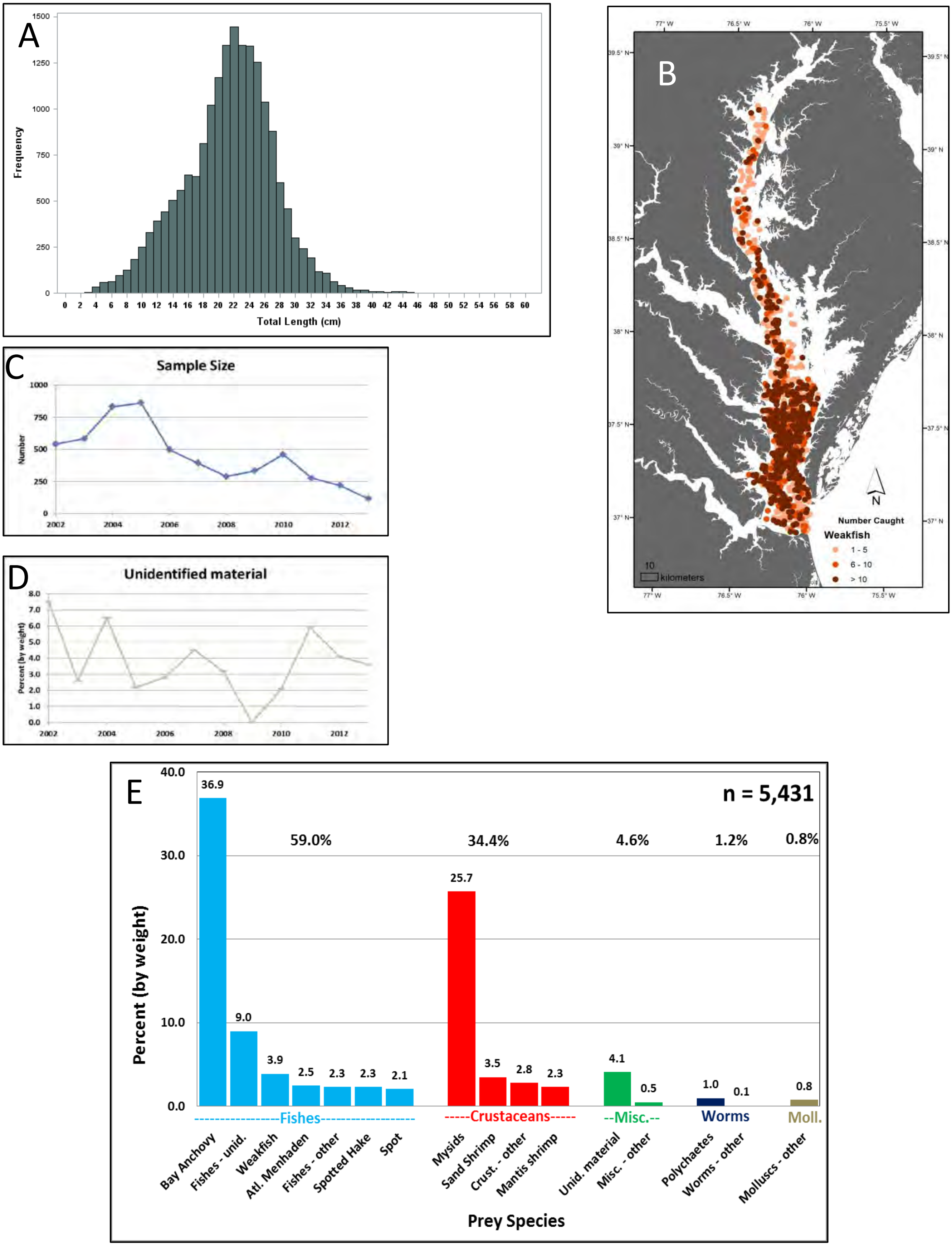


Figure E18. VIMS Trammel Net Survey Summer Flounder diet summary (2004-2005).



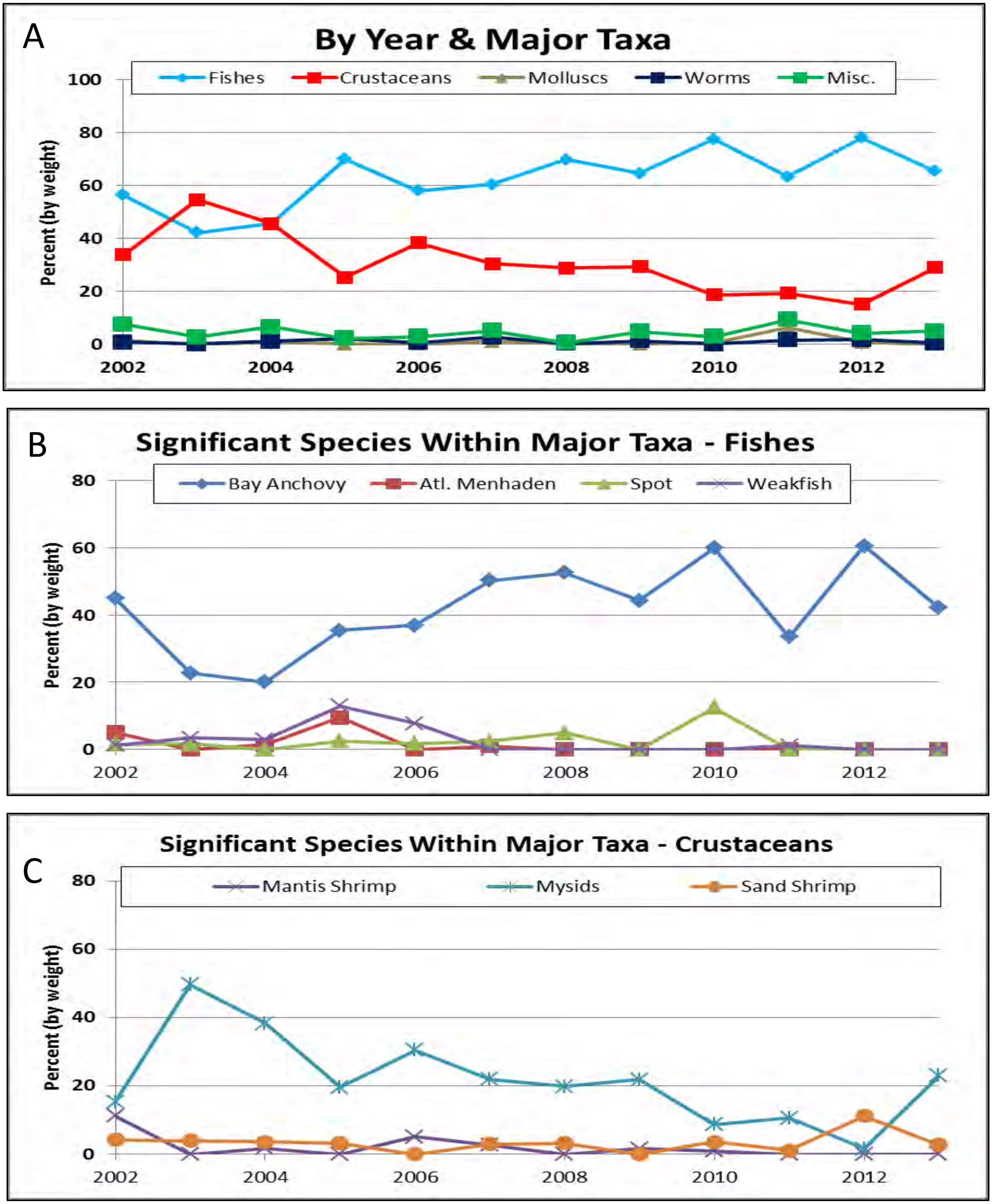
Weakfish

Figure E19. ChesMMAP Weakfish length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), yearly percentage of unidentifiable matter in stomachs (D), and food habits percentages for all data combined for years 2002-2013 (E).



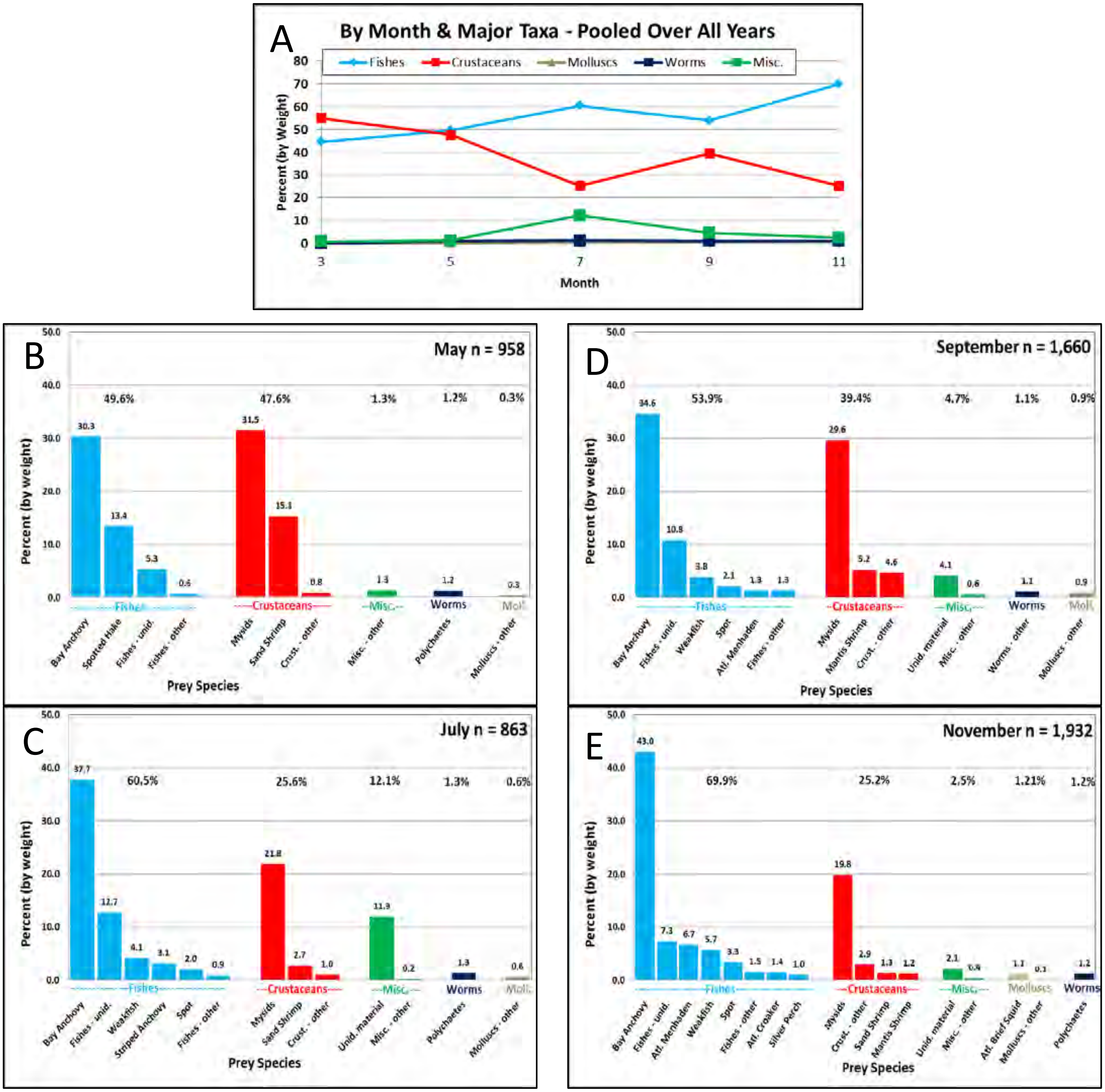
Weakfish

Figure E20. ChesMMAP Weakfish diet summaries by year, with data pooled over all sample months and areas, for all species combined within major taxa (A), and for selected species within the fish (B) and crustacean (C) taxa.



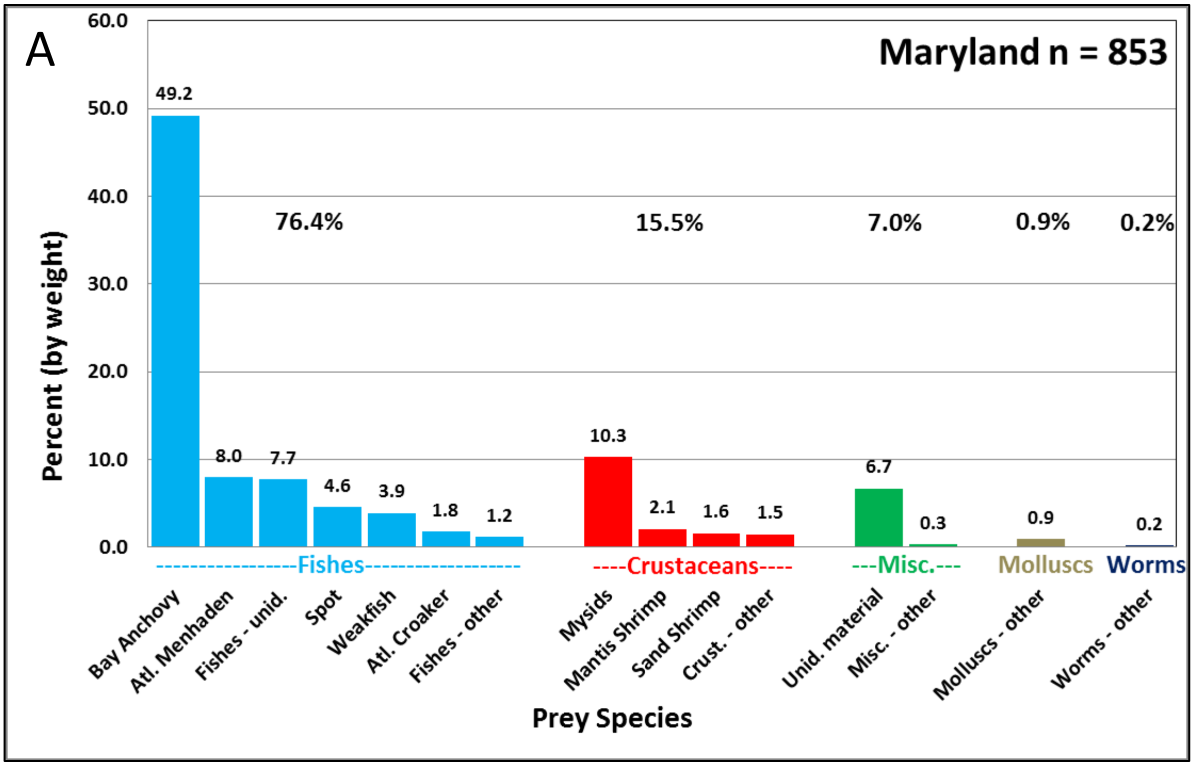
Weakfish

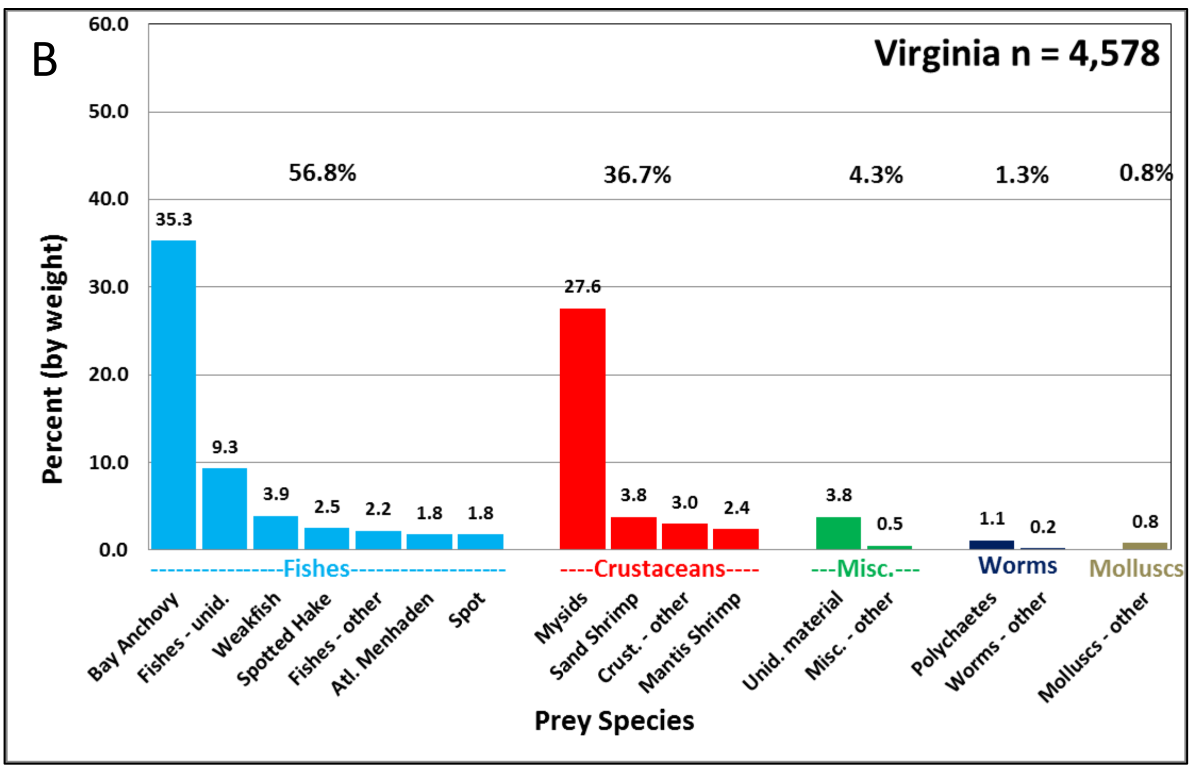
Figure E21. ChesMMAP Weakfish diet summaries by month, with data pooled over all sample years (2002-2013), for prey types summed over major taxa (A), and by species within major taxa for May (B), July (C), September (D), and November (E).



Weakfish

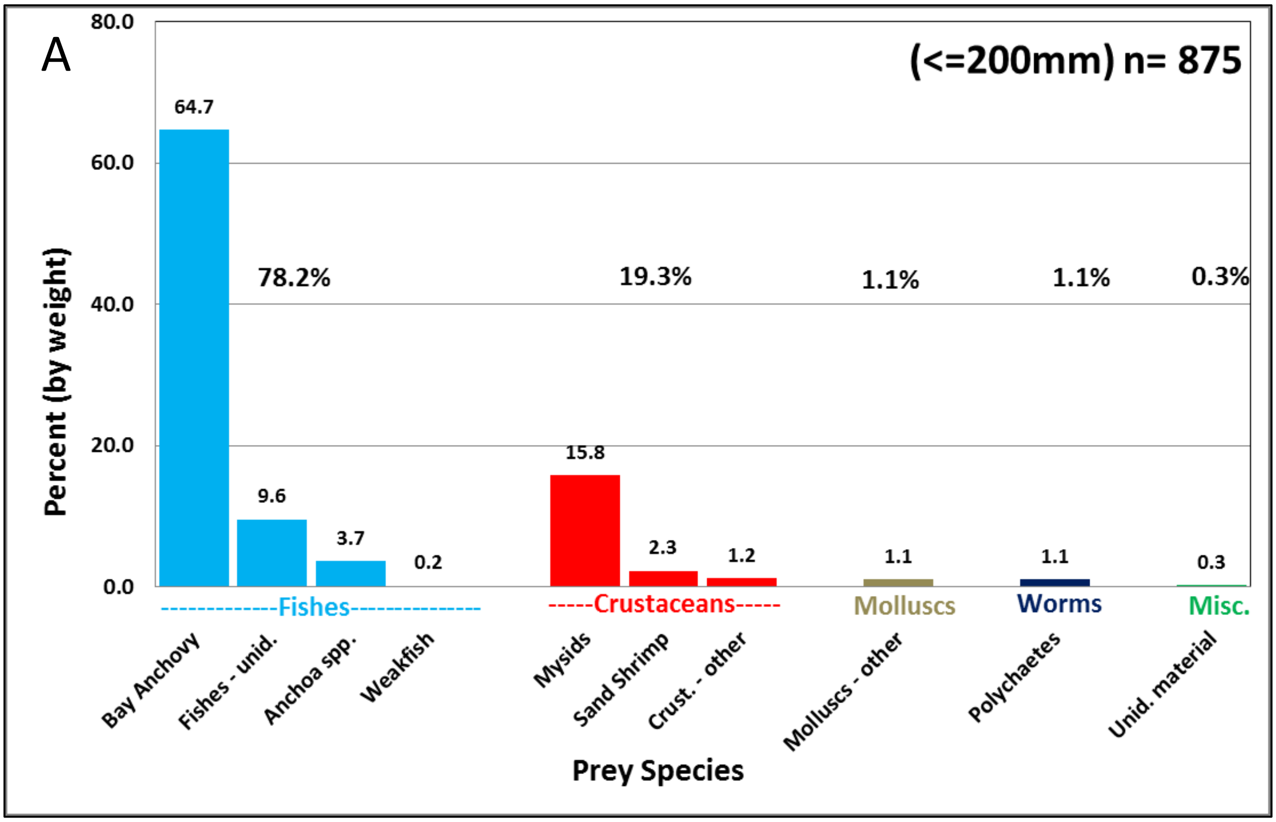
Figure E22. ChesMMAP Weakfish diet summaries by state, with data pooled over all sample years (2002-2013) and months, for Maryland (A), and Virginia (B).

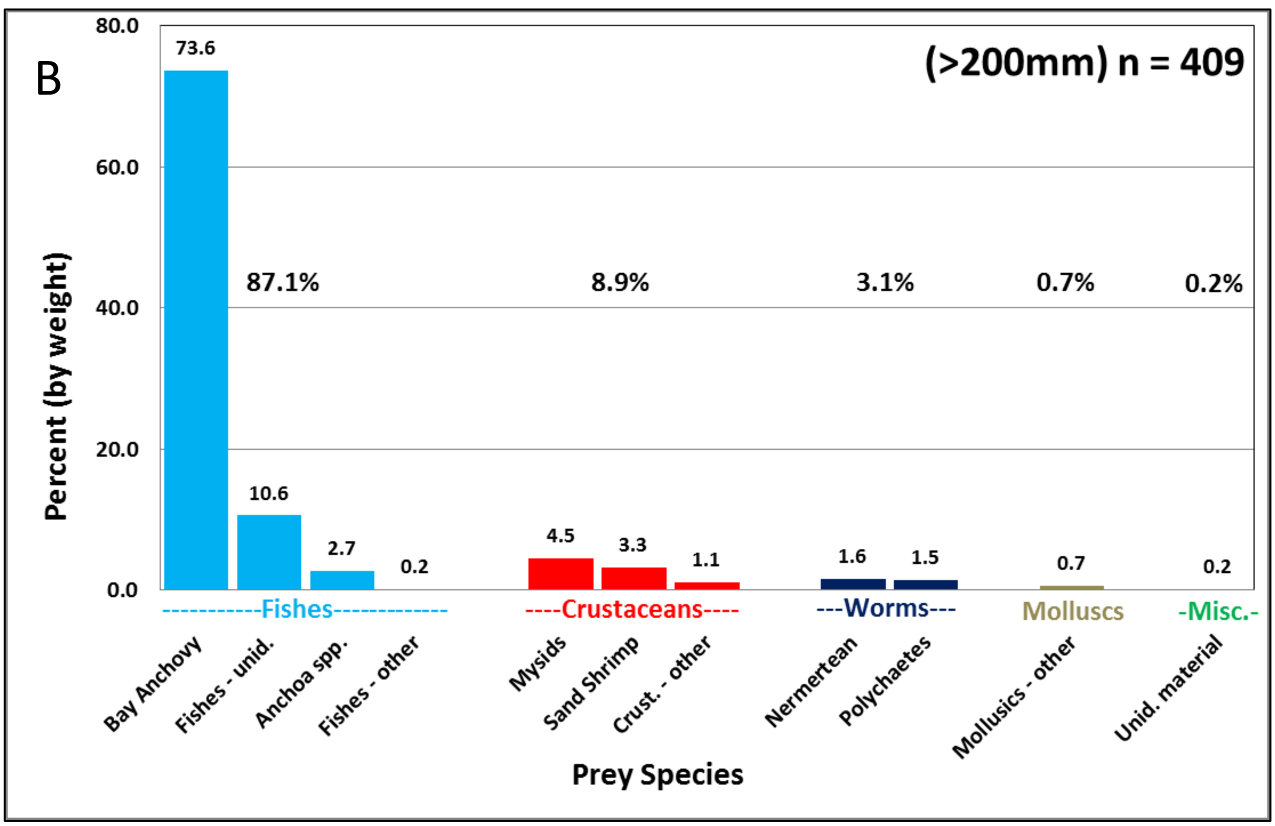




Weakfish

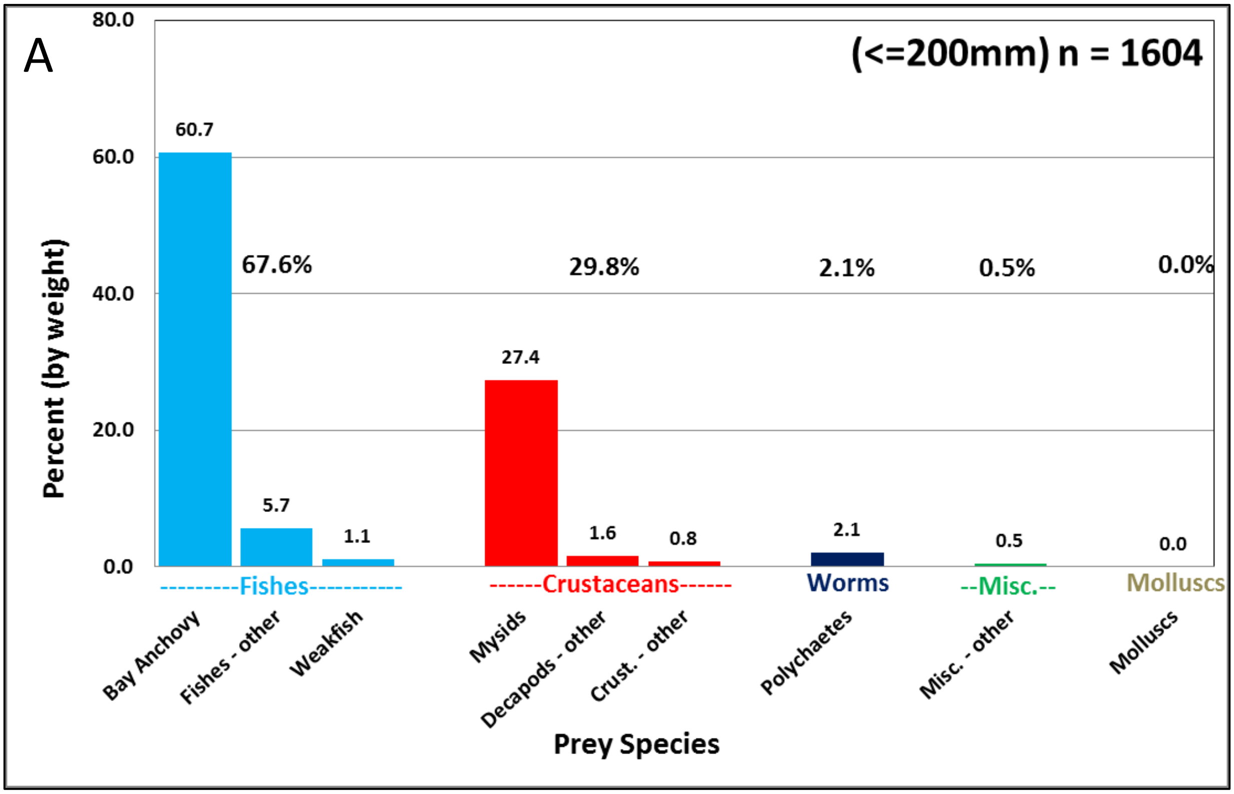
Figure E23. CHESFIMS Weakfish diet summaries by size group with data pooled over all sample years and months for specimens 200mm and smaller (A) and 201mm and larger (B).

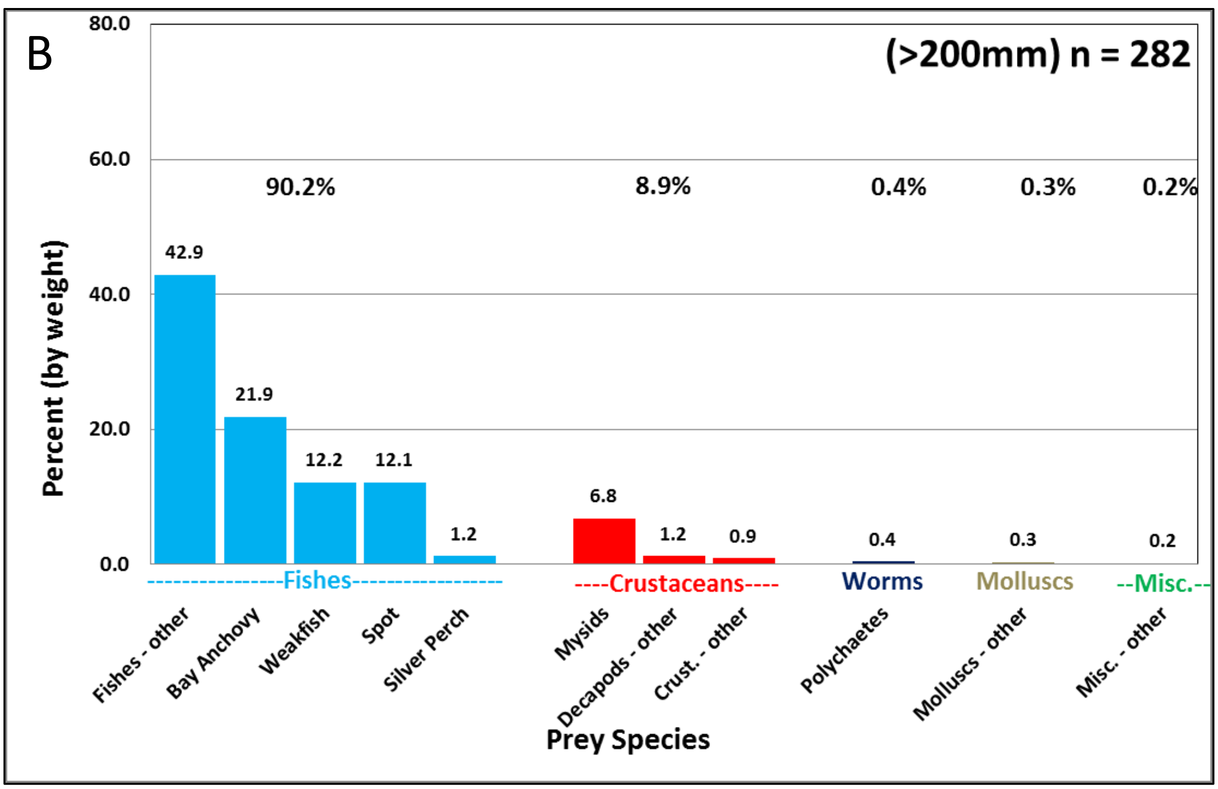




Weakfish

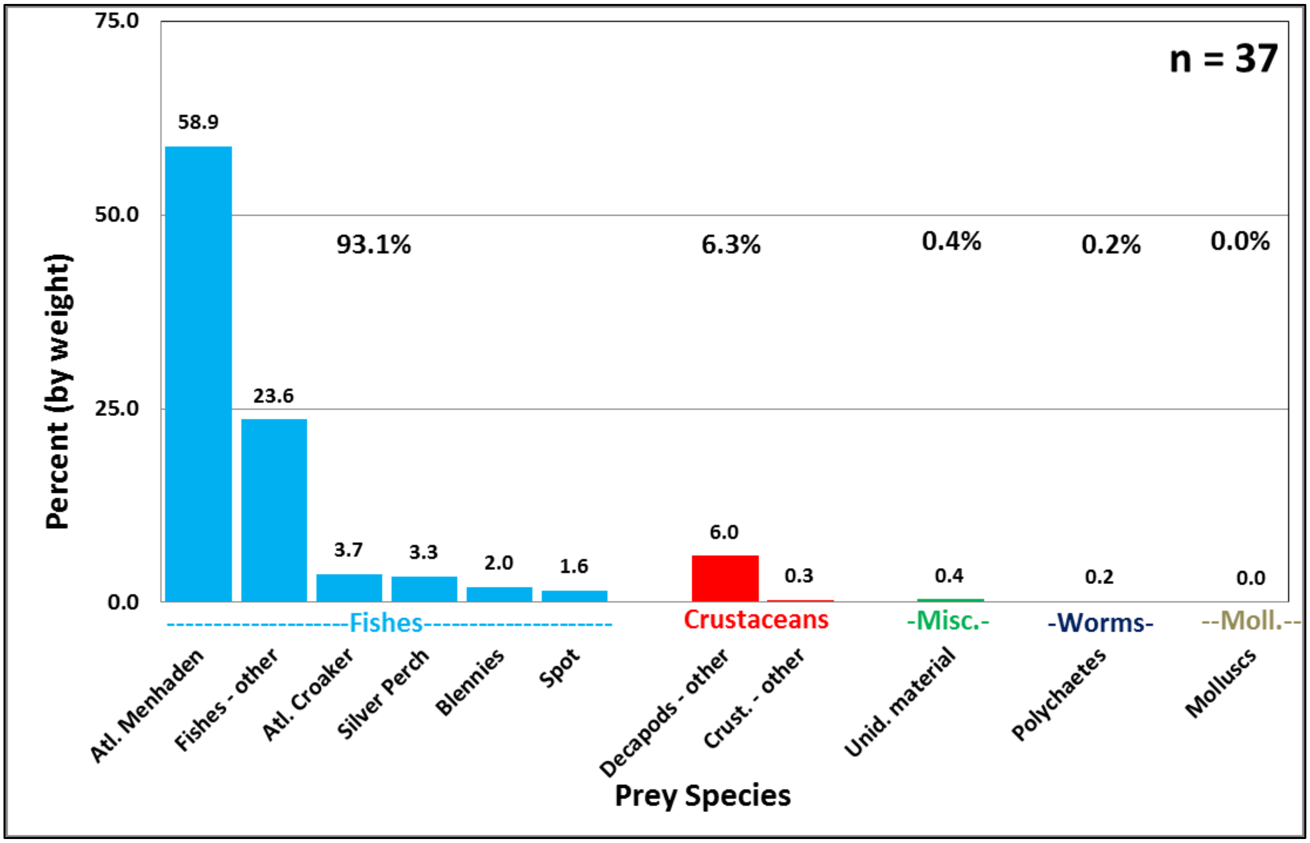
Figure E24. VIMS Juvenile Fishes Trawl Survey Weakfish diet summaries by size group with data pooled over all sample years and months for specimens 250mm and smaller (A) and 251mm and larger (B).





Weakfish

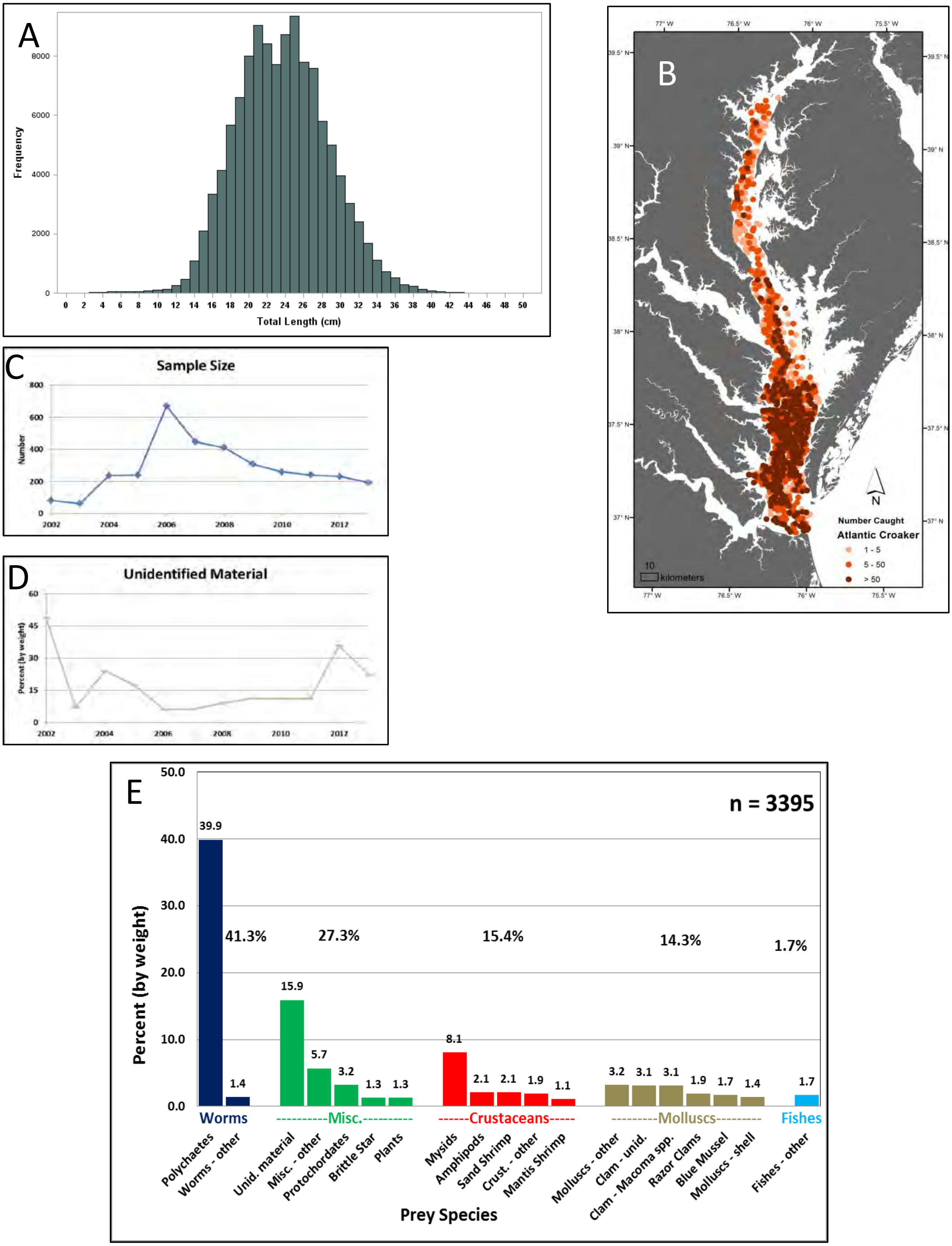
Figure E25. VIMS Trammel Net Survey Weakfish diet summary (2004-2005).



Baywide Benthic Fishes

Atlantic Croaker

Figure E26. ChesMMAP Atlantic Croaker length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), yearly percentage of unidentifiable matter in stomachs (D), and food habits percentages for all data combined for years 2002-2013 (E).



Atlantic Croaker

Figure E27. ChesMMAP Atlantic Croaker diet summaries by year and major taxa, with data pooled over all sample months and areas.

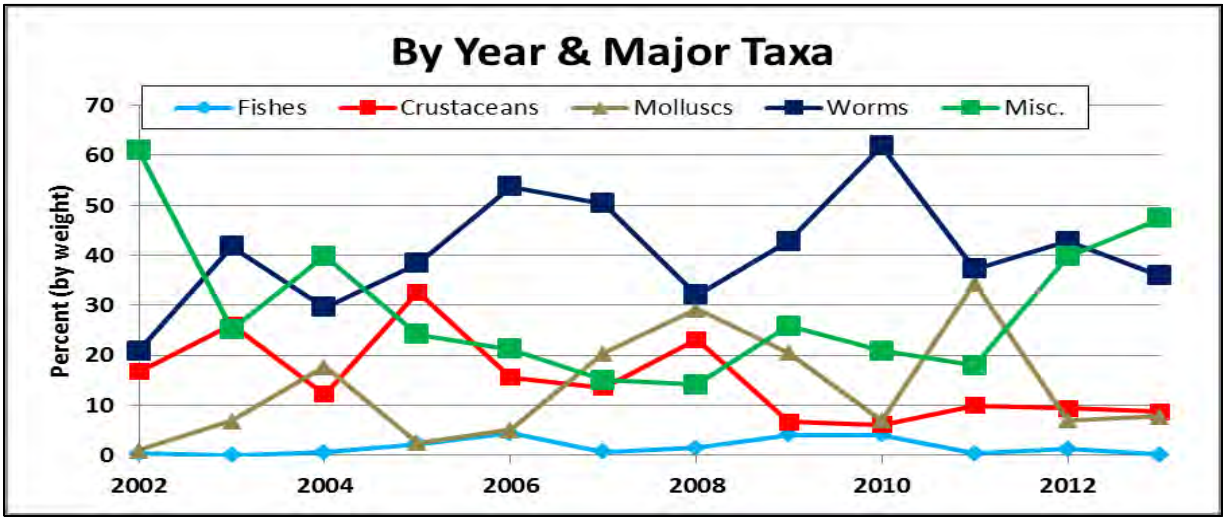
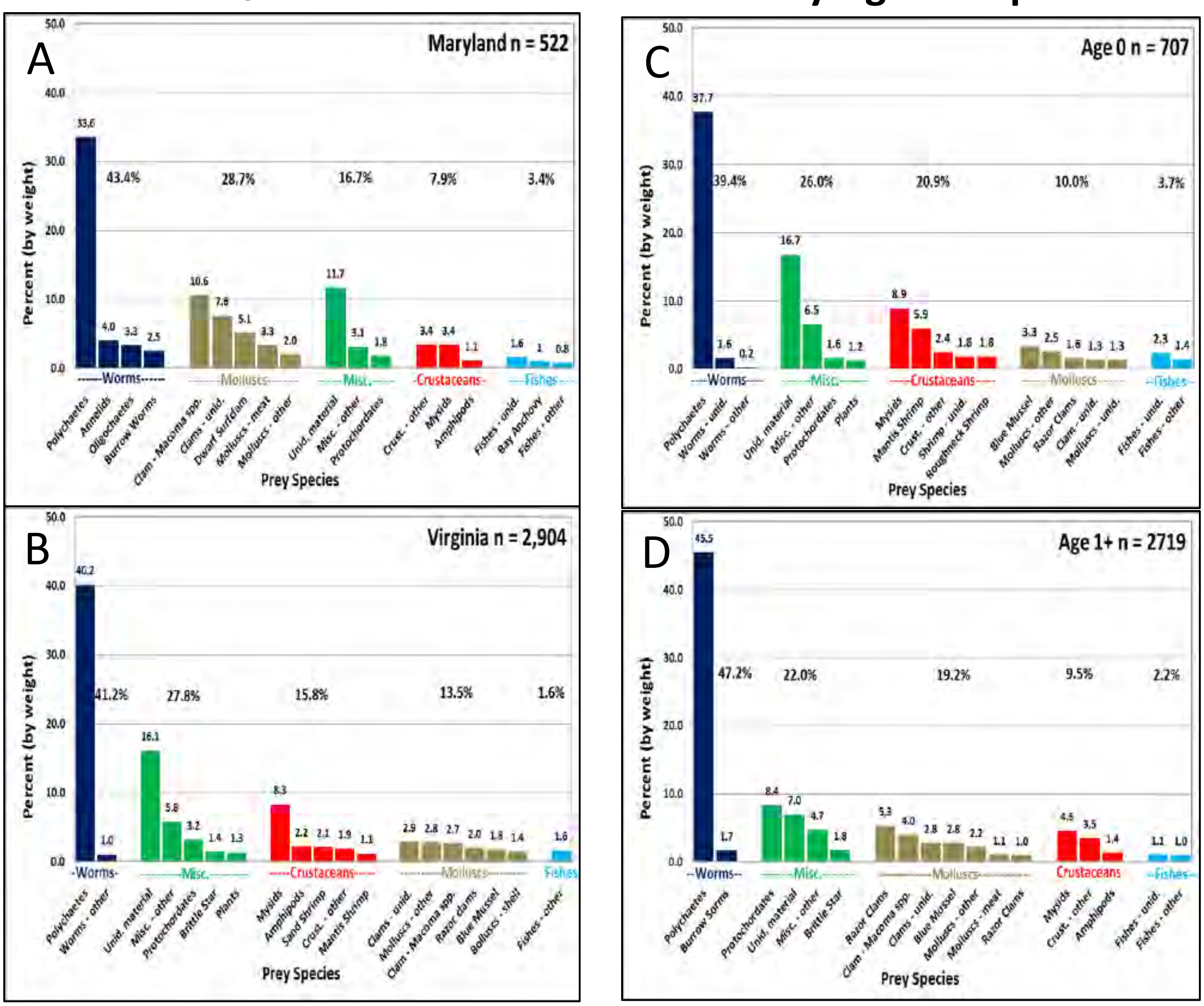


Figure E28. ChesMMAP Atlantic Croaker diet summaries by state with data pooled over all sample years (2002-2013) and months for Maryland (A) and Virginia (B); and by age group with data pooled over all years, months, and areas for ages0-1 (C) and ages-2 and older (D).

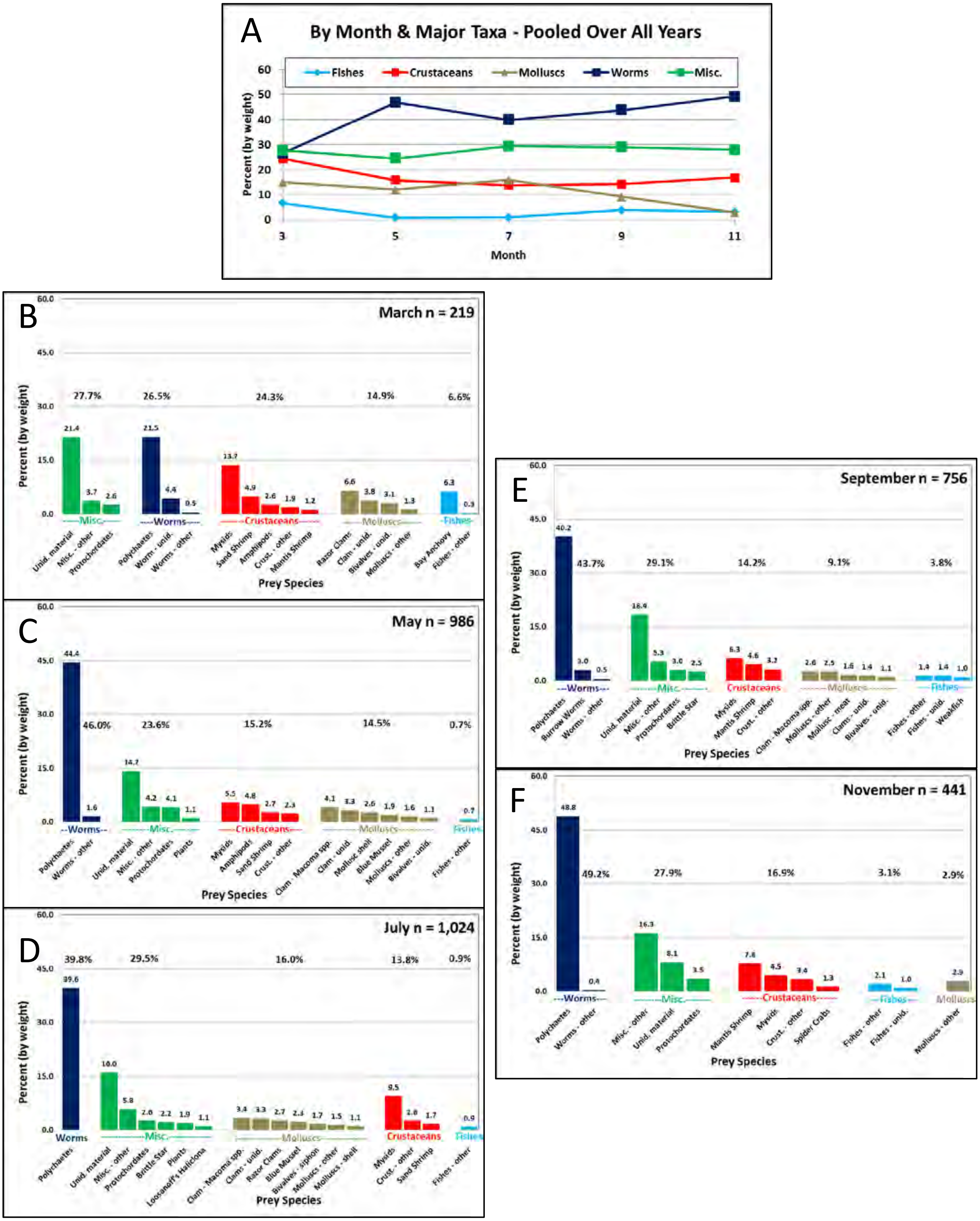
By State

By Age Group



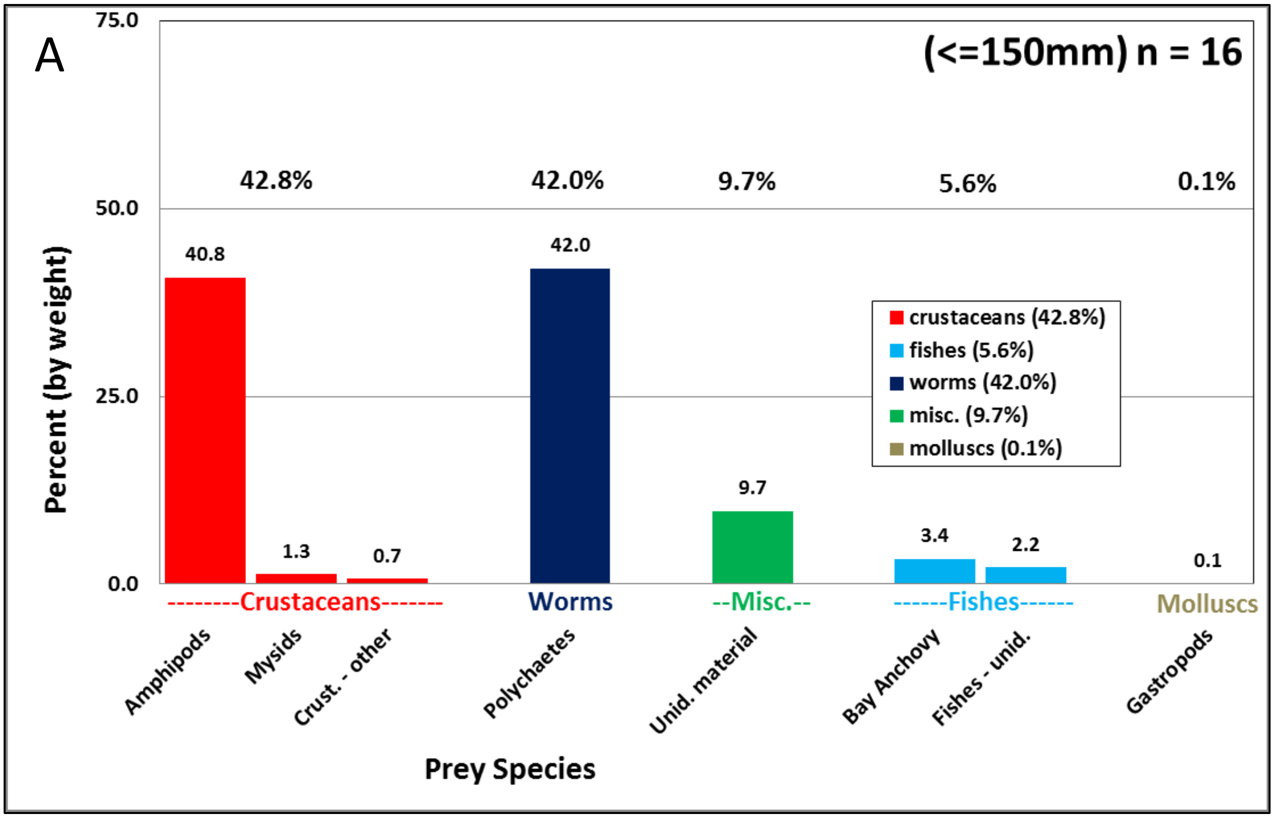
Atlantic Croaker

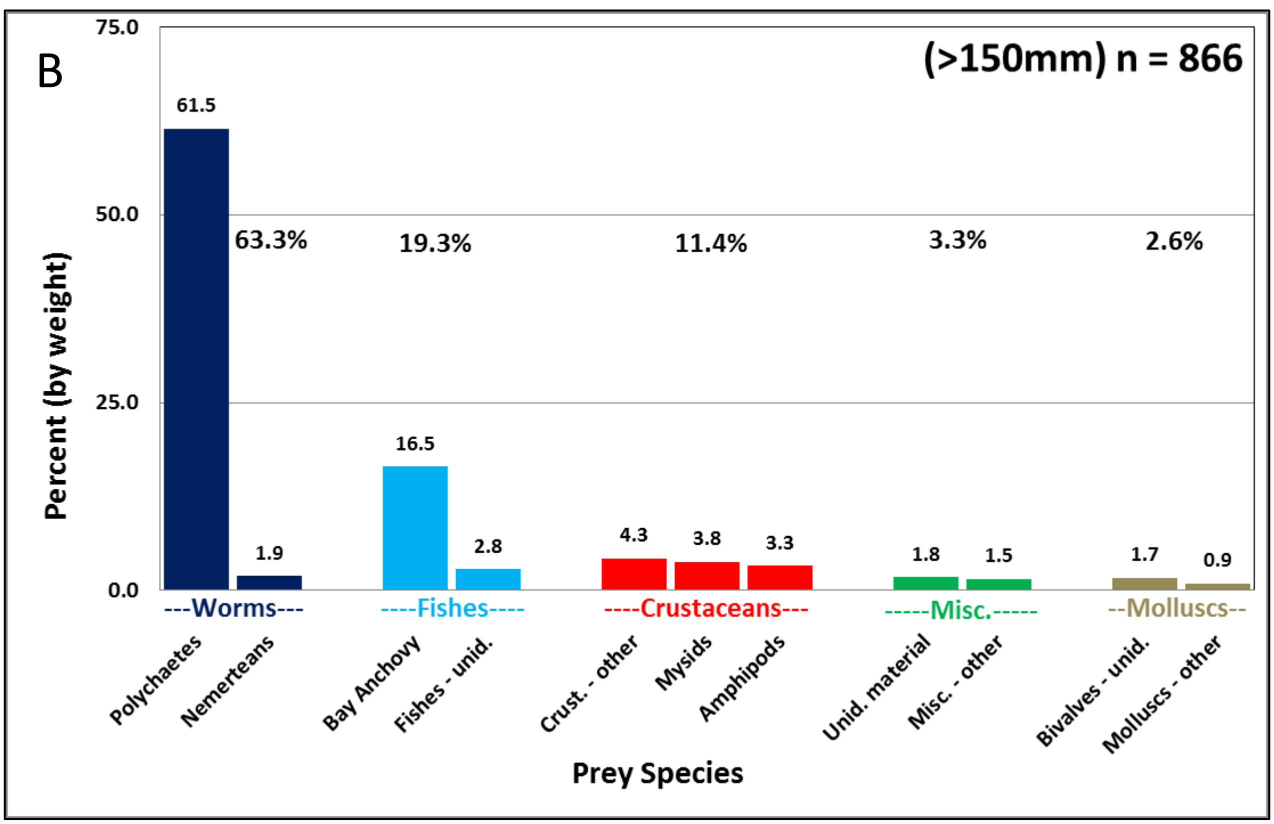
Figure E29. ChesMMAP Atlantic Croaker diet summaries by month, with data pooled over all sample years (2002-2013), for prey types summed over major taxa (A), and by species within major taxa for March (B), May (C), July (D), September (E), and November (F).



Atlantic Croaker

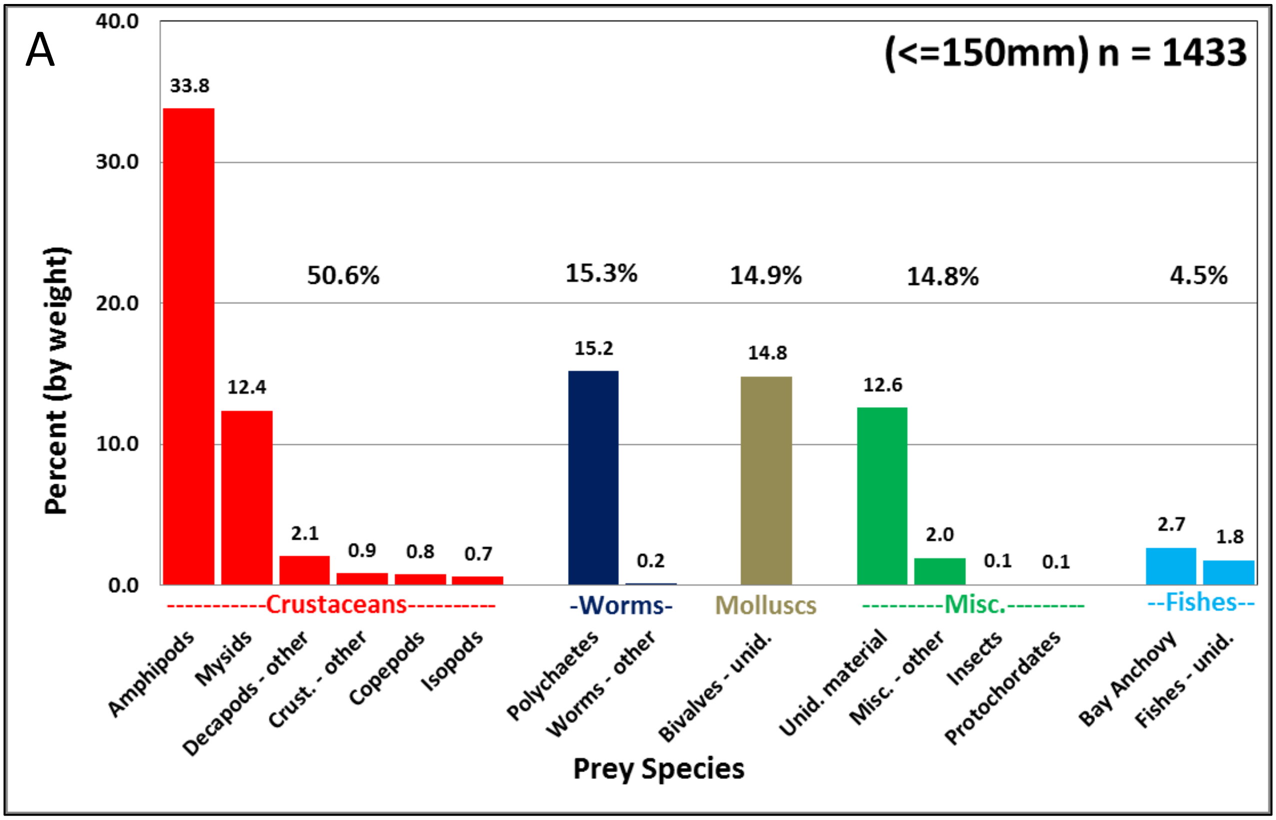
Figure E30. CHESFIMS Atlantic Croaker diet summaries by size group with data pooled over all sample years and months for specimens 200mm and smaller (A) and 201mm and larger (B).

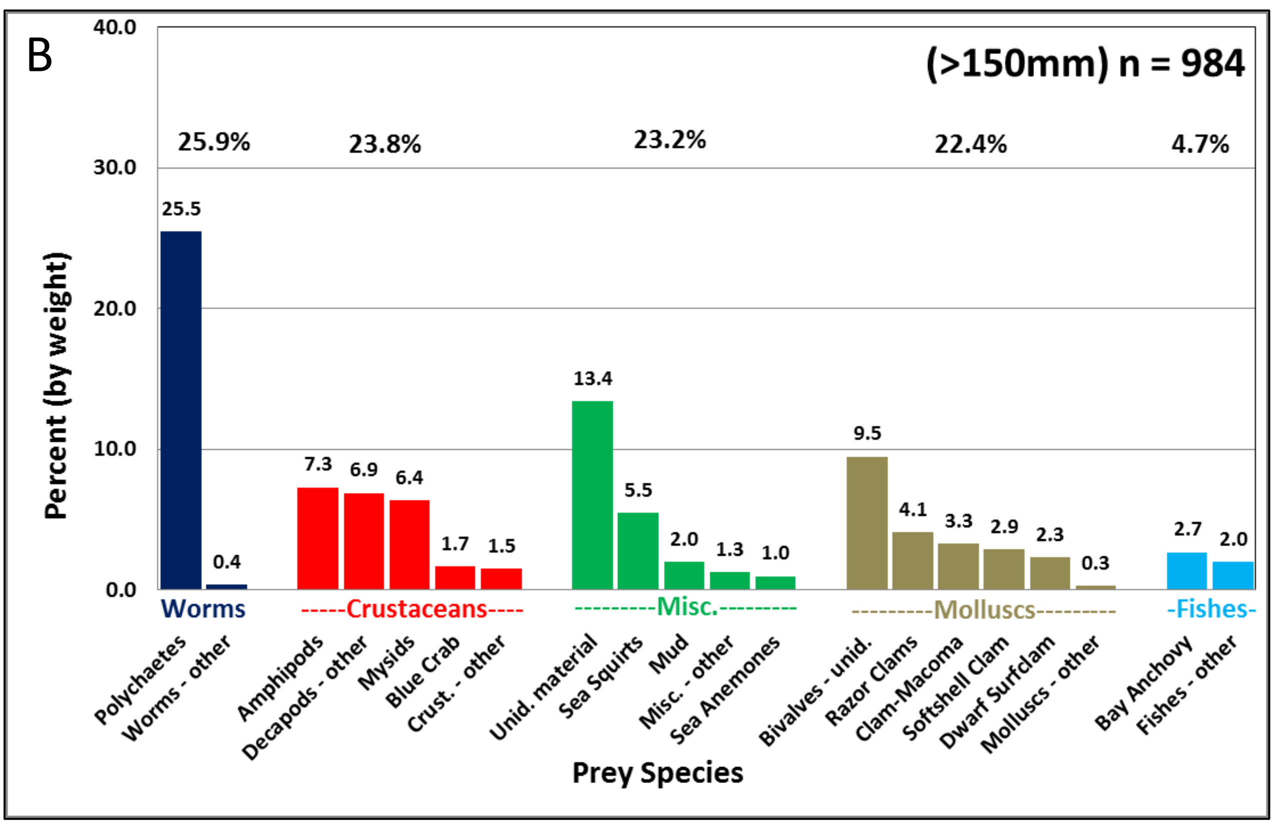




Atlantic Croaker

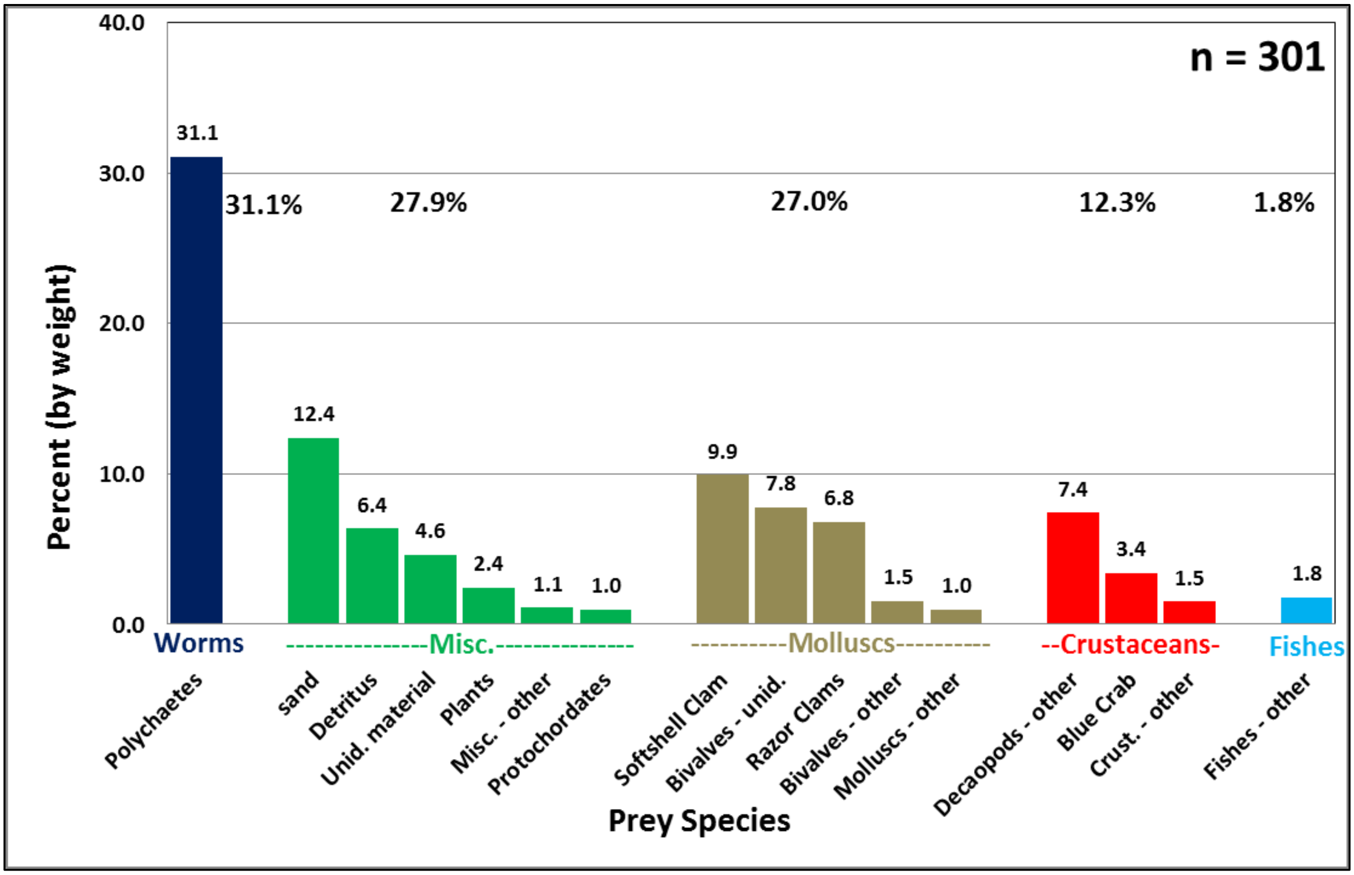
Figure E31. VIMS Juvenile Fishes Trawl Survey Atlantic Croaker diet summaries by size group with data pooled over all sample years and months for specimens 150mm and smaller (A) and 151mm and larger (B).





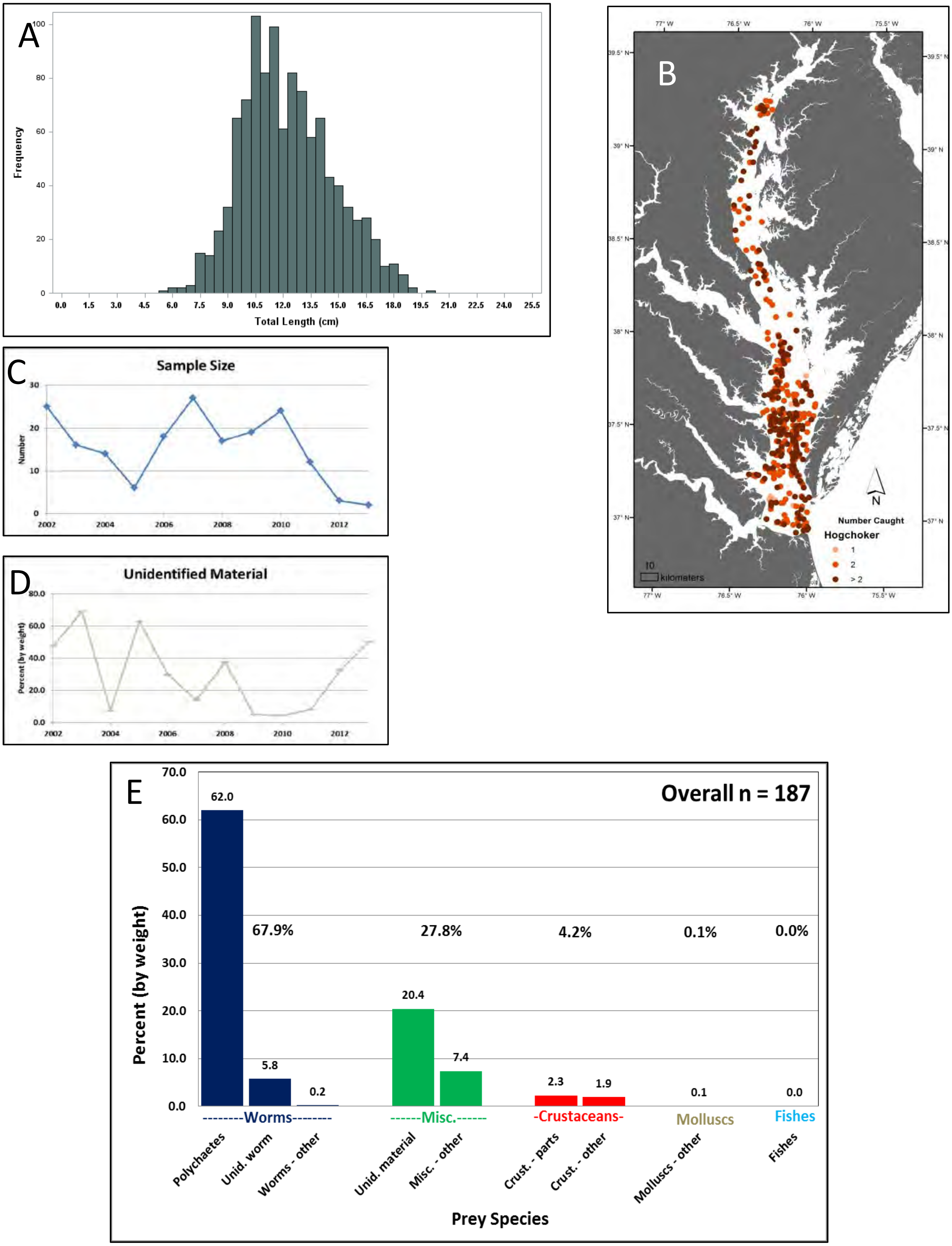
Atlantic Croaker

Figure E32. VIMS Trammel Net Survey Atlantic Croaker diet summary (2004-2005).



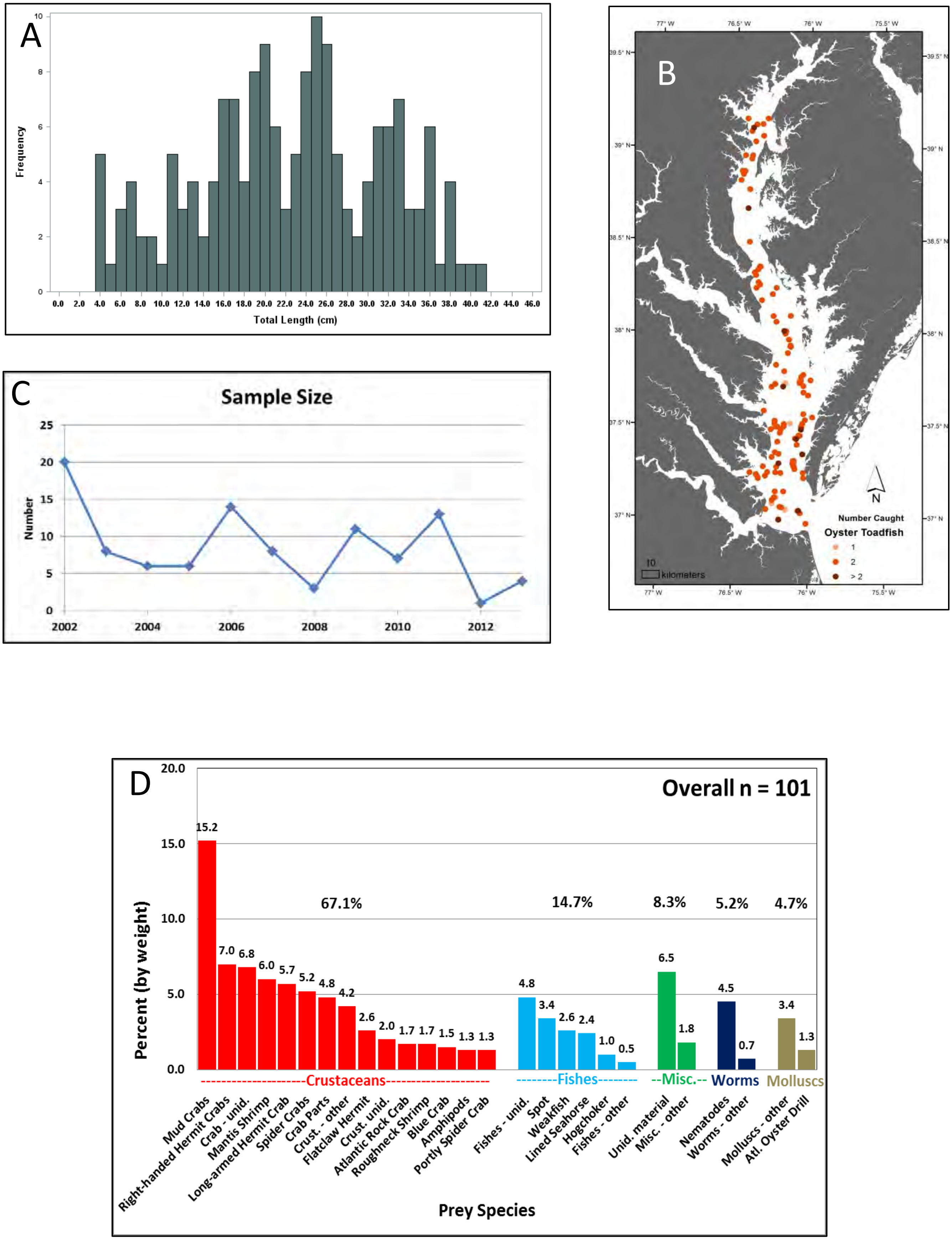
Hogchoker

Figure E33. ChesMMAP Hogchoker length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), yearly percentage of unidentifiable matter in stomachs (D), and food habits percentages for all data combined for years 2002-2013 (E).



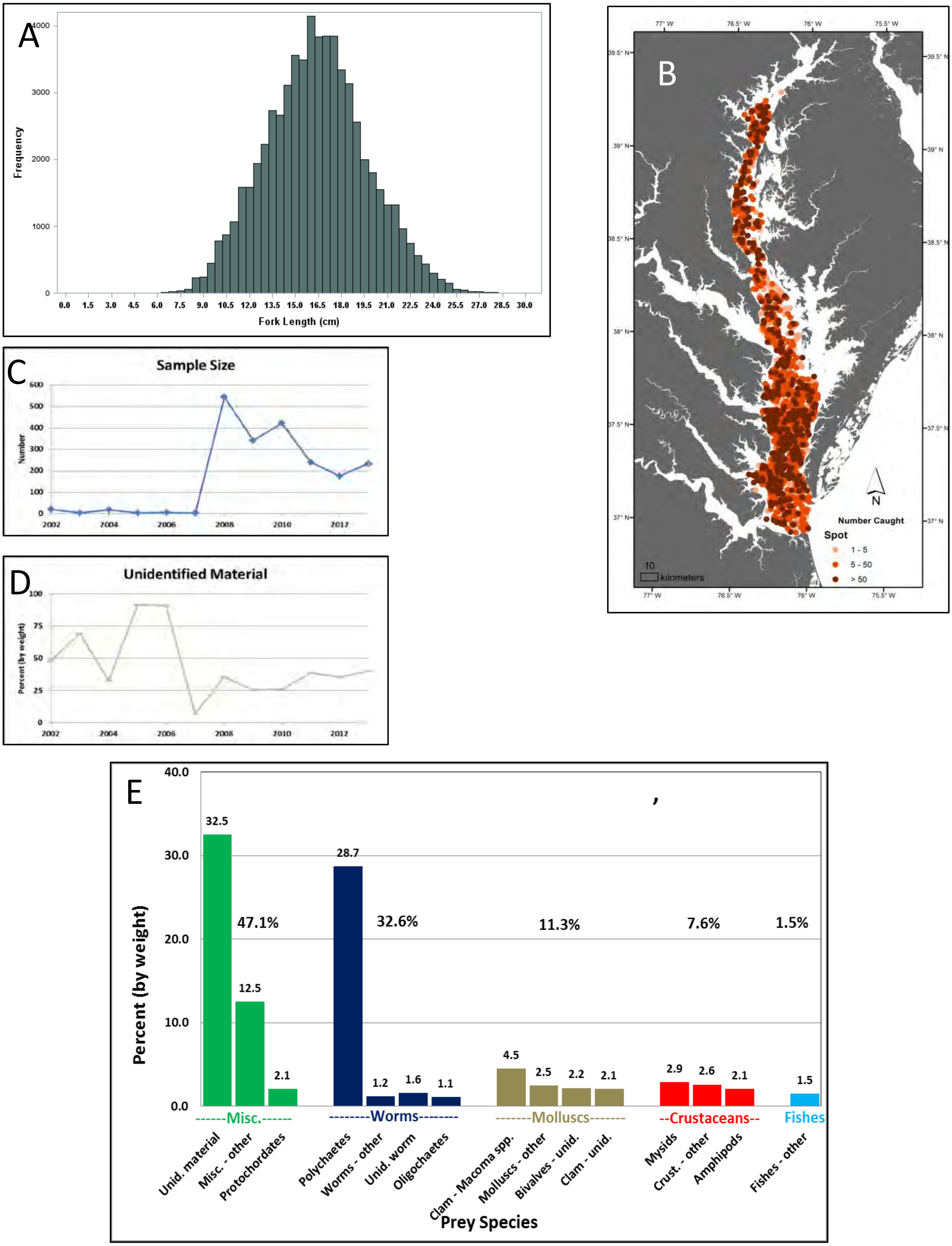
Oyster Toadfish

Figure E34. ChesMMAP Oyster Toadfish length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), and food habits percentages for all data combined for years 2002-2013 (D).



Spot

Figure E35. ChesMMAP Spot length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), yearly percentage of unidentifiable matter in stomachs (D), and food habits percentages for all data combined for years 2002-2013 (E).



Spot

Figure E36. ChesMMAP Spot diet summaries by year and major taxa, with data pooled over all sample months and areas.

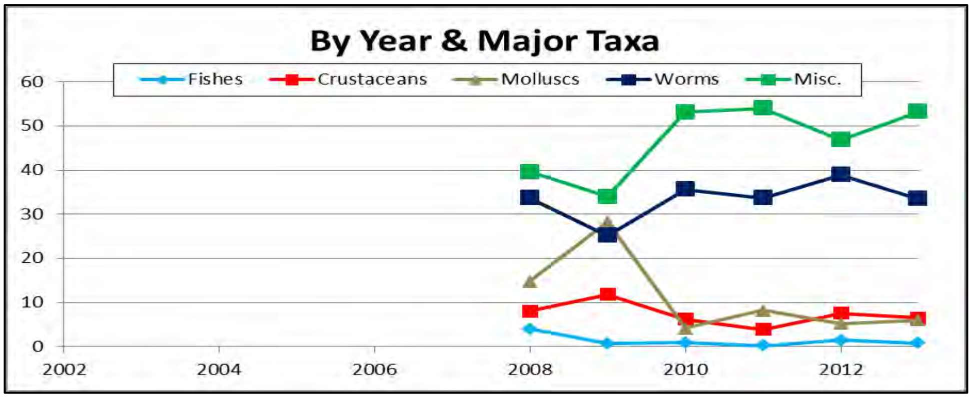
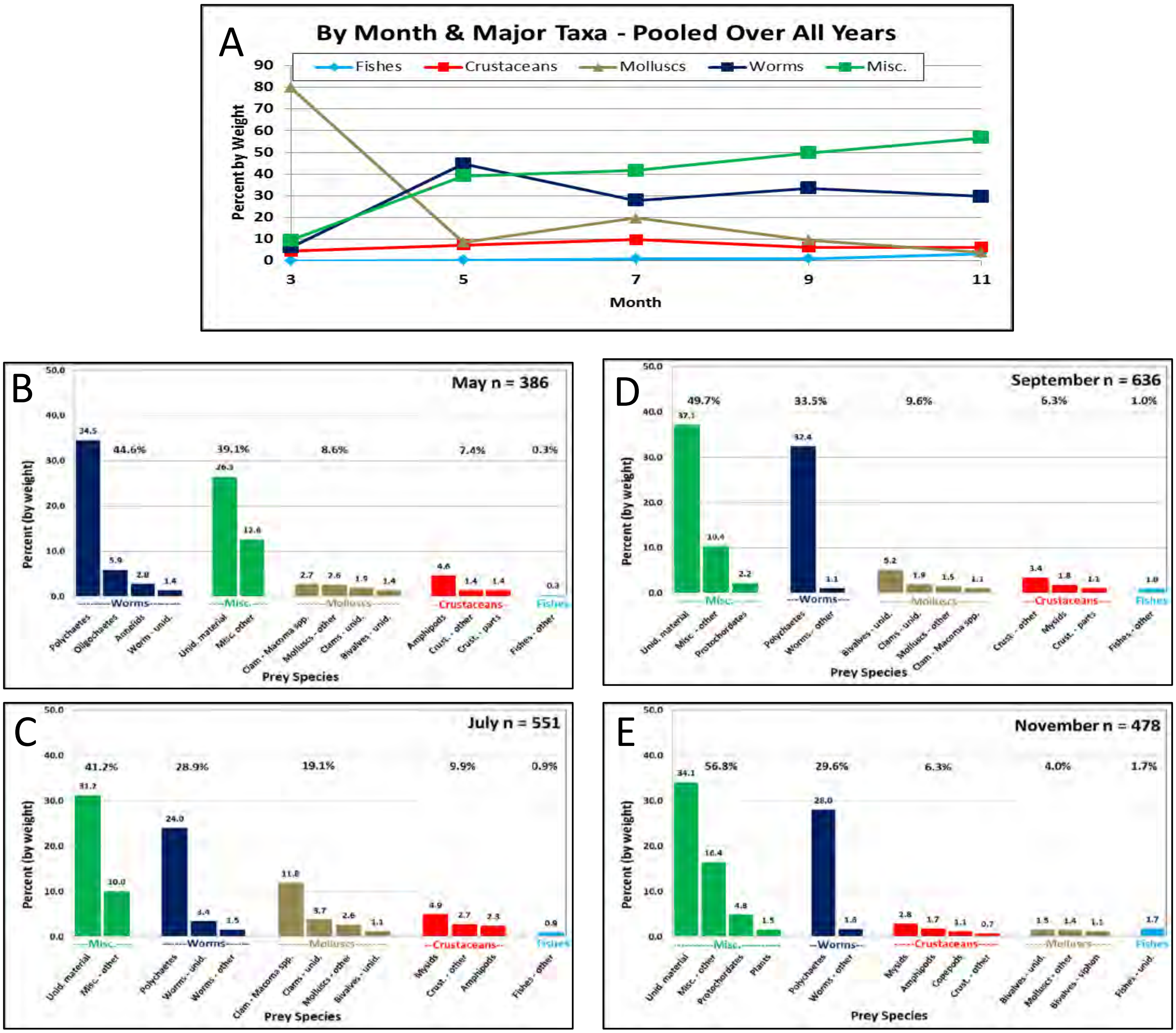
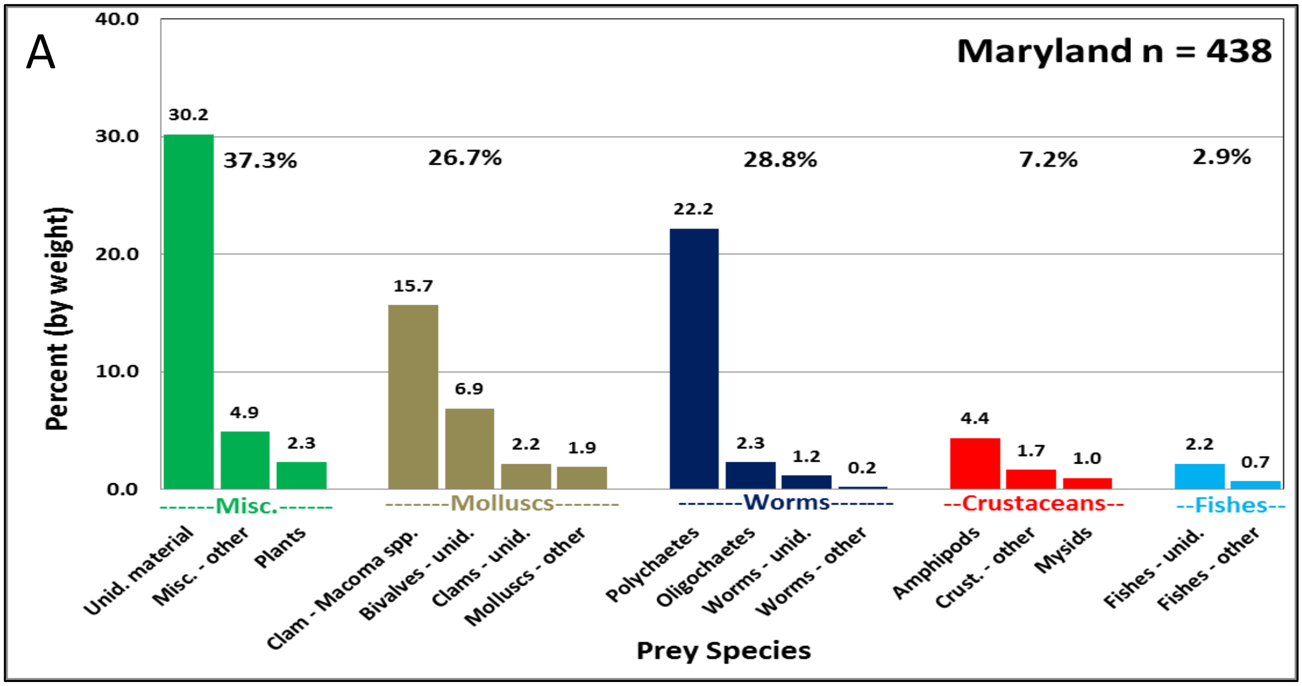


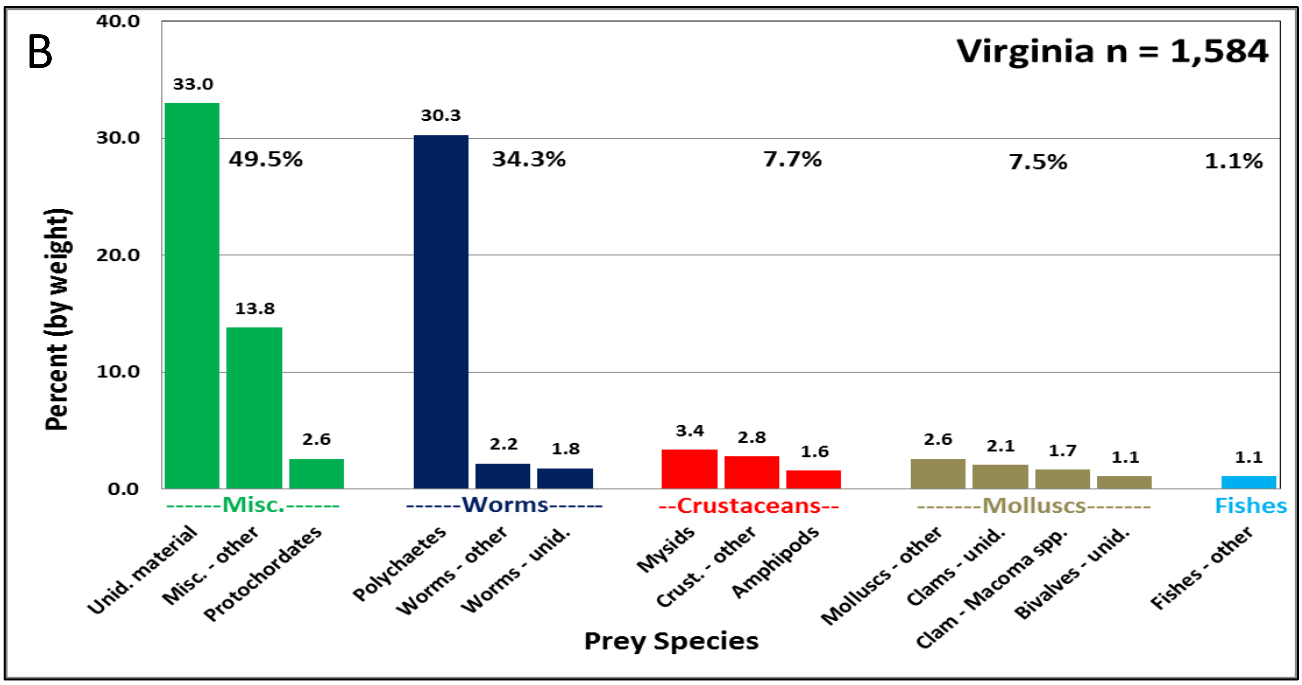
Figure E37. ChesMMAP Spot diet summaries by month, with data pooled over all sample years (2002-2013), for prey types summed over major taxa (A), and by species within major taxa for May (B), July (C), September (D), and November (E).



Spot

Figure E38. ChesMMAP Spot diet summaries by state with data pooled over all sample years (2002-2013) and months for Maryland (A) and Virginia (B).





Spot

Figure E39. CHESFIMS Spot diet summaries with data pooled over all sample years, months and sizes.

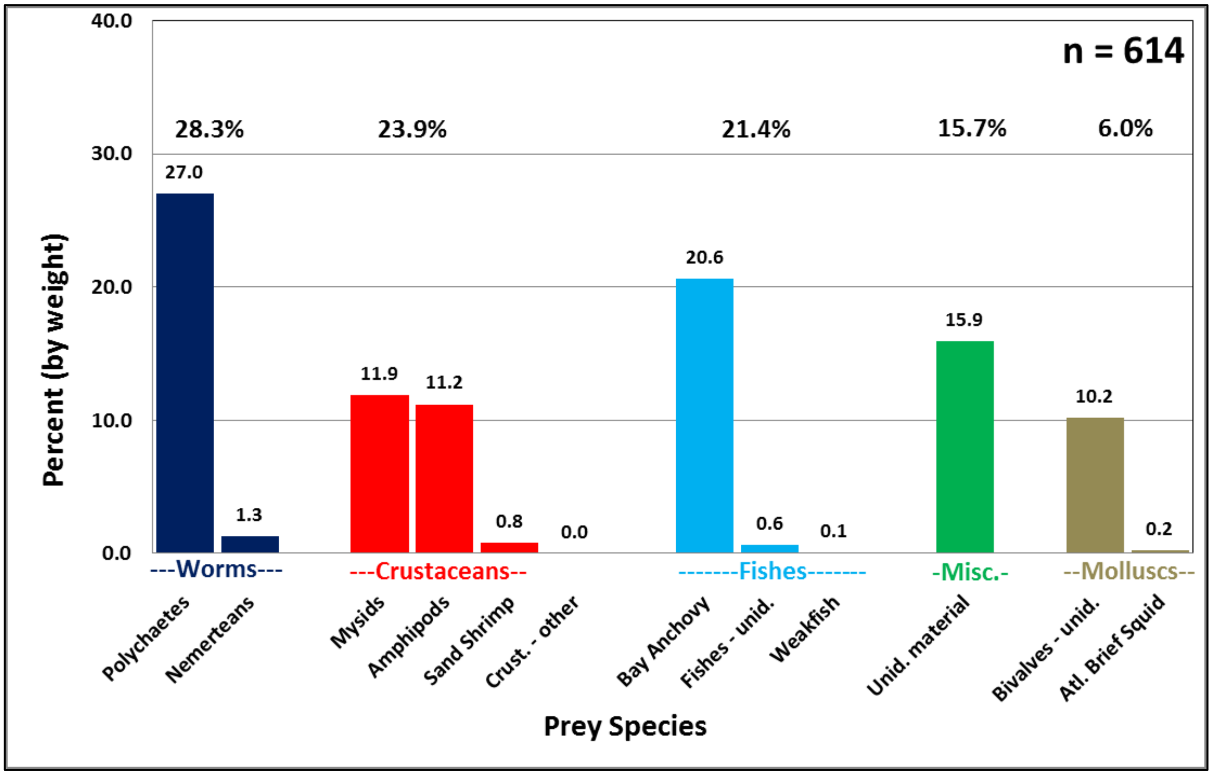
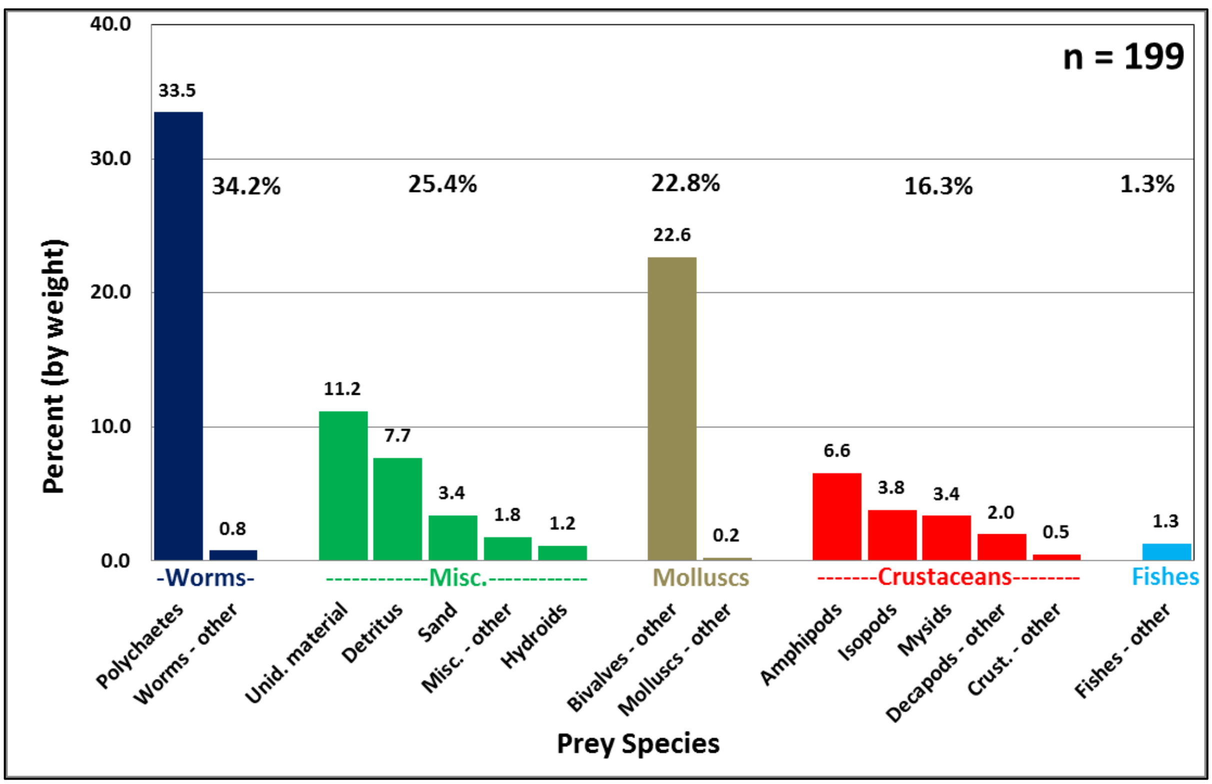
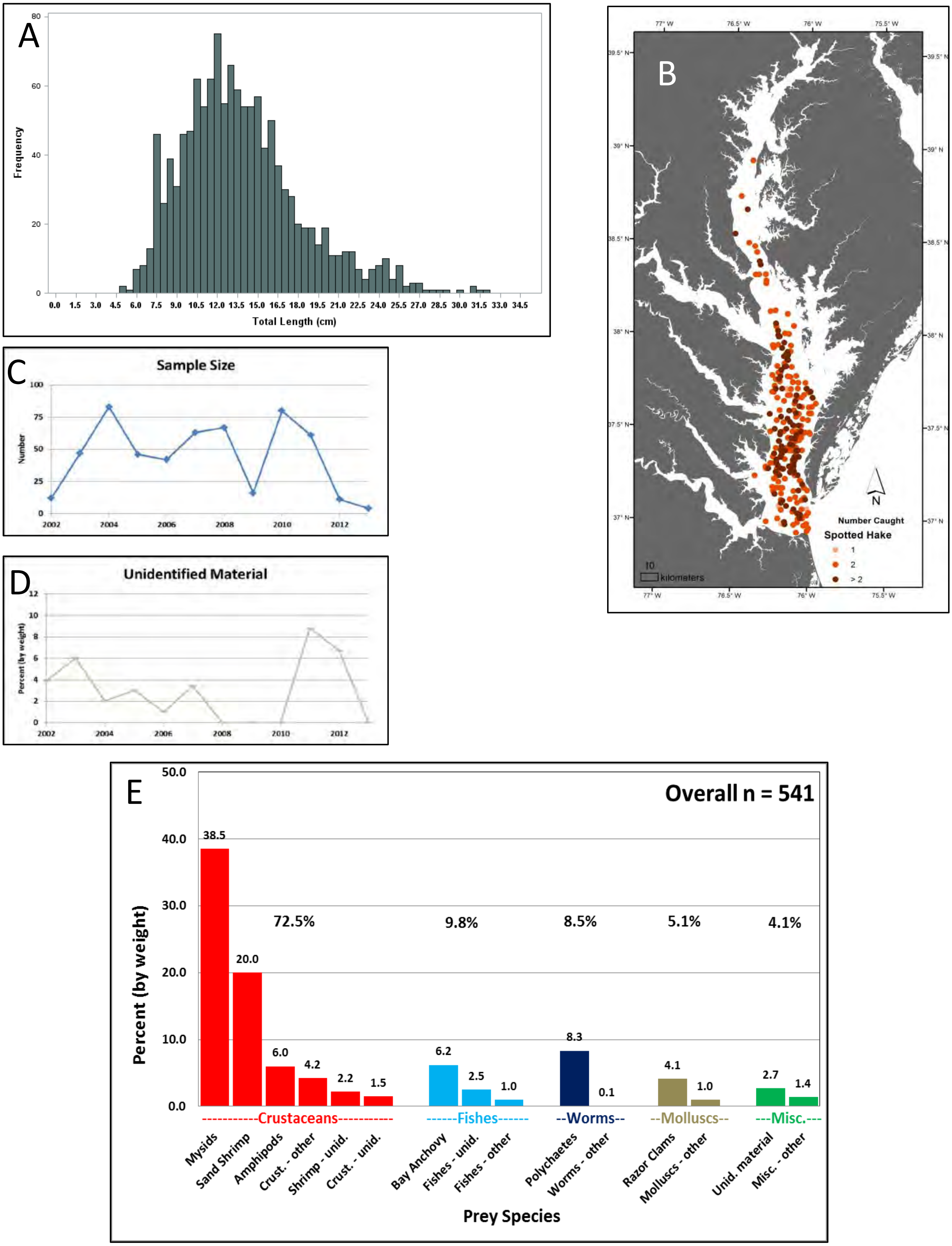


Figure E40. VIMS Trammel Net Survey Spot diet summary (2004-2005).



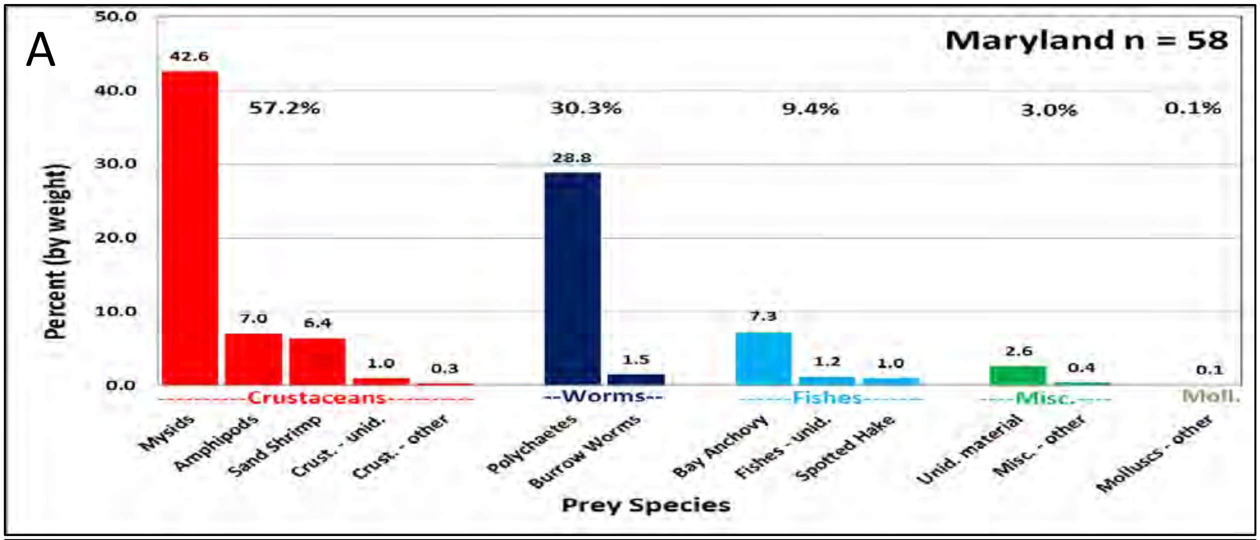
Spotted Hake

Figure E41. ChesMMAP Spotted Hake length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), yearly percentage of unidentifiable matter in stomachs (D), and food habits percentages for all data combined for years 2002-2013 (E).



Spotted Hake

Figure E42. ChesMMAP Spotted Hake diet summaries by state with data pooled over all sample years (2002-2013) and months for Maryland (A) and Virginia (B).



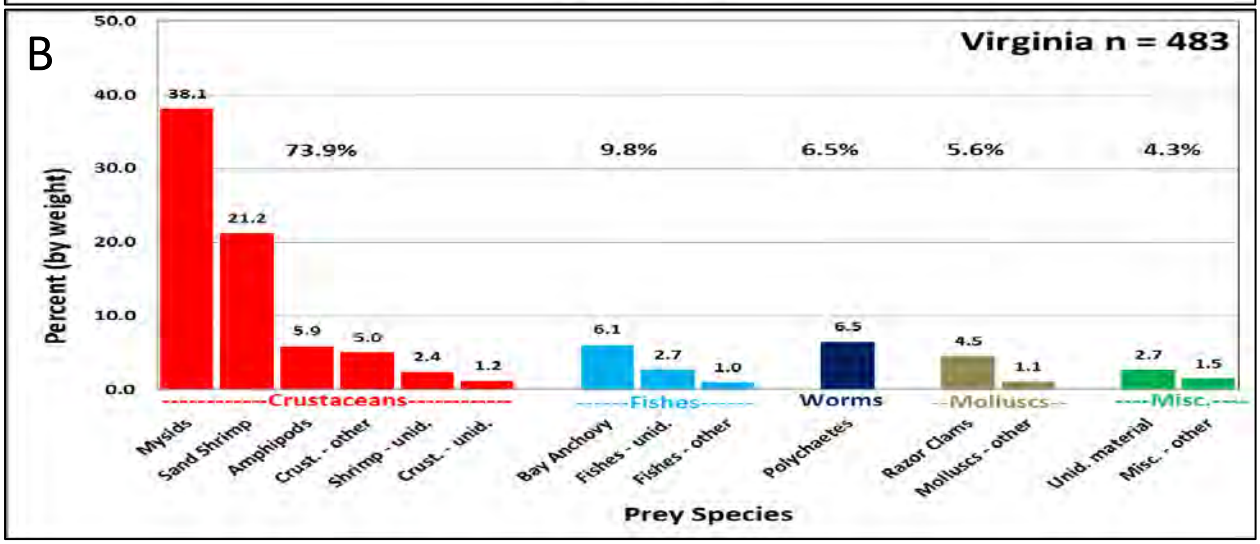
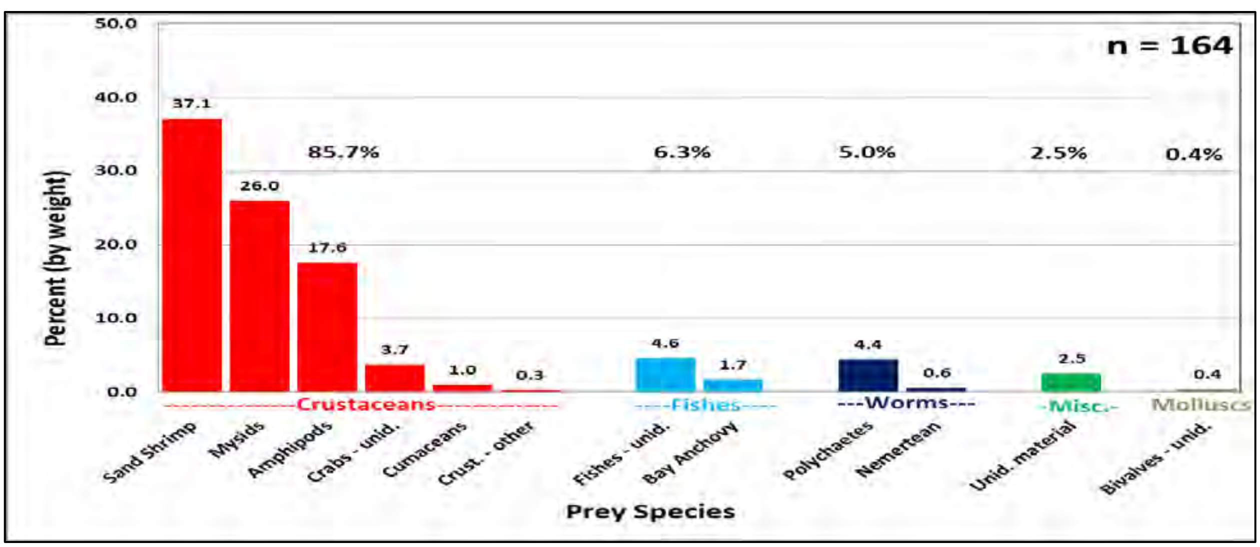


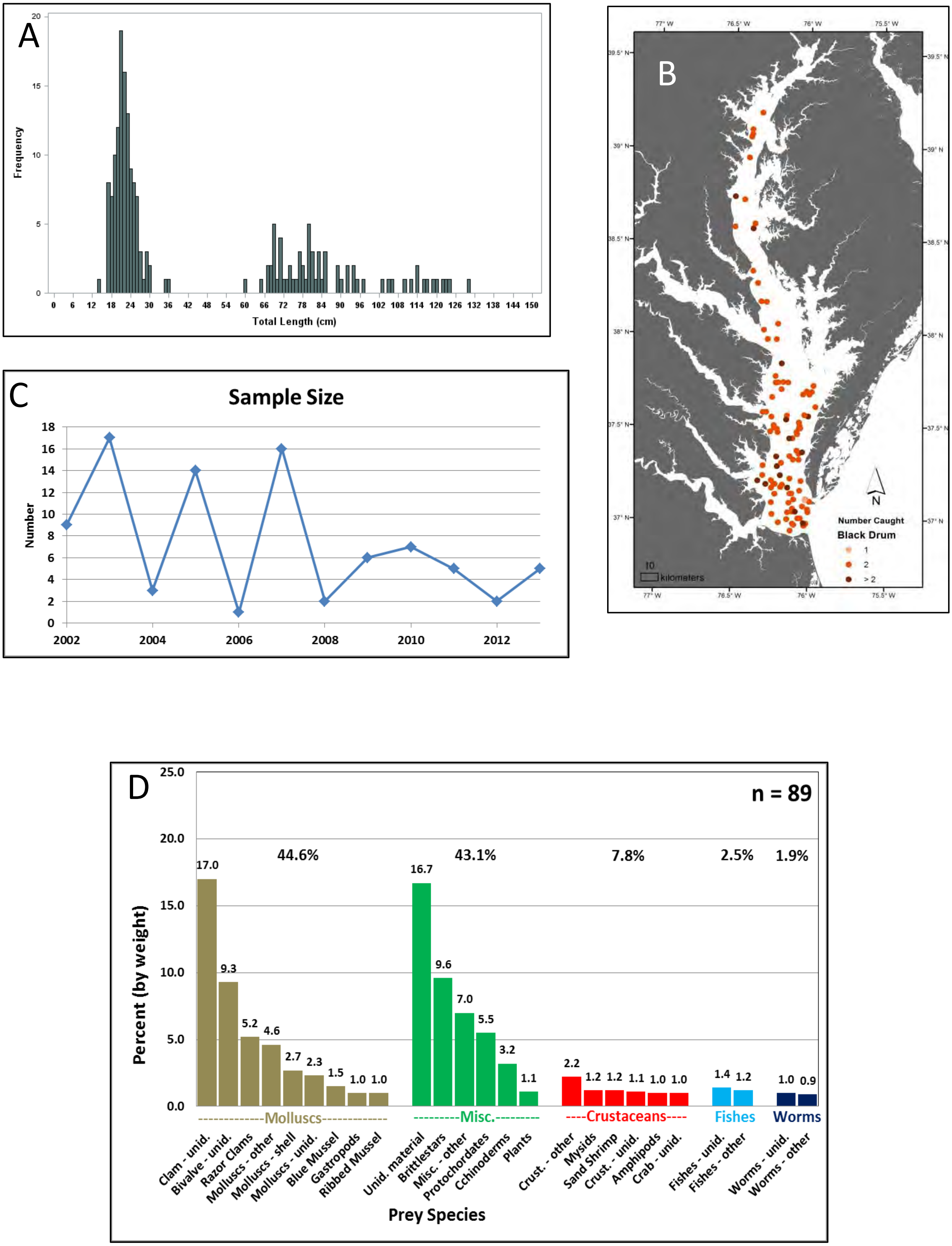
Figure E43. CHESFIMS Spotted Hake diet summaries with data pooled over all sample years, months and sizes.



Other Managed Fishes

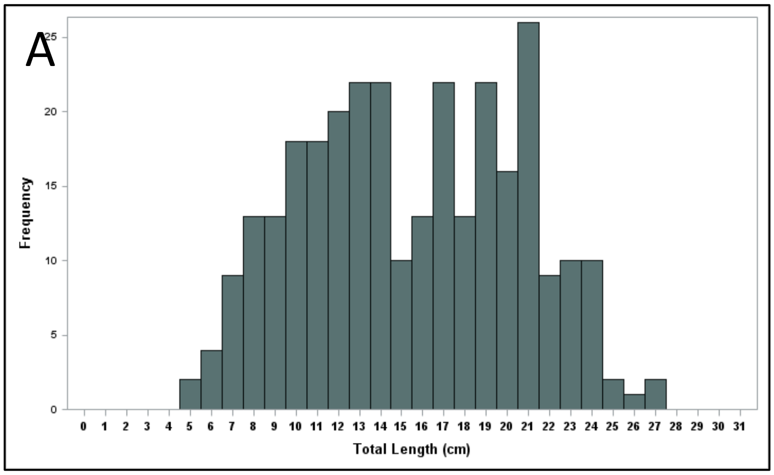
Black Drum

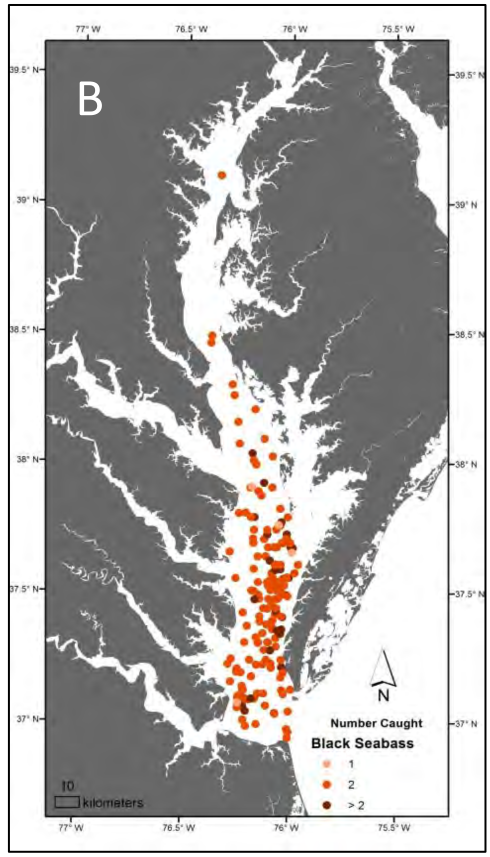
Figure E44. ChesMMAP Black Drum length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), and food habits percentages for all data combined for years 2002-2013 (D).

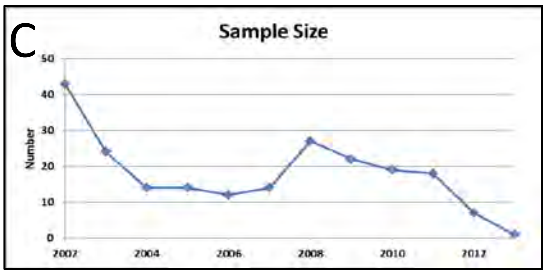


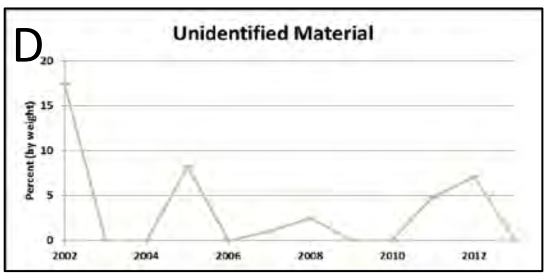
Black Sea Bass

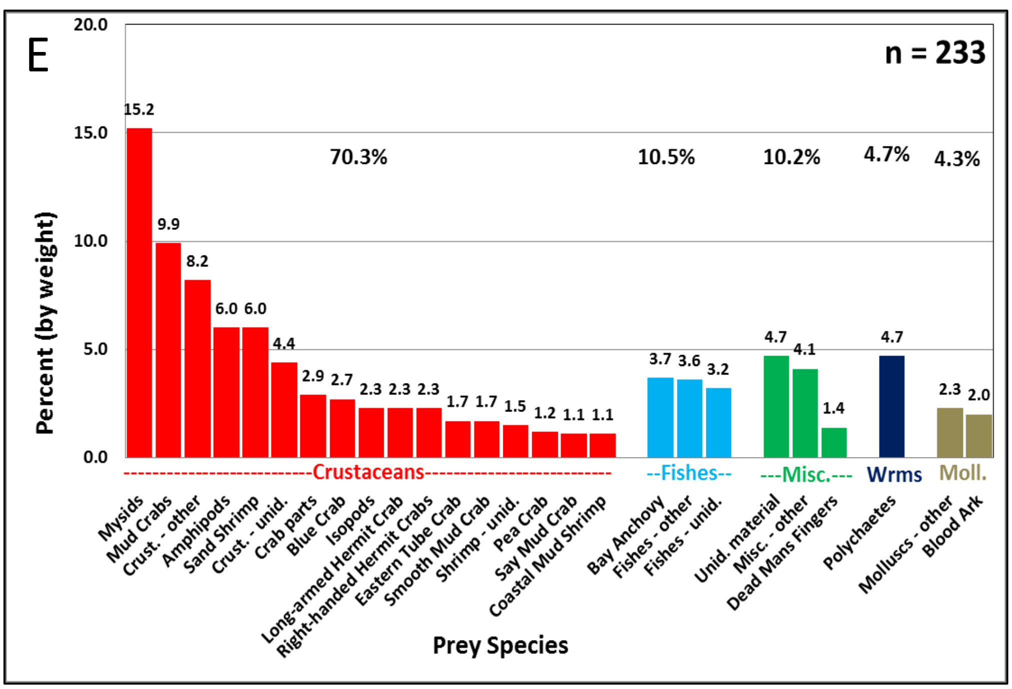
Figure E45. ChesMMAP Black Sea Bass length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), yearly percentage of unidentifiable matter in stomachs (D), and food habits percentages for all data combined for years 2002-2013 (E).





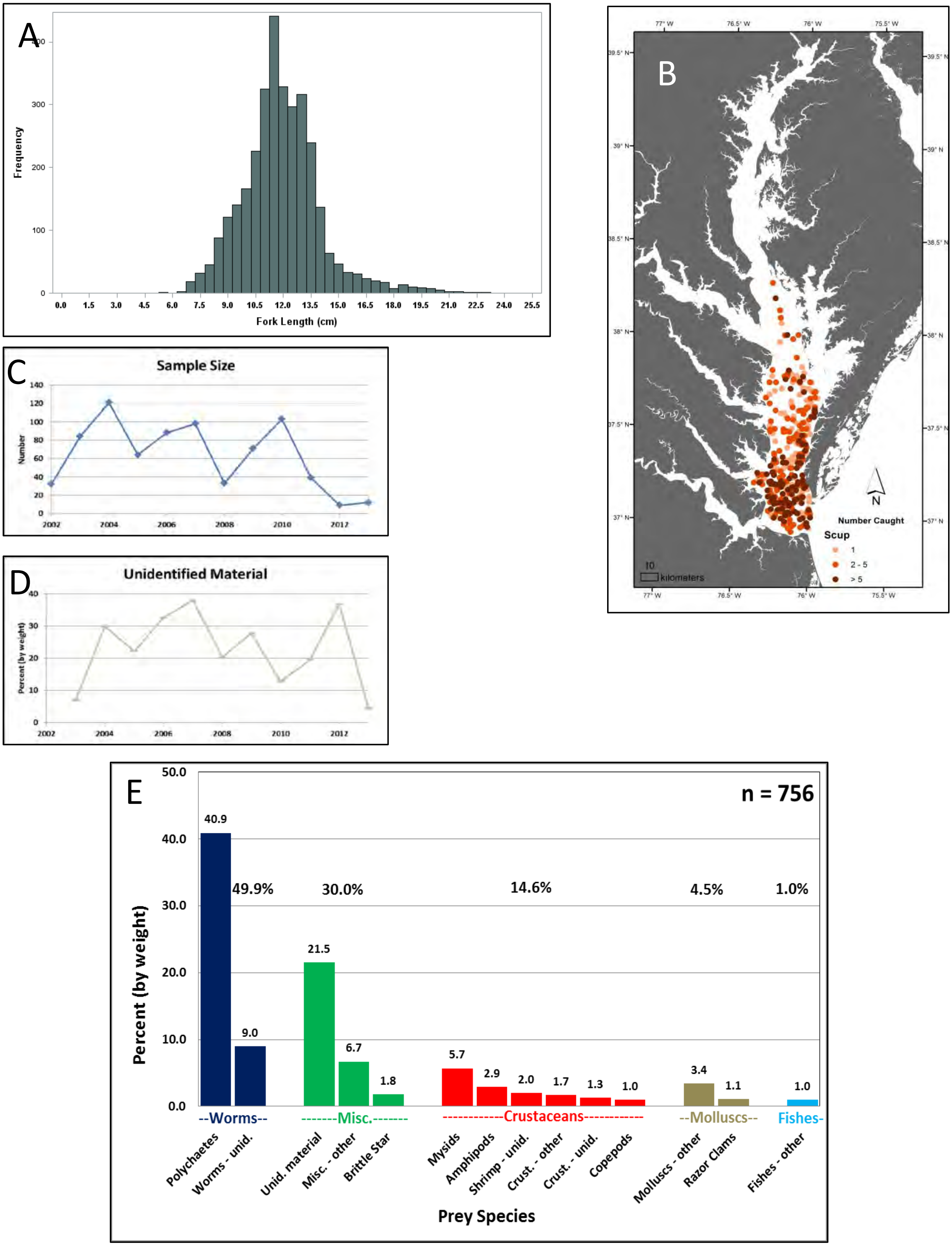






Scup

Figure E46. ChesMMAP Scup length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), yearly percentage of unidentifiable matter in stomachs (D), and food habits percentages for all data combined for years 2002-2013 (E).



Scup

Figure E47. ChesMMAP Scup diet summaries by year and major taxa, with data pooled over all sample months and areas.

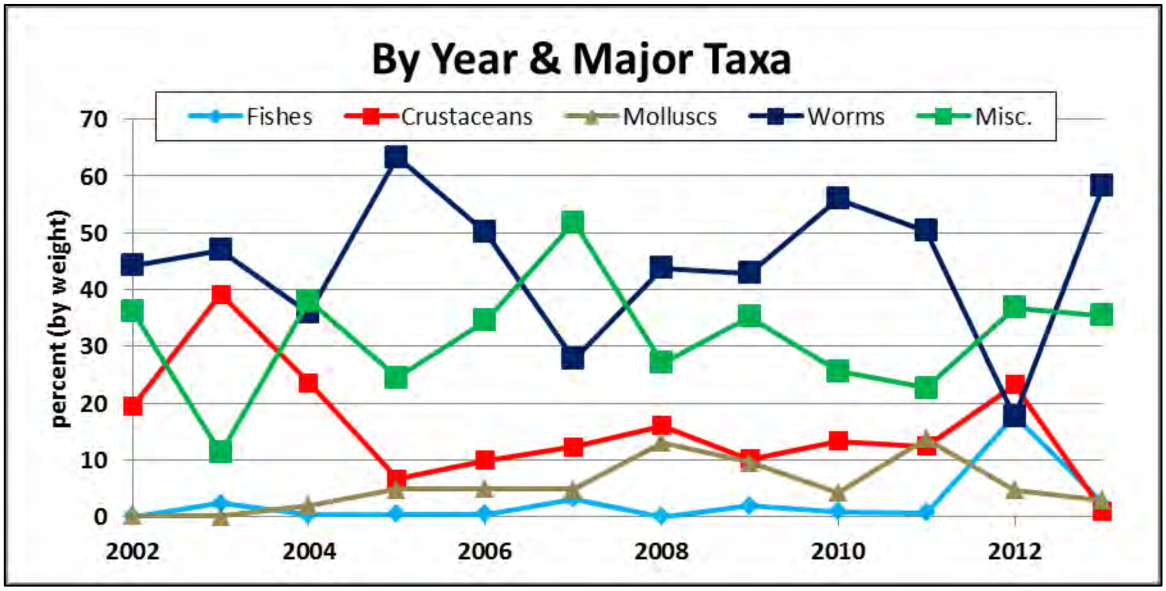
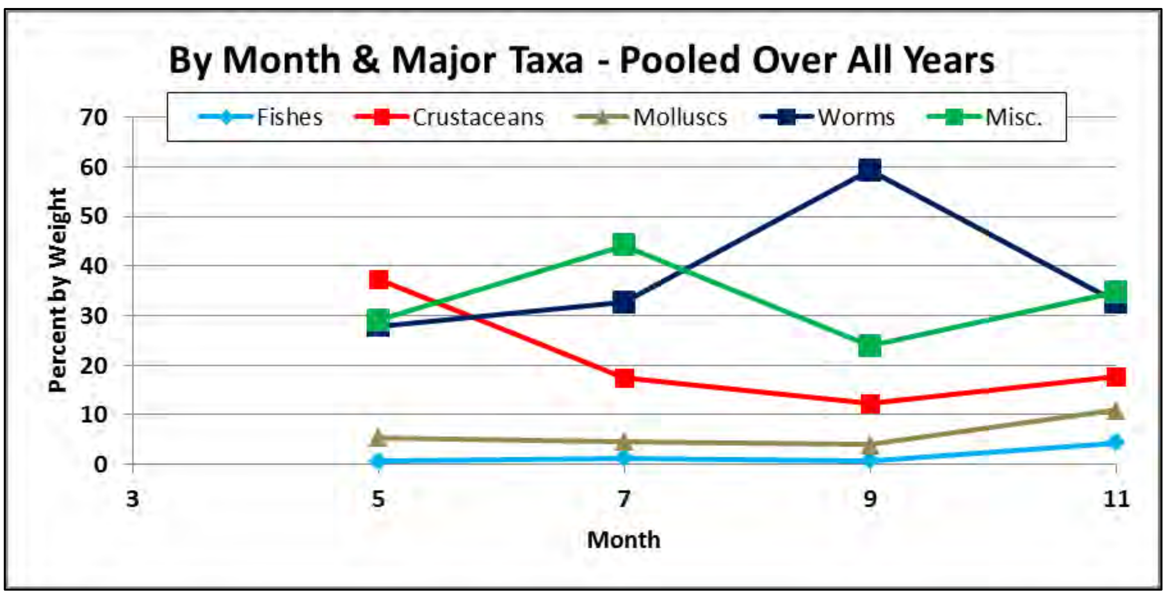


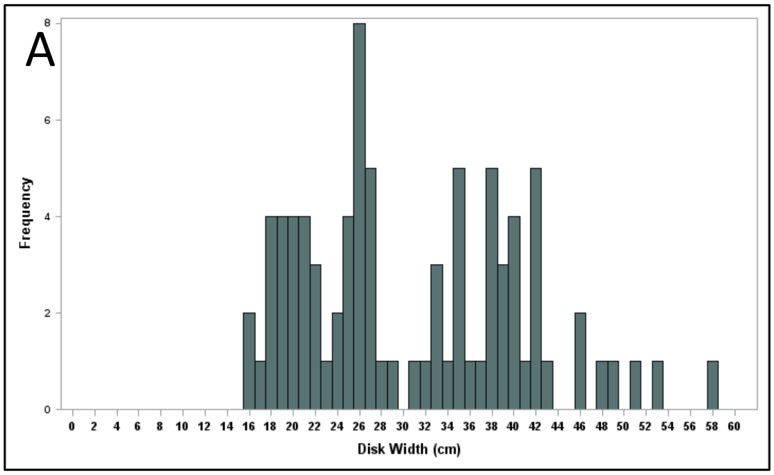
Figure E48. ChesMMAP Scup diet summaries by month, with data pooled over all sample years (2002-2013), for prey types summed over major taxa.

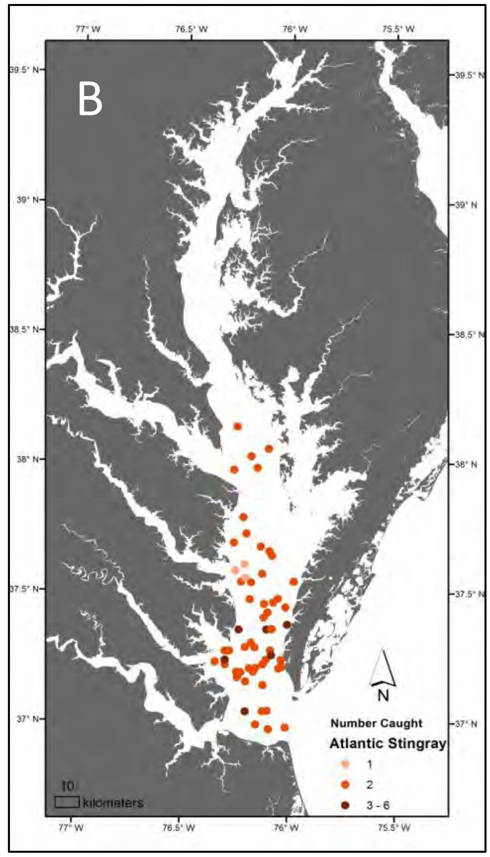


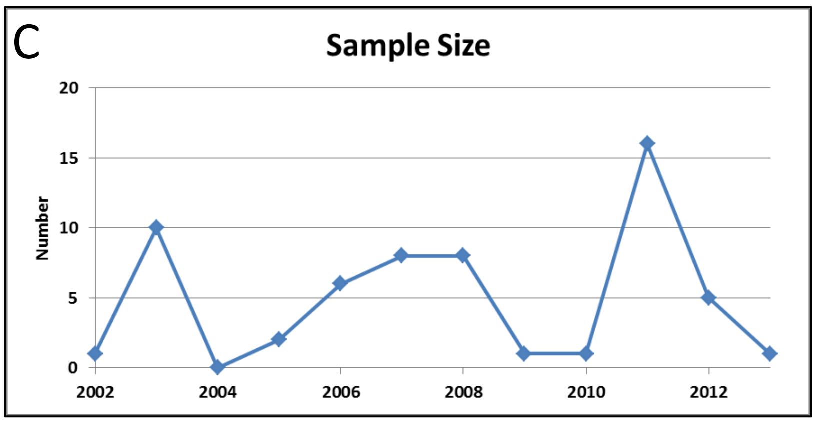
Skates and Rays

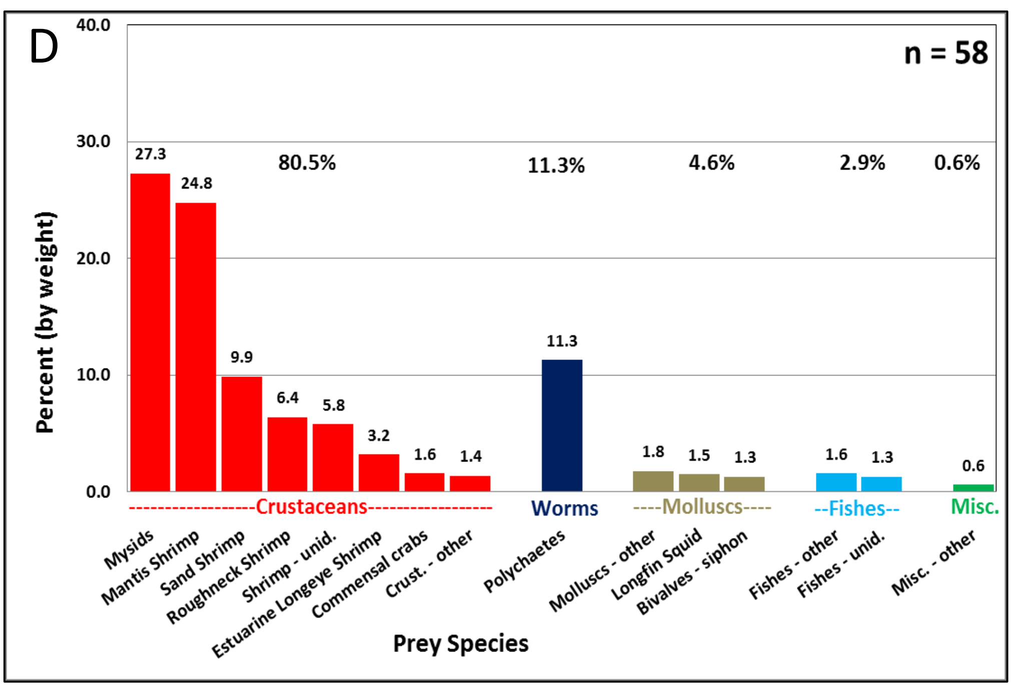
Atlantic Stingray

Figure E49. ChesMMAP Atlantic Stingray length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), and food habits percentages for all data combined for years 2002-2013 (D).



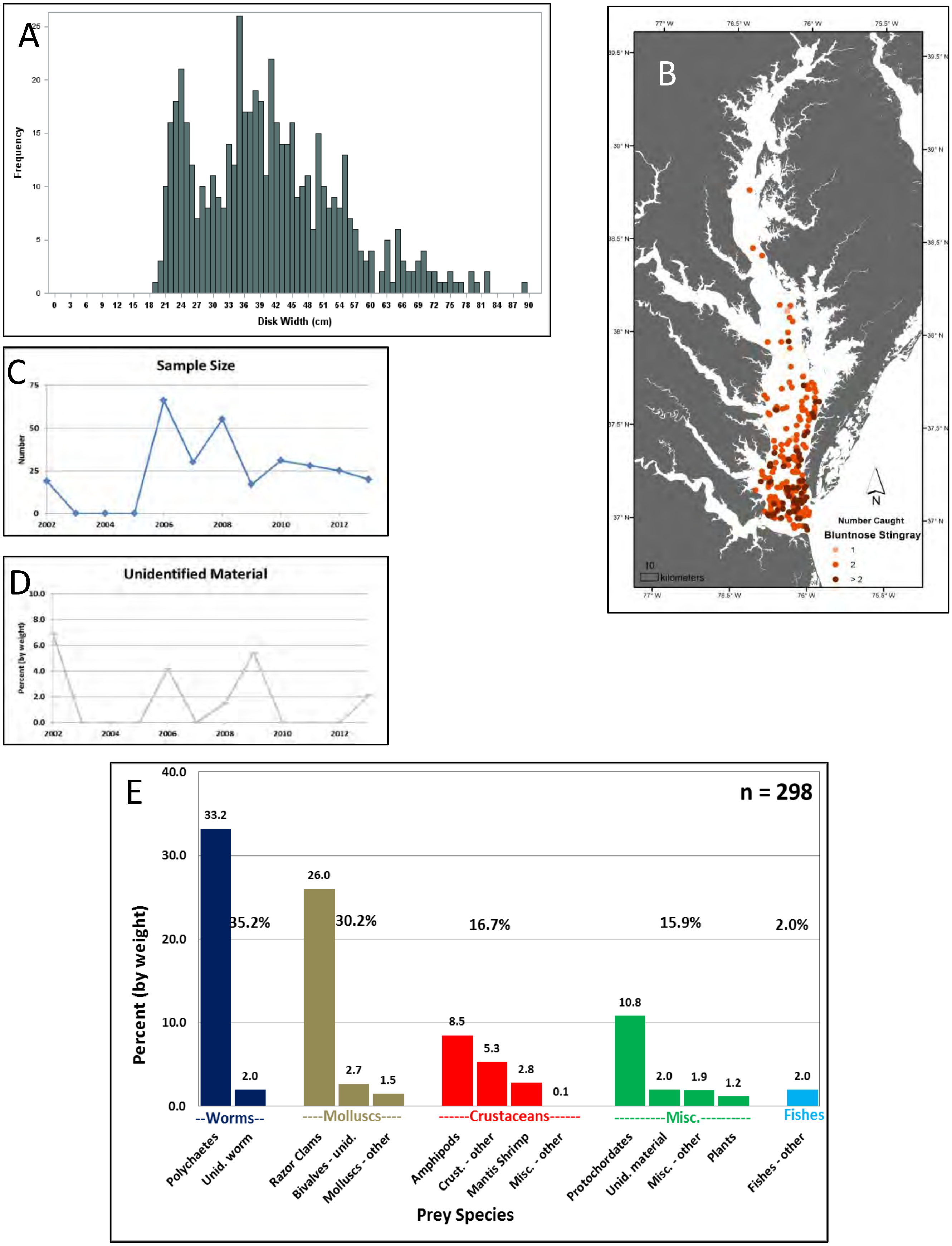






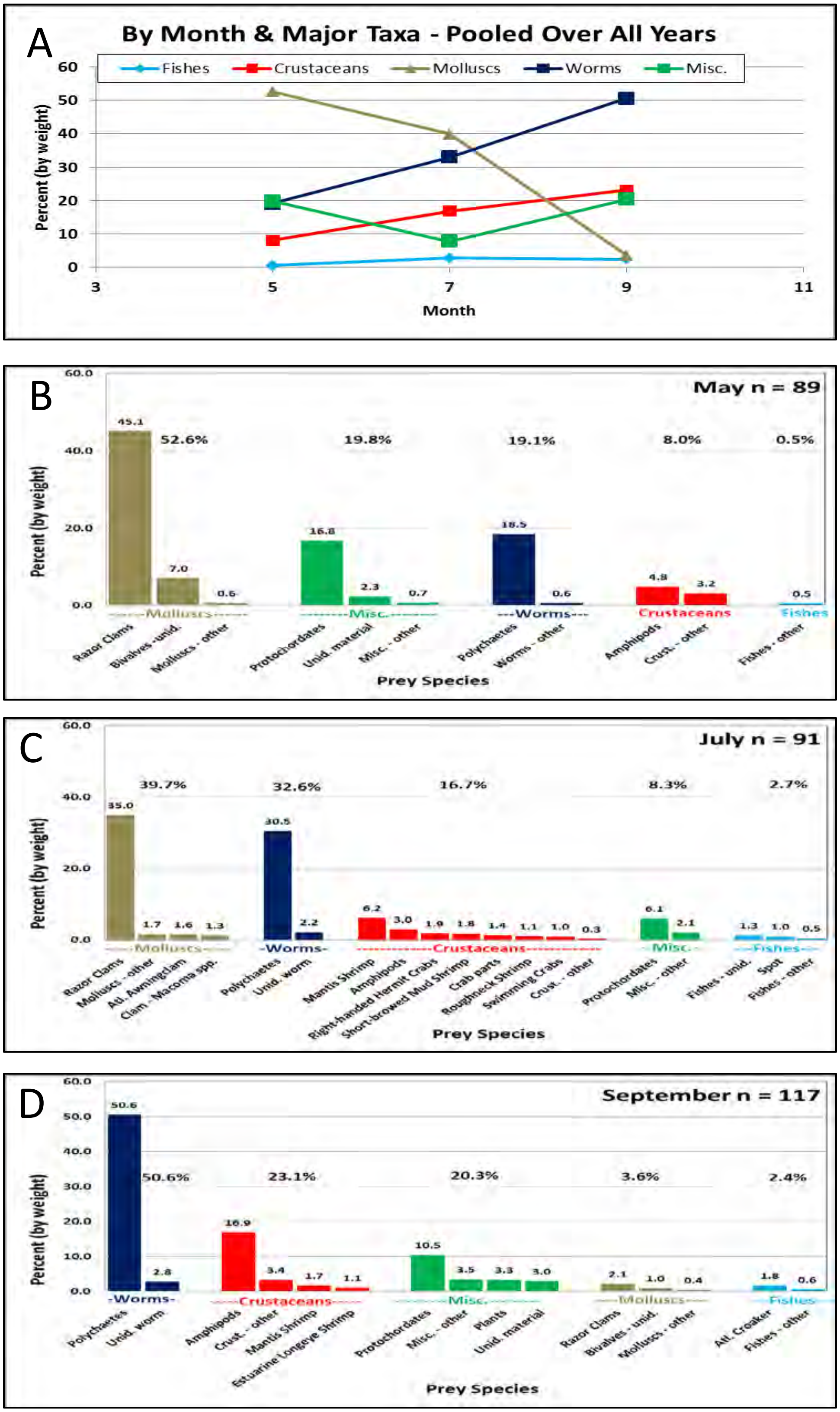
Bluntnose Stingray

Figure E50. ChesMMAP Bluntnose Stingray length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), yearly percentage of unidentifiable matter in stomachs (D), and food habits percentages for all data combined for years 2002-2013 (E).



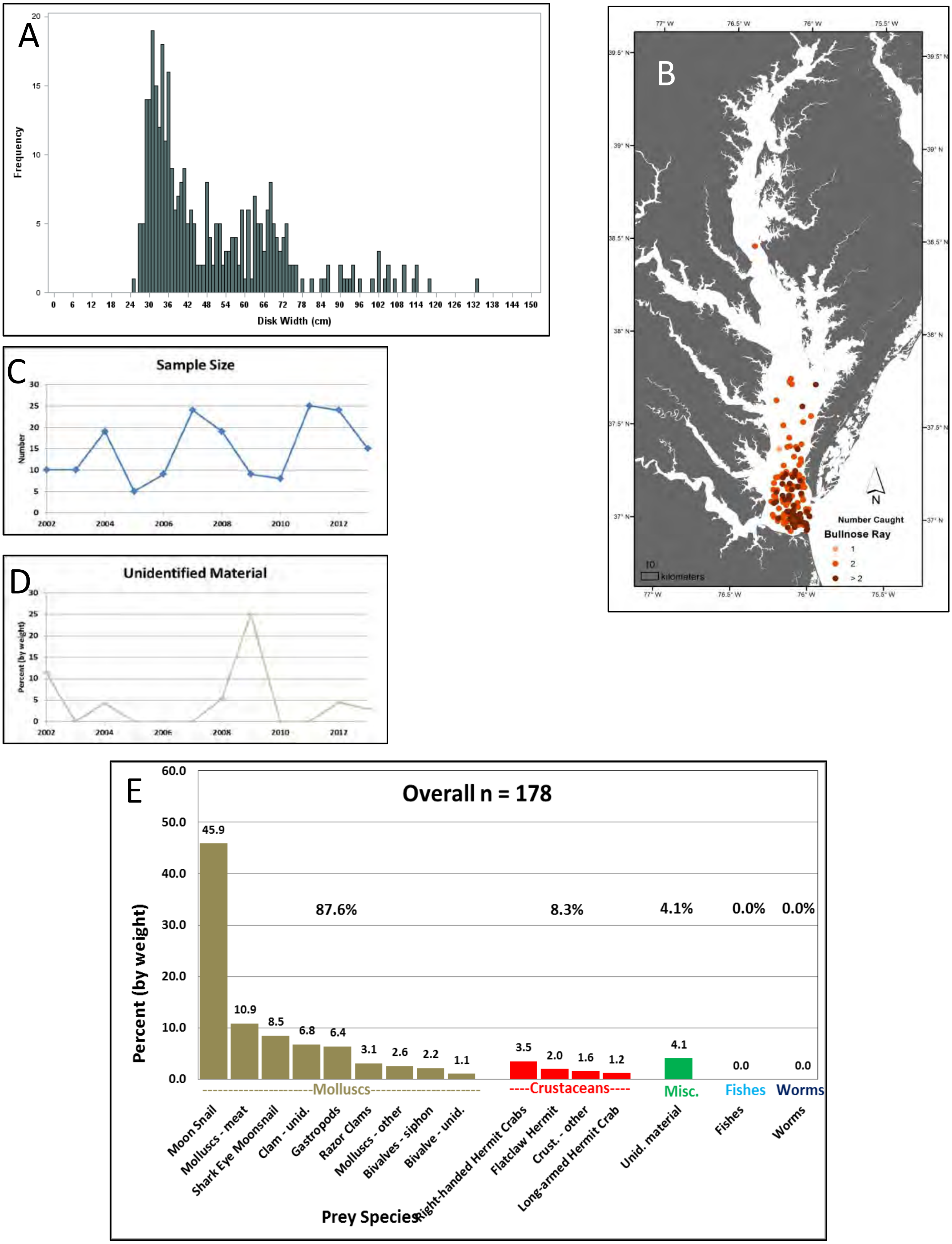
Bluntnose Stingray

Figure E51. ChesMMAP Bluntnose Stingray diet summaries by month, with data pooled over all sample years (2002-2013), for prey types summed over major taxa (A), and by species within major taxa for May (B), July (C), September (D).



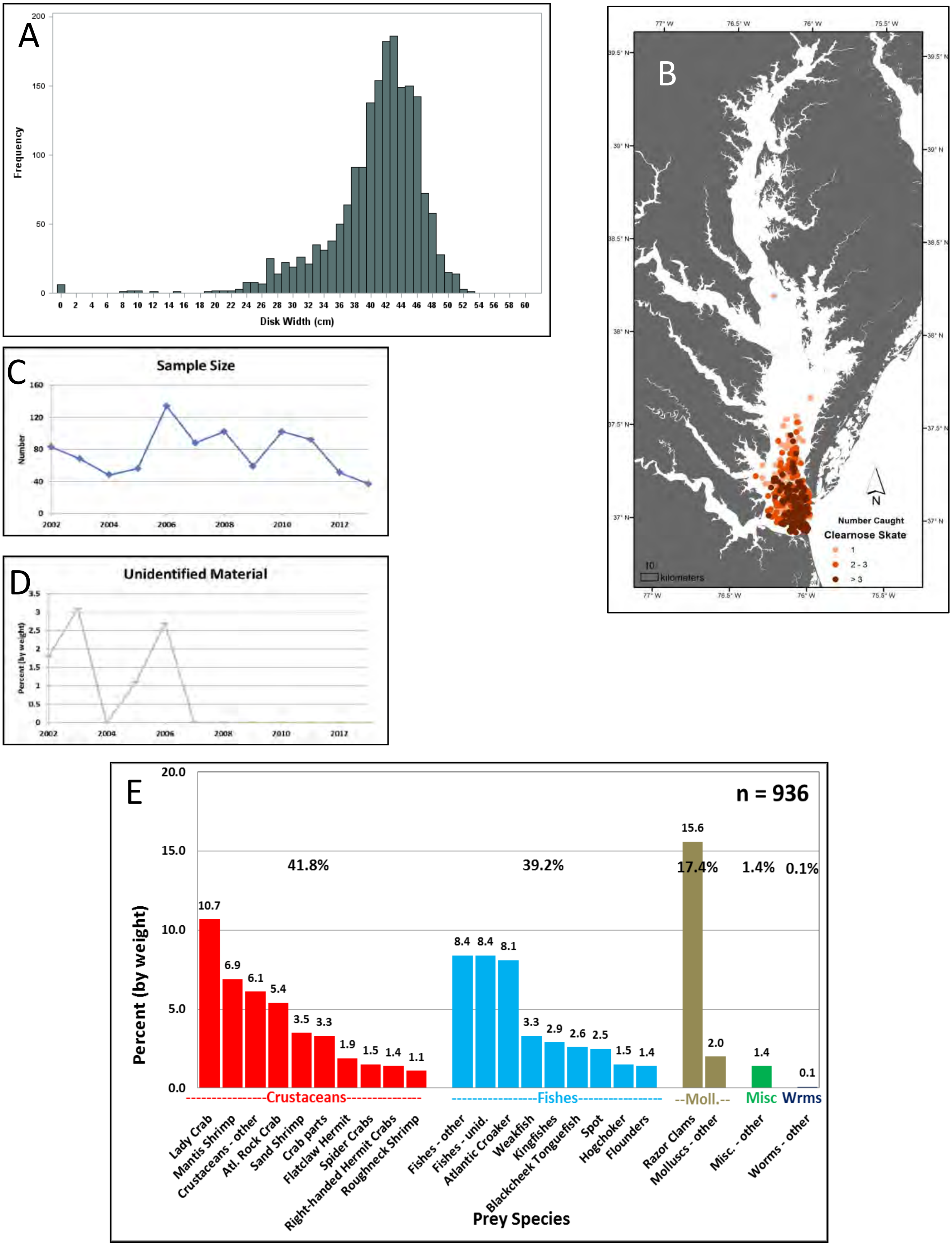
Bullnose Stingray

Figure E52. ChesMMAP Bullnose Stingray length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), yearly percentage of unidentifiable matter in stomachs (D), and food habits percentages for all data combined for years 2002-2013 (E).



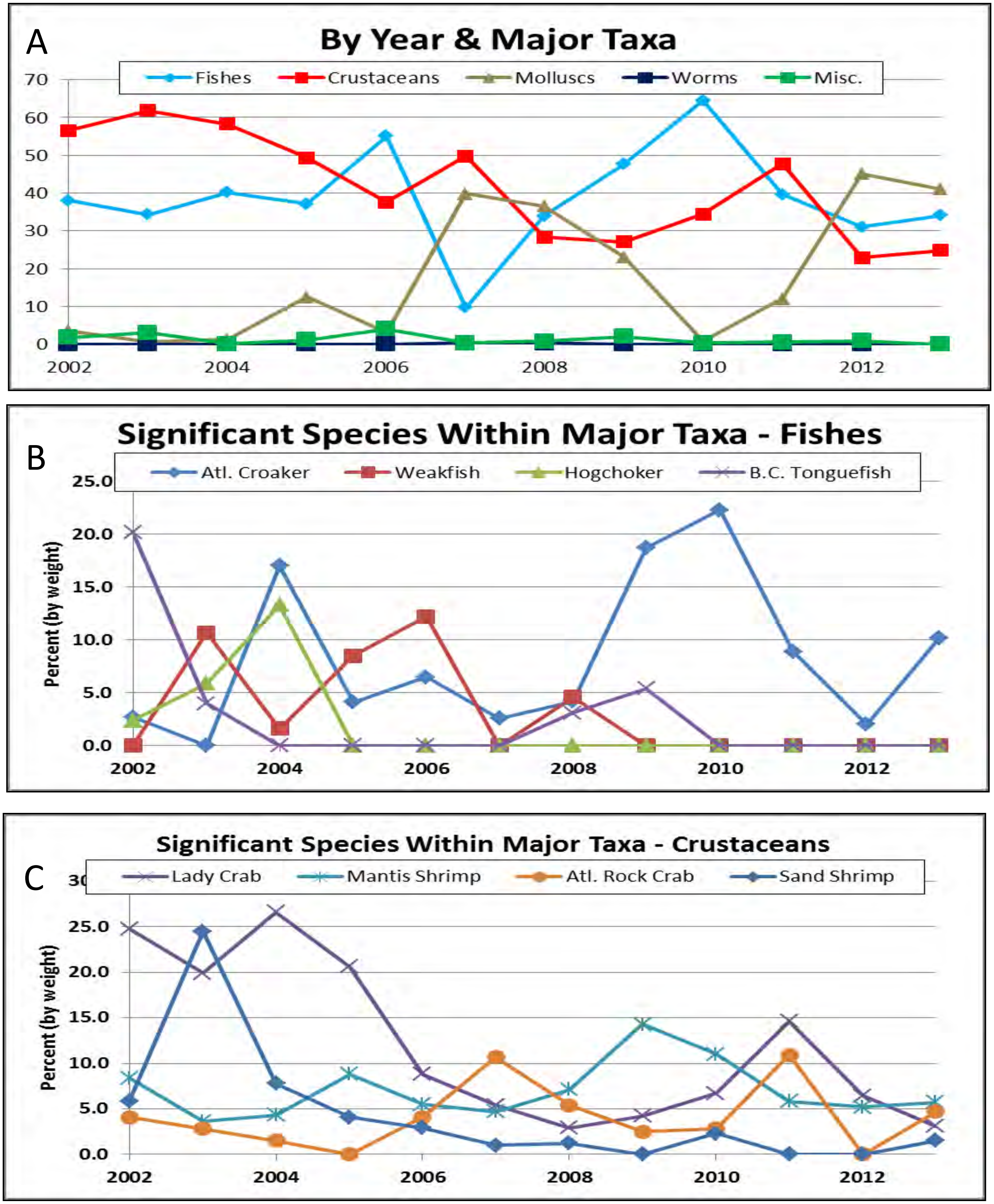
Clearnose Skate

Figure E53. ChesMMAP Clearnose Skate length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), yearly percentage of unidentifiable matter in stomachs (D), and food habits percentages for all data combined for years 2002-2013 (E).



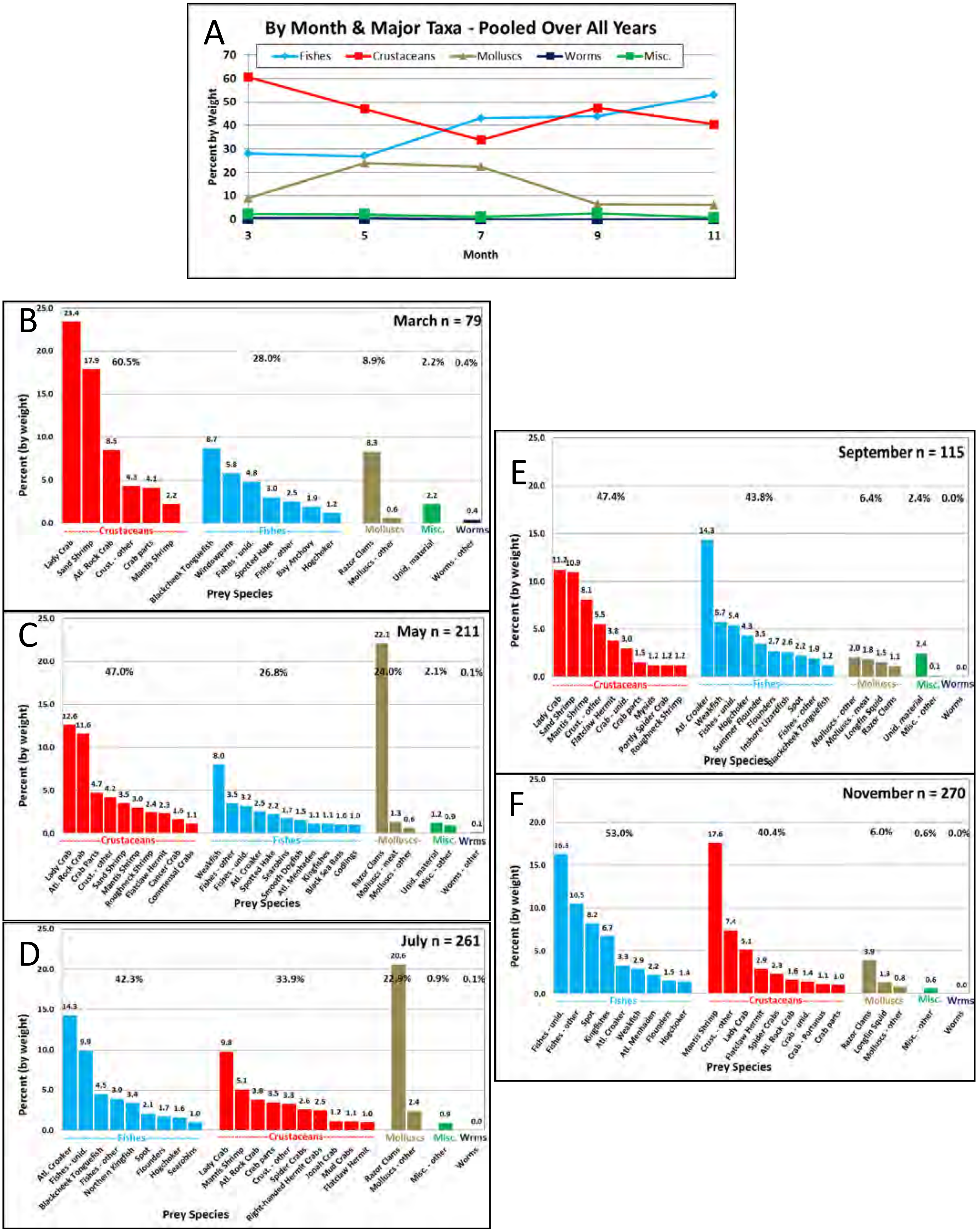
Clearnose Skate

Figure E54. ChesMMAP Clearnose Skate diet summaries by year, with data pooled over all sample months and areas, for all species combined within major taxa (A), and for selected species within the fish (B) and crustacean (C) taxa.



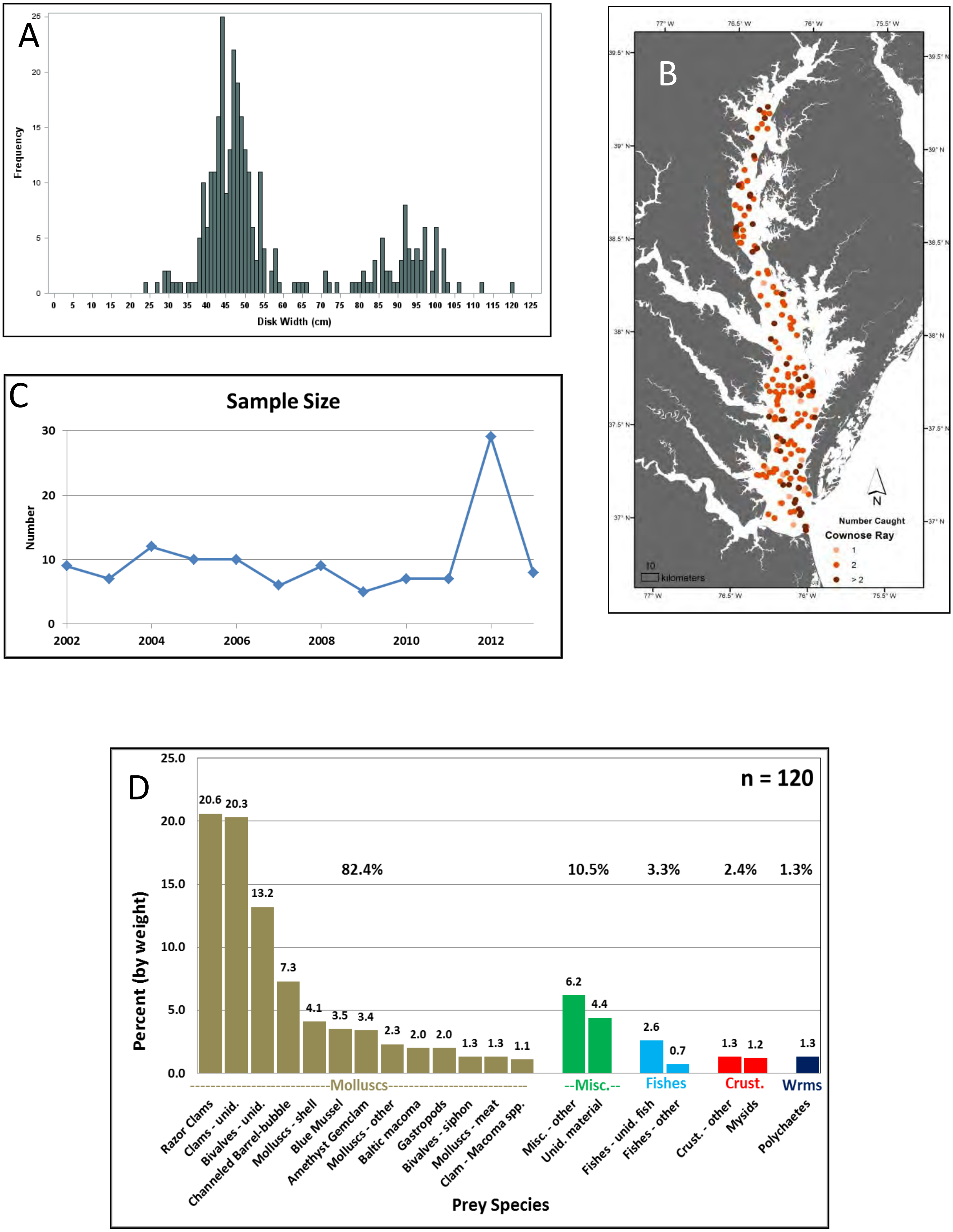
Clearnose Skate

Figure E55. ChesMMAP Clearnose Skate diet summaries by month, with data pooled over all sample years (2002-2013), for prey types summed over major taxa (A), and by species within major taxa for March (B), May (C), July (D), September (E), and November (F).



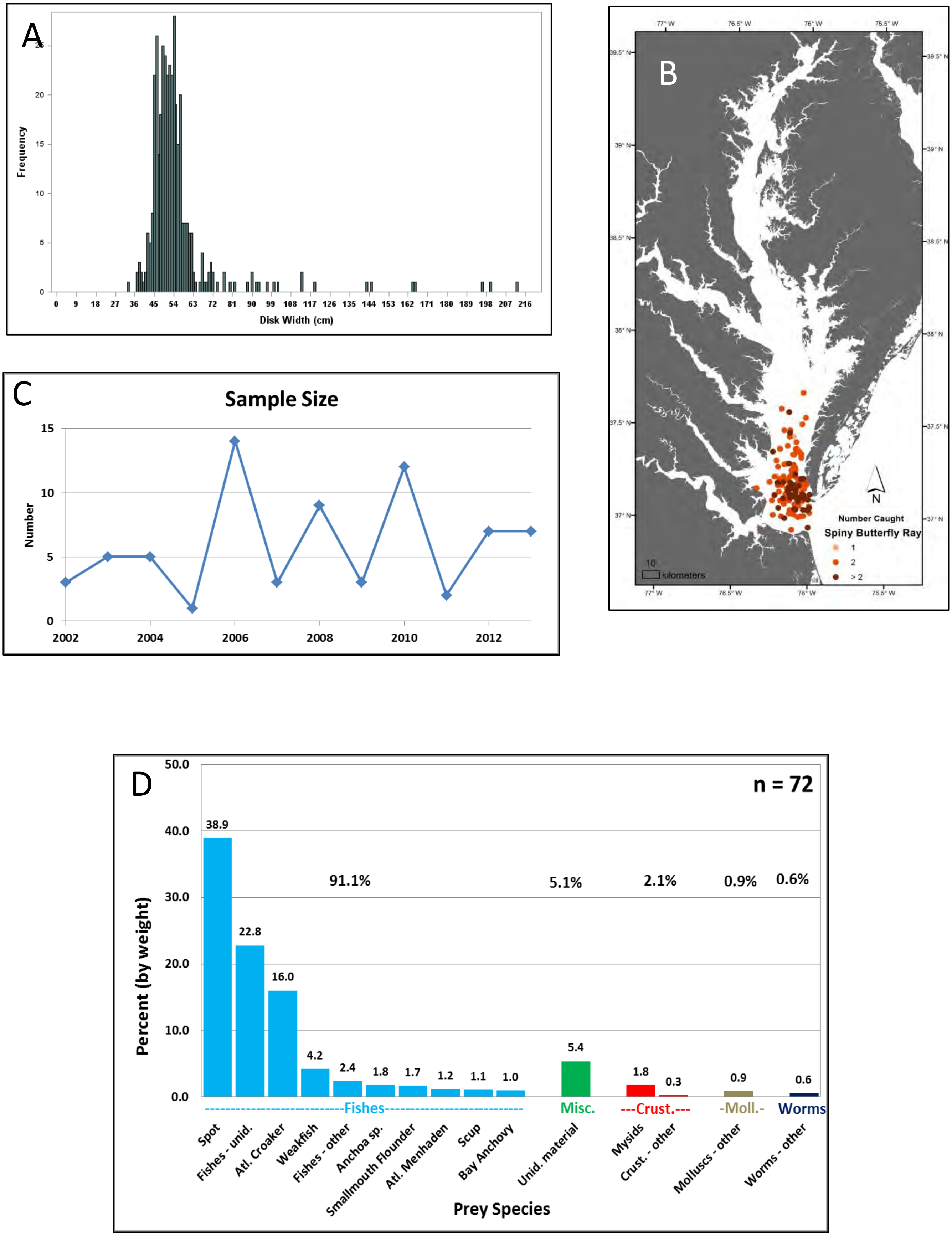
Cownose Ray

Figure E56. ChesMMAP Cownose Ray length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), and food habits percentages for all data combined for years 2002-2013 (D).



Spiny Butterfly Ray

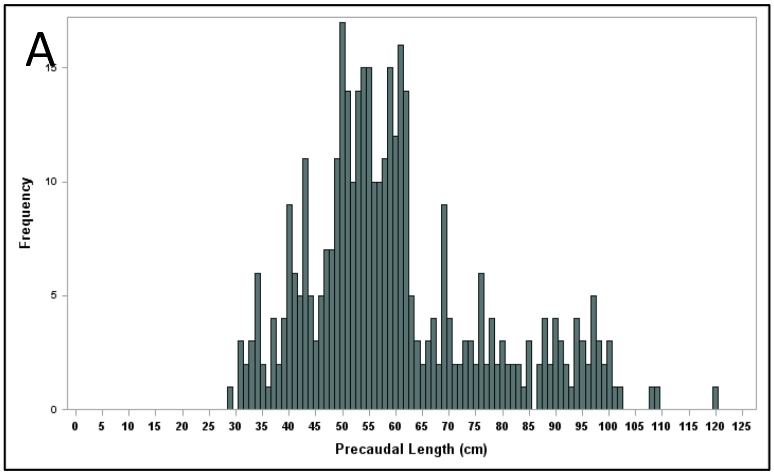
Figure E57. ChesMMAP Spiny Butterfly Ray length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), and food habits percentages for all data combined for years 2002-2013 (D).

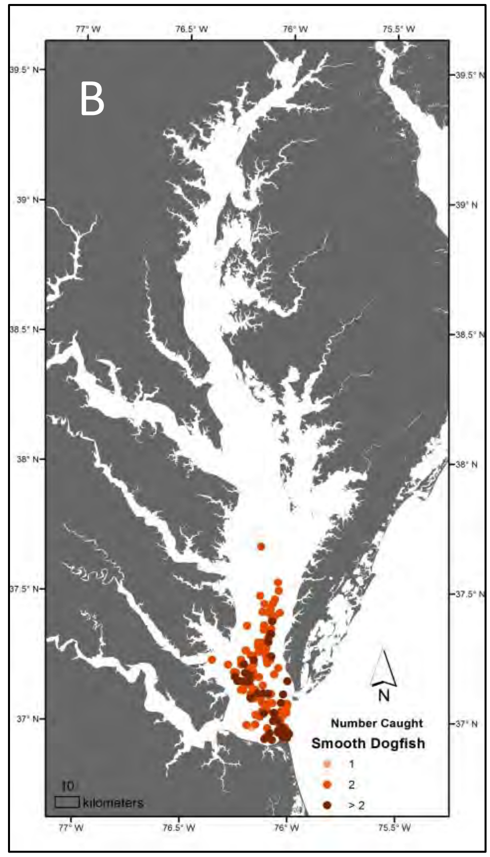


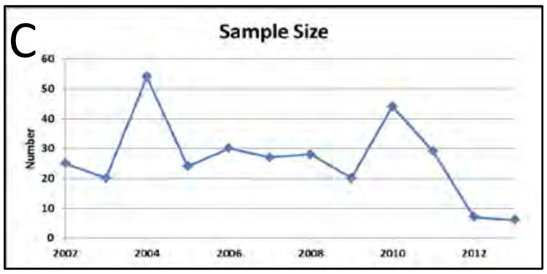
Dogfishes

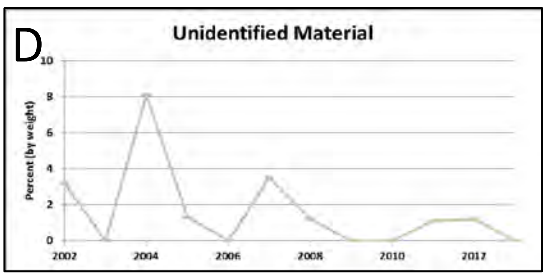
Smooth Dogfish

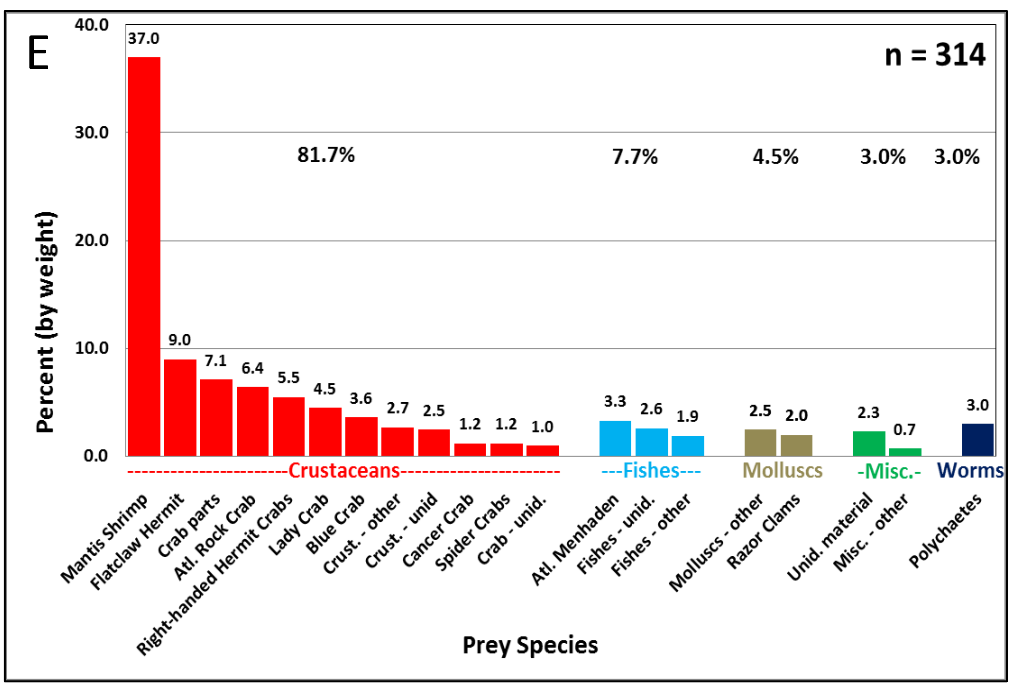
Figure E58. ChesMMAP Smooth Dogfish length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), yearly percentage of unidentifiable matter in stomachs (D), and food habits percentages for all data combined for years 2002-2013 (E).





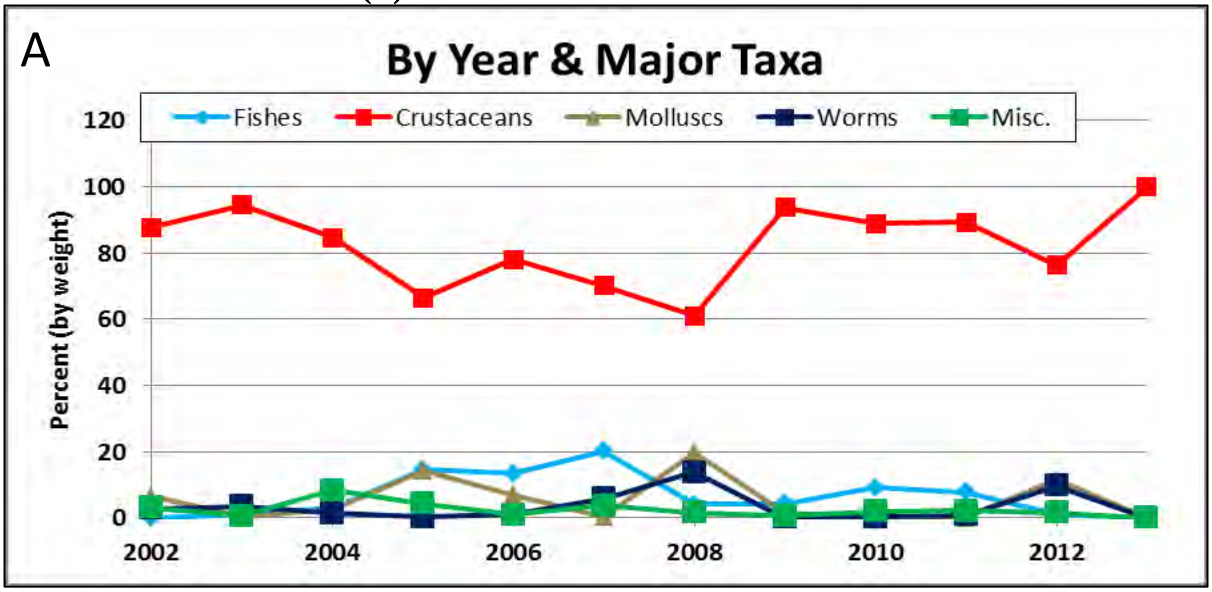


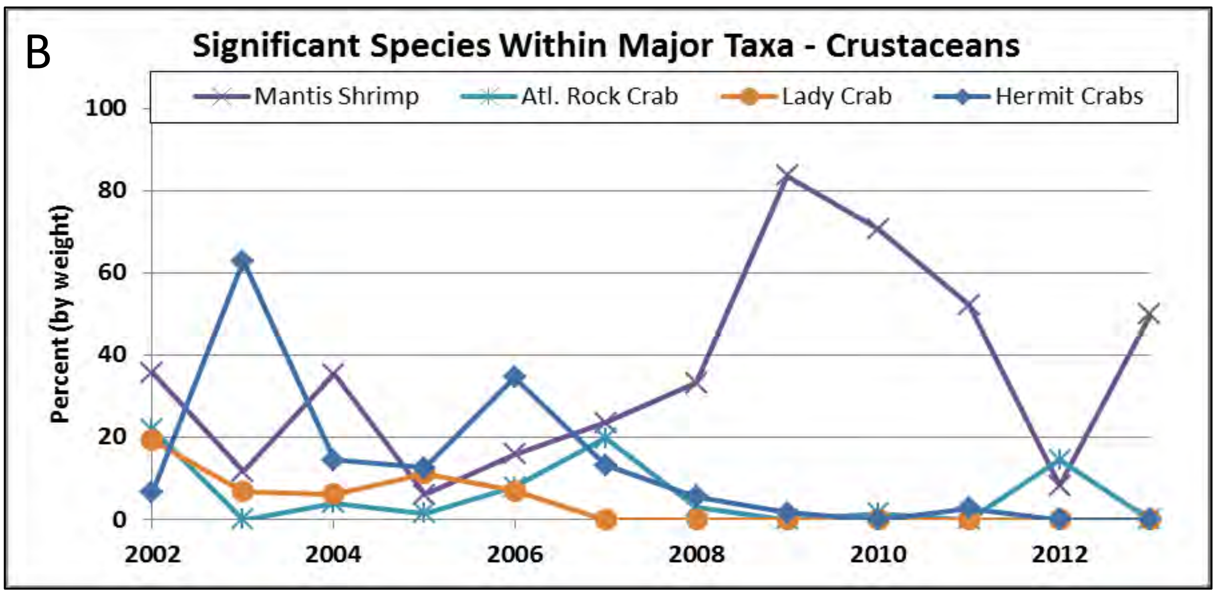




Smooth Dogfish

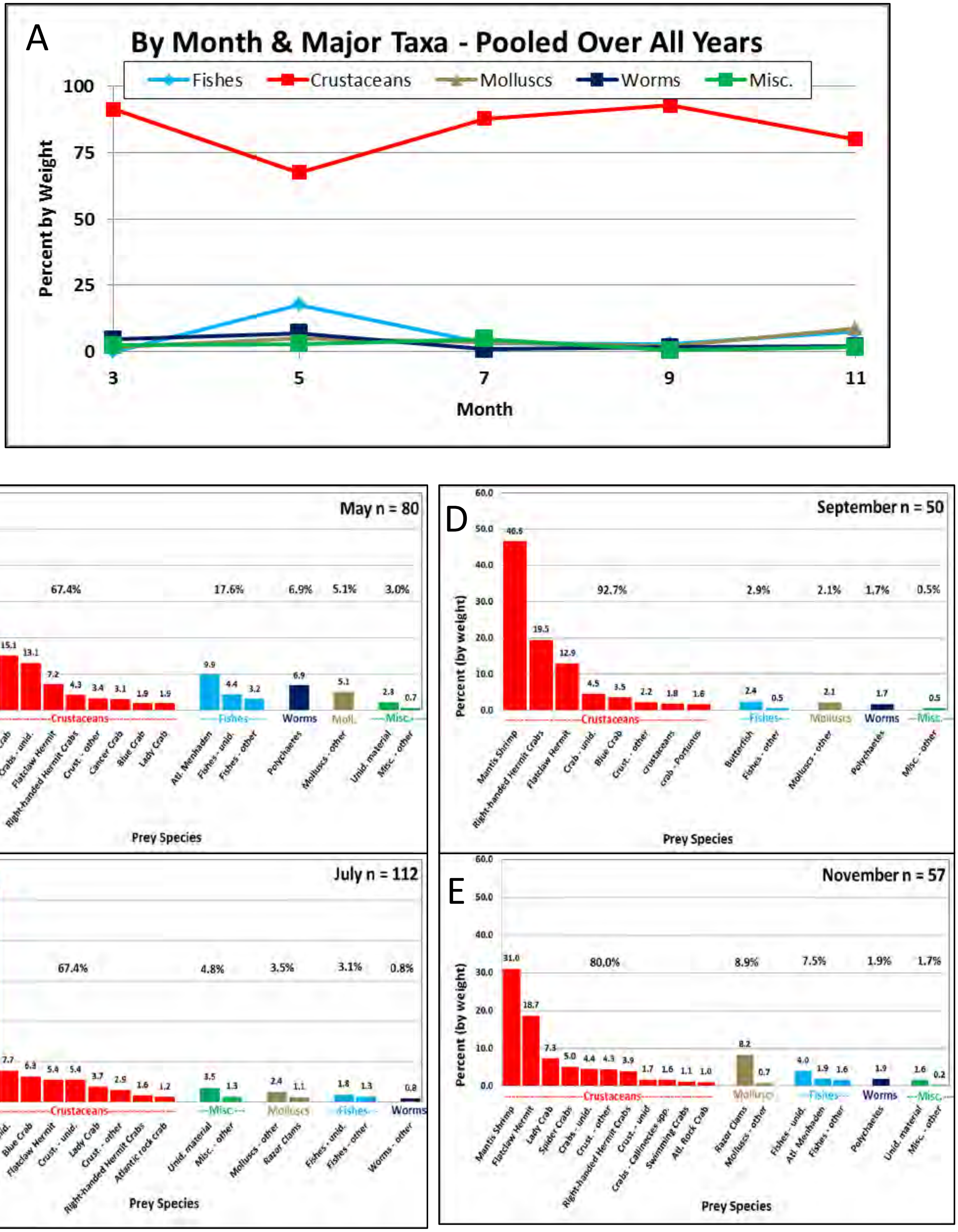
Figure E59. ChesMMAP Smooth Dogfish diet summaries by year, with data pooled over all sample months and areas, for all species combined within major taxa (A), and for selected species within the crustacean (B) taxon.





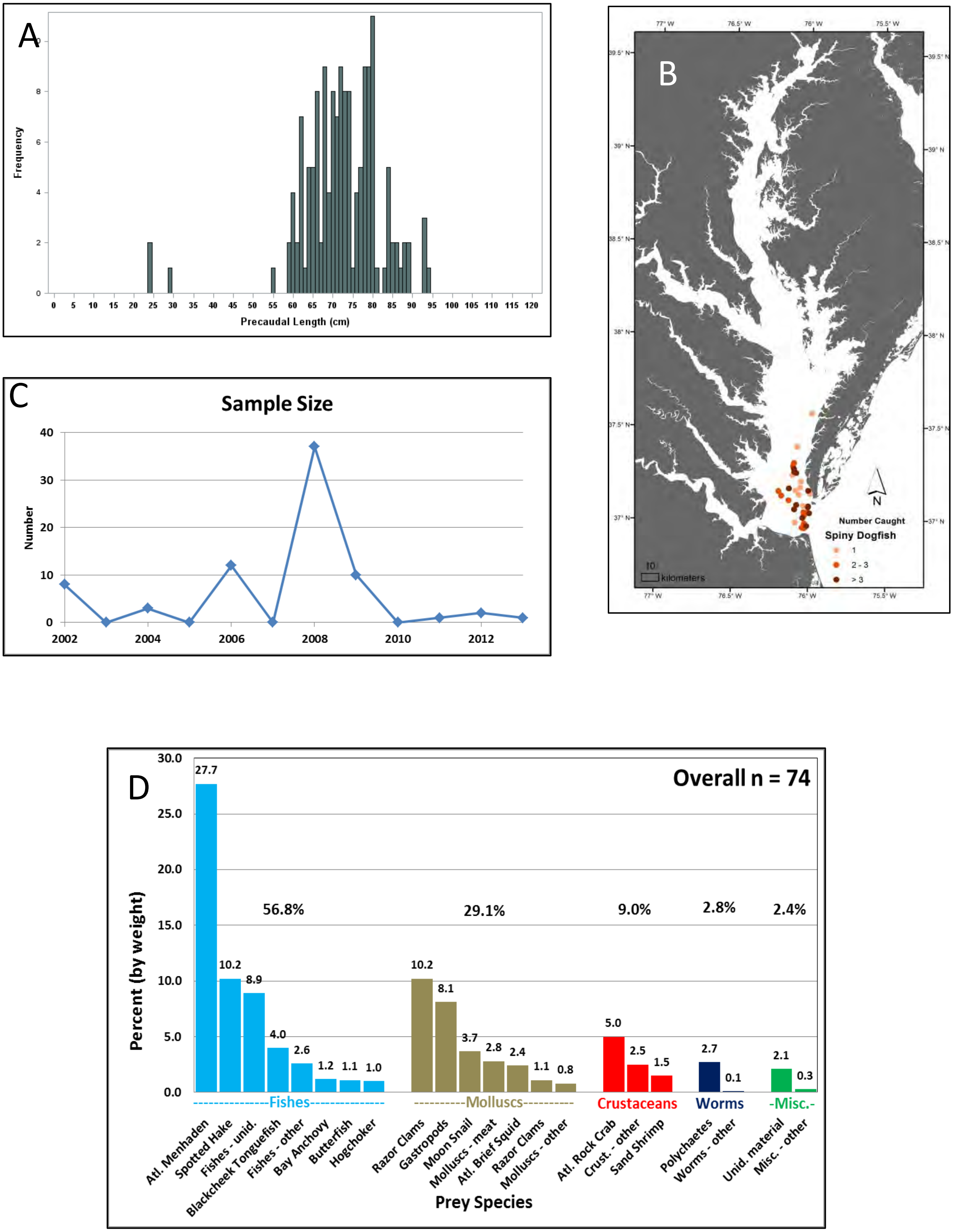
Smooth Dogfish

Figure E60. ChesMMAP Smooth Dogfish diet summaries by month, with data pooled over all sample years (2002-2013), for prey types summed over major taxa (A), and by species within major taxa for May (B), July (C), September (D), and November (E).



Spiny Dogfish

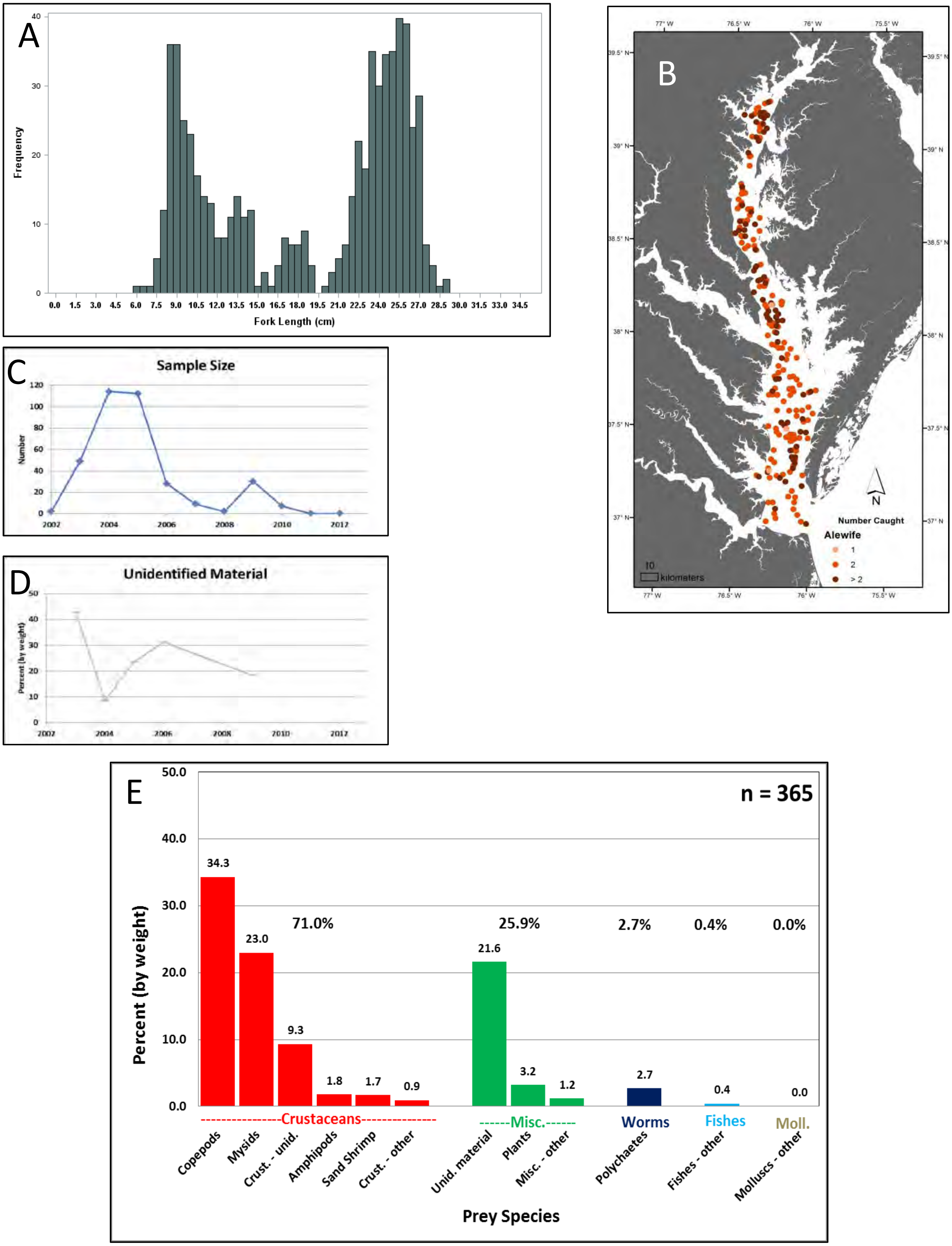
Figure E61. ChesMMAP Spiny Dogfish length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), and food habits percentages for all data combined for years 2002-2013 (D).



River Herring

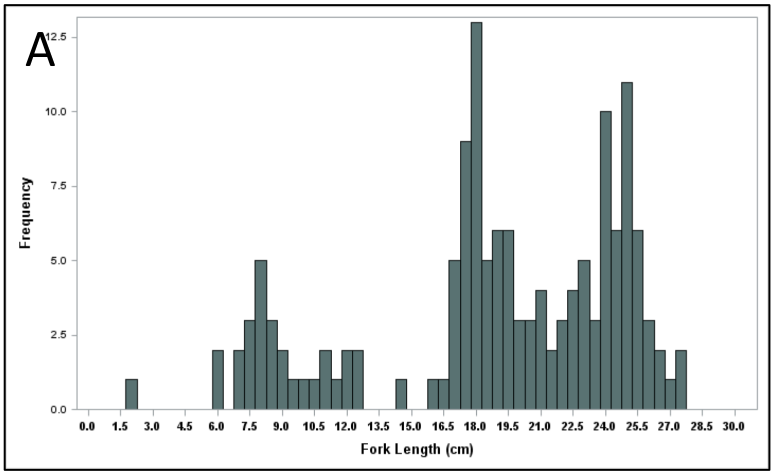
Alewife

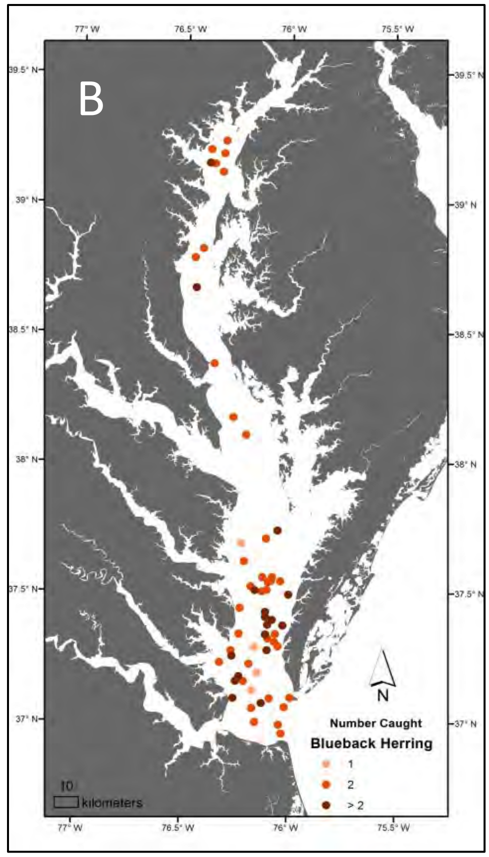
Figure E62. ChesMMAP Alewife length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), yearly percentage of unidentifiable matter in stomachs (D), and food habits percentages for all data combined for years 2002-2013 (E).

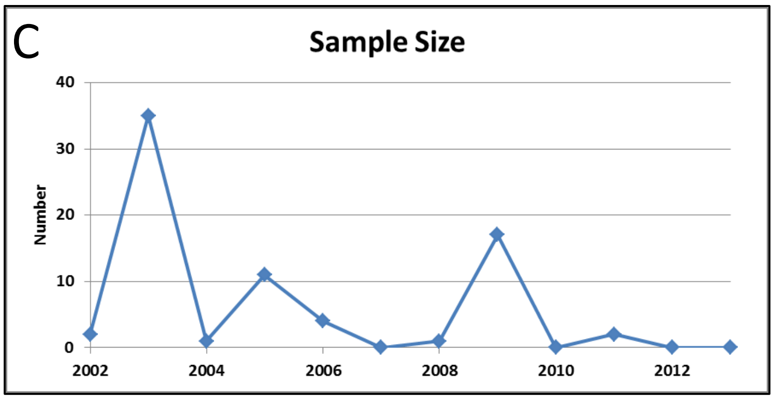


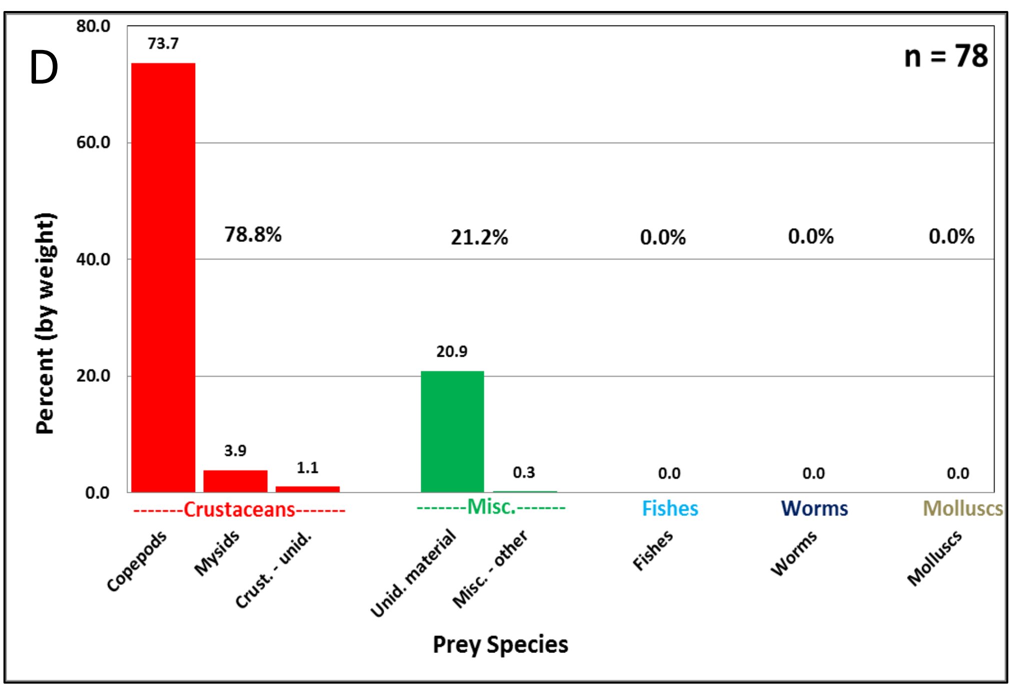
Blueback Herring

Figure E63. ChesMMAP Blueback Herring length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), and food habits percentages for all data combined for years 2002-2013 (D).





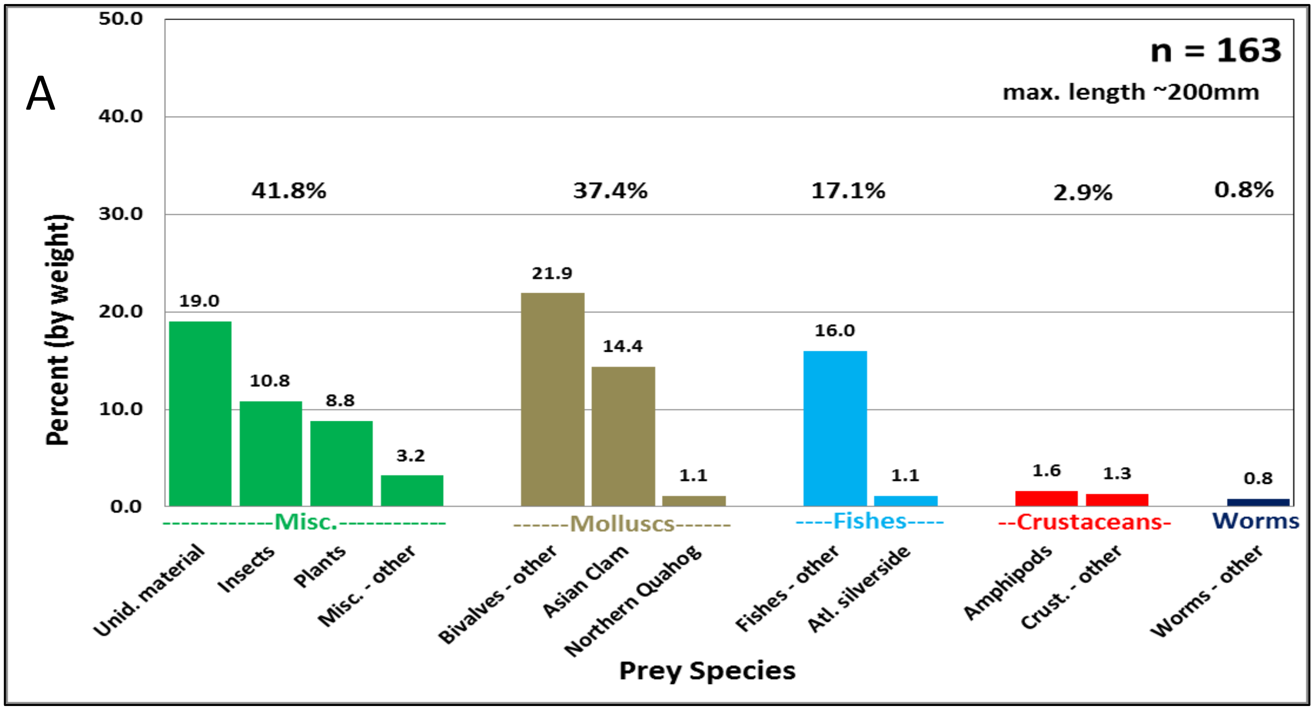


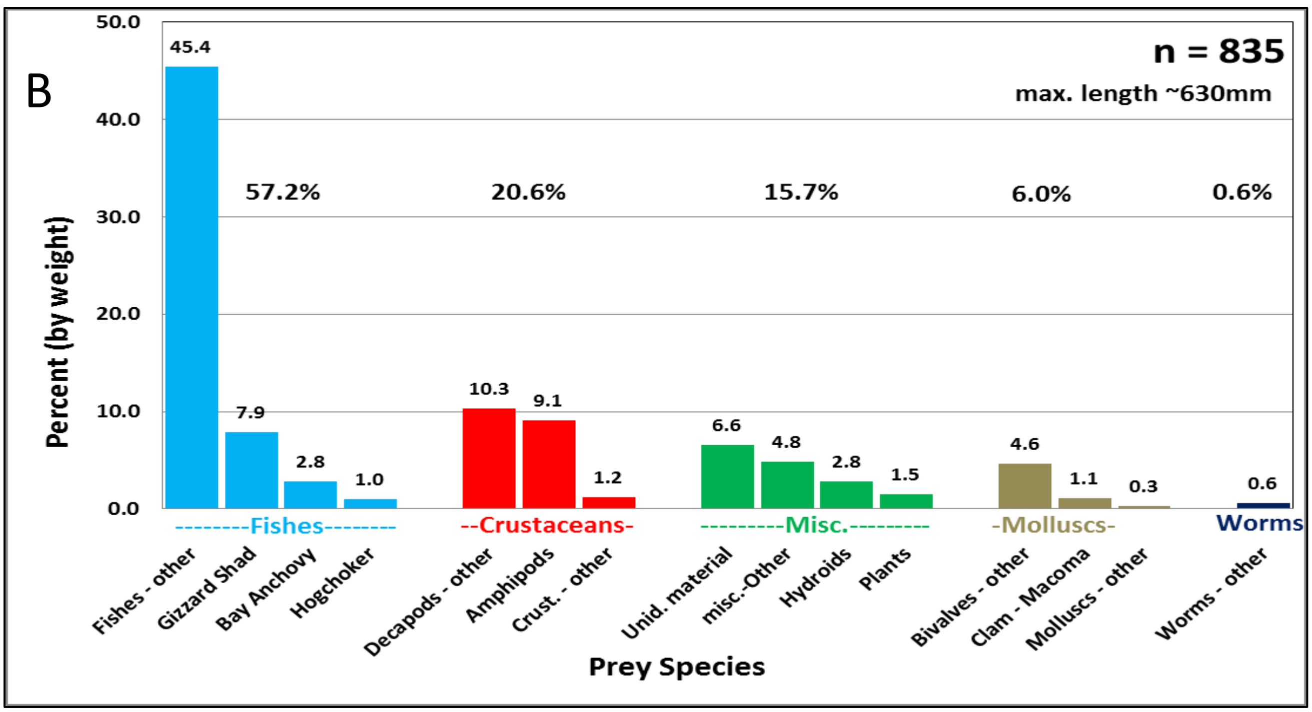


Oligo/Meso-haline Fishes

Blue Catfish

Figure E64. Virginia Seine Survey (A – 2004-2006) and Juvenile Fishes Trawl Survey (B – 2004-2007) Blue Catfish diet summaries.*

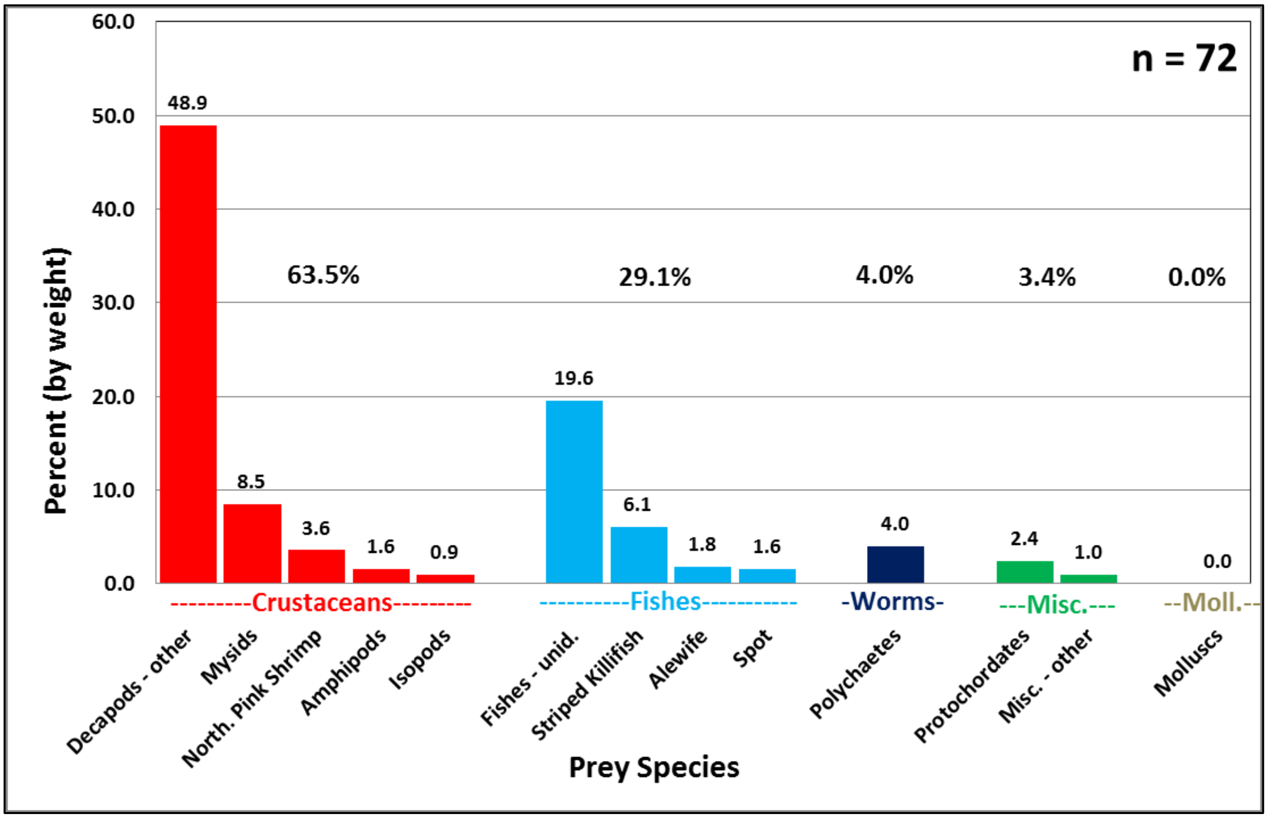




*** Size distributions between these two samples overlap substantially but specimens from the Seine Survey are generally smaller than 200mm while those from the Trawl Survey generally range between 150-630mm.**

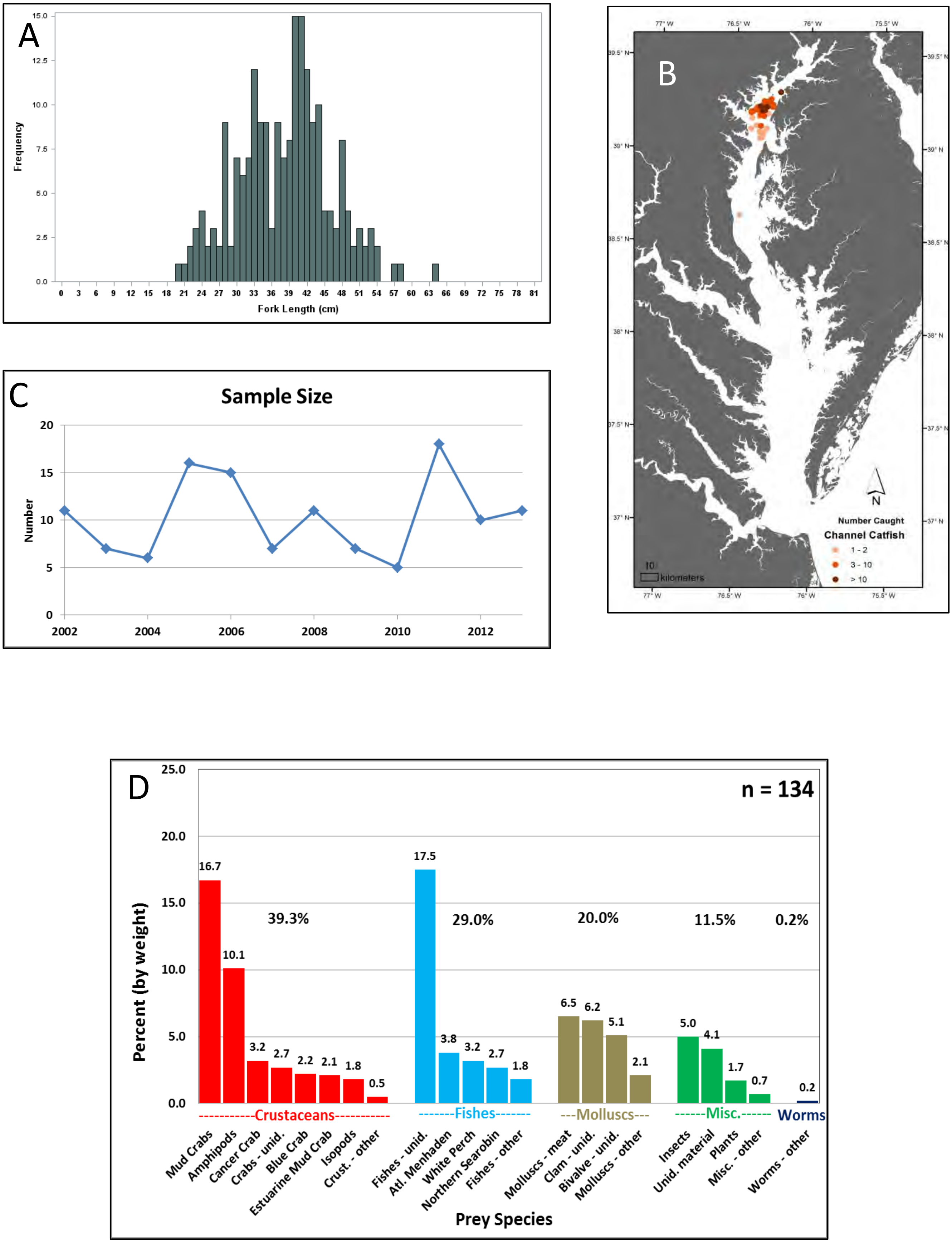
Blue Catfish

Figure E65. VIMS Trammel Net Survey Blue Catfish diet summary (2004-2005).



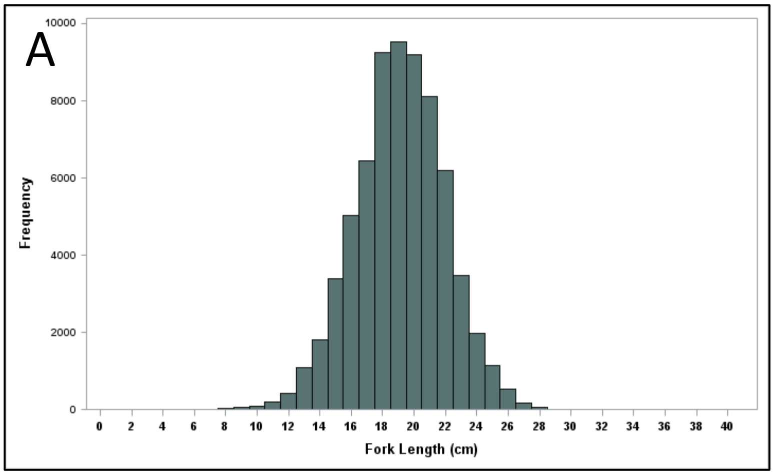
Channel Catfish

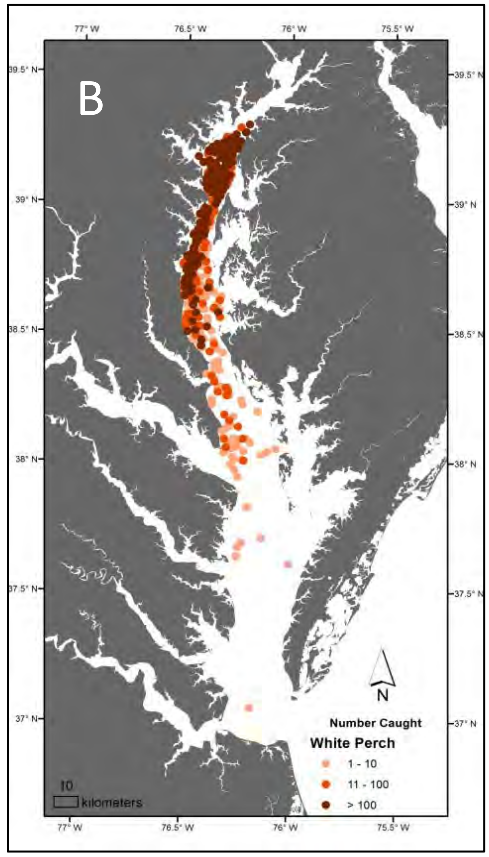
Figure E66. ChesMMAP Channel Catfish length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), and food habits percentages for all data combined for years 2002-2013 (D).

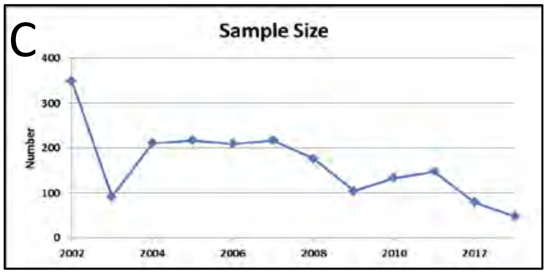


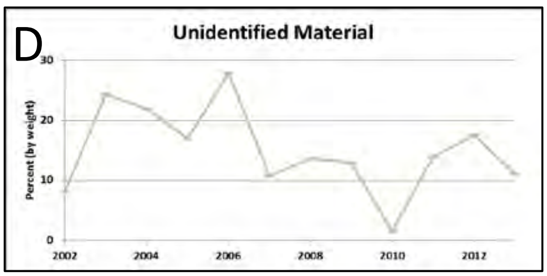
White Perch

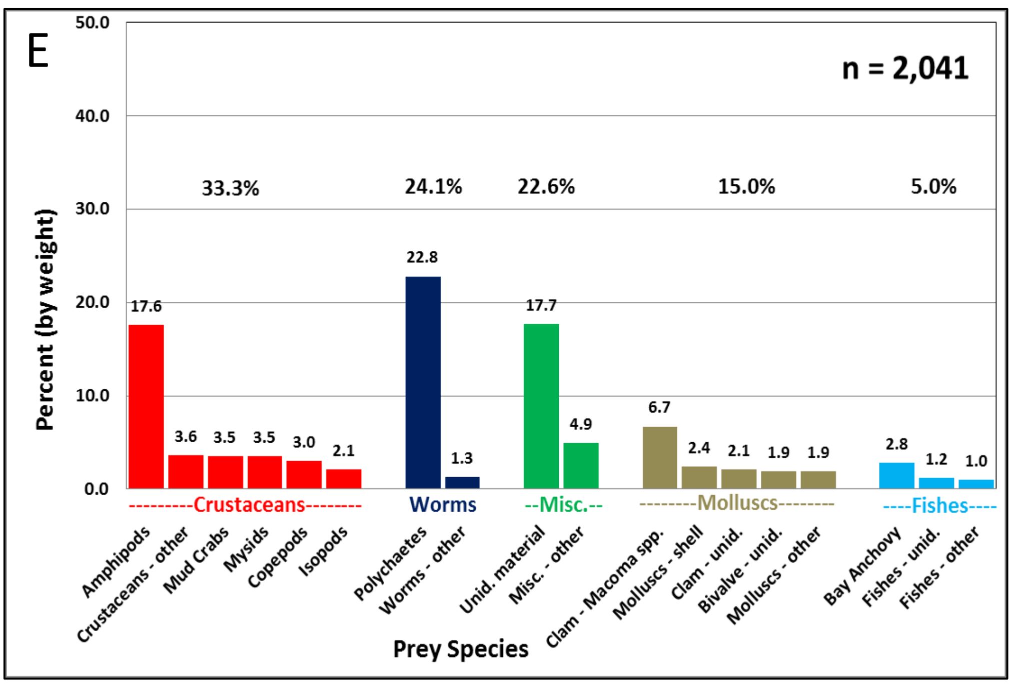
Figure E67. ChesMMAP White Perch length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), yearly percentage of unidentifiable matter in stomachs (D), and food habits percentages for all data combined for years 2002-2013 (E).





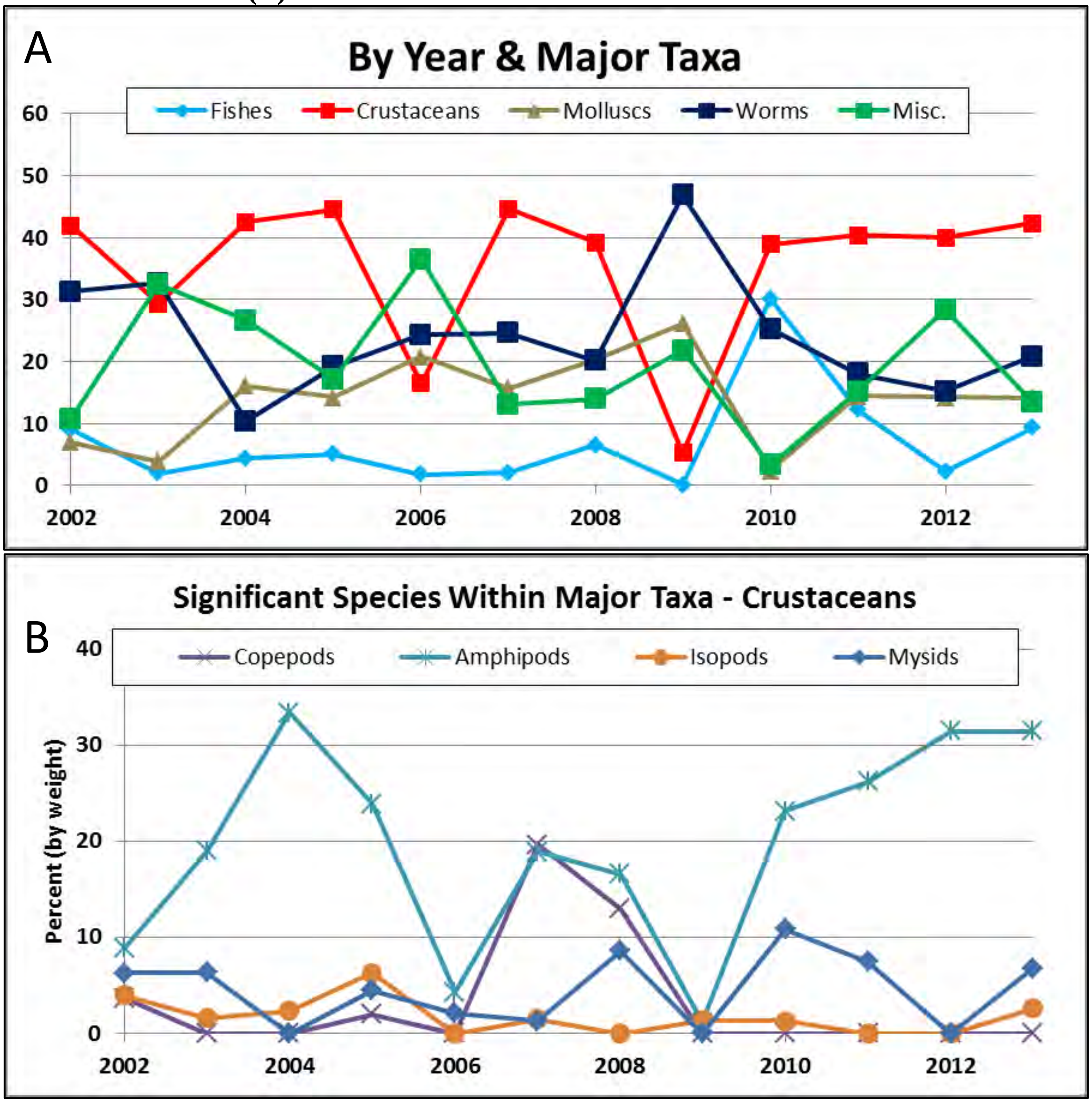






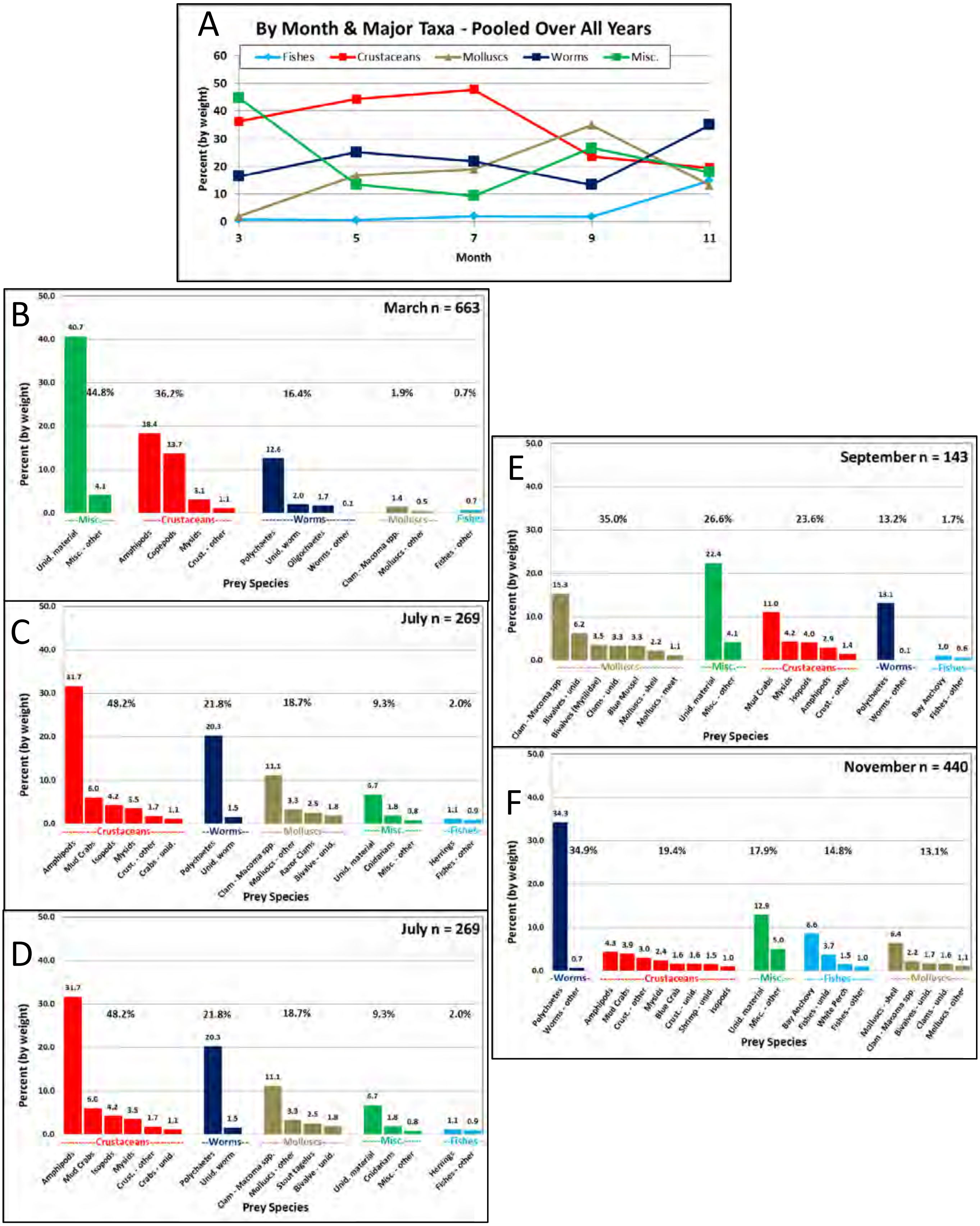
White Perch

Figure E68. ChesMMAP White Perch diet summaries by year, with data pooled over all sample months and areas, for all species combined within major taxa (A), and for selected species within the crustacean (B) taxon.



White Perch

Figure E69. ChesMMAP White Perch diet summaries by month, with data pooled over all sample years (2002-2013), for prey types summed over major taxa (A), and by species within major taxa for March (B), May (C), July (D), September (E), and November (F).



White Perch

Figure E70. CHESFIMS White Perch diet summaries with data pooled over all sample years, areas, and sizes.

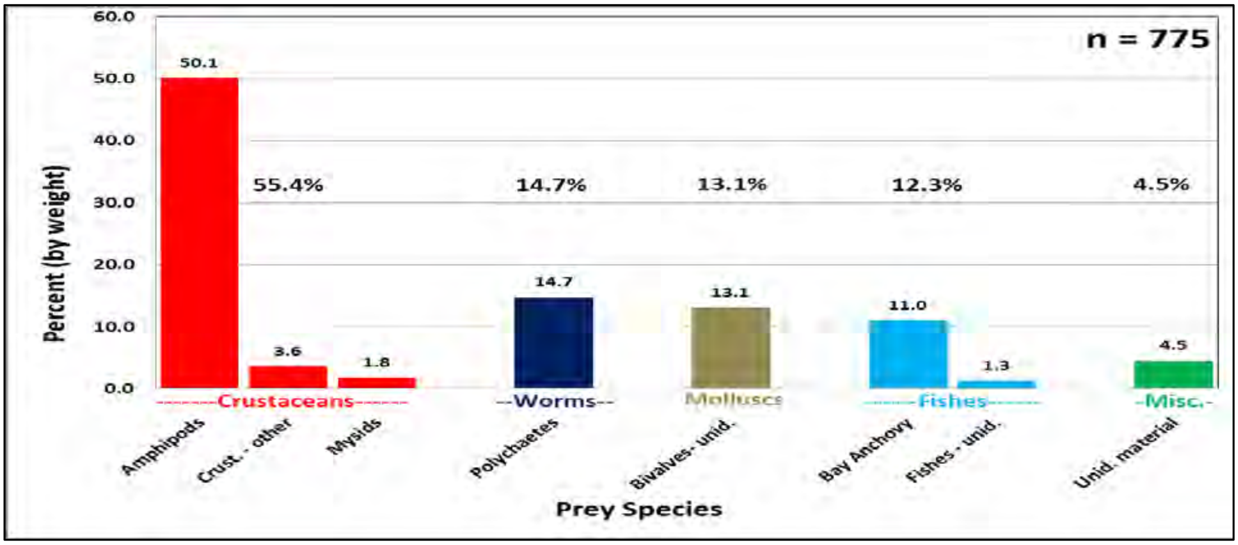


Figure E71. VIMS Seine Survey White Perch diet summaries with data pooled over all sample years, areas and sizes.

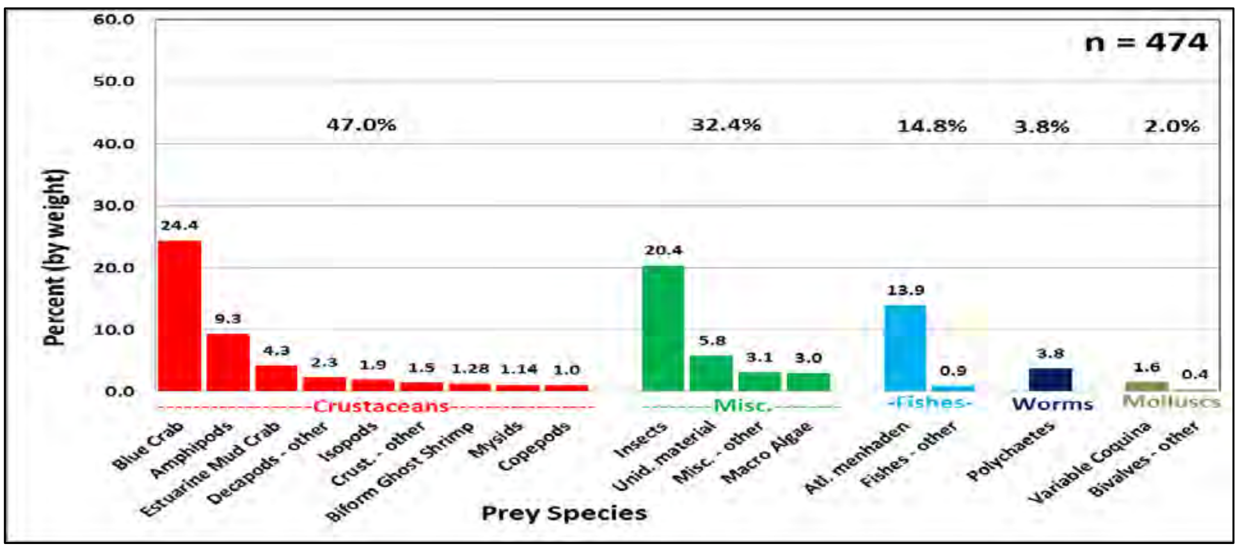
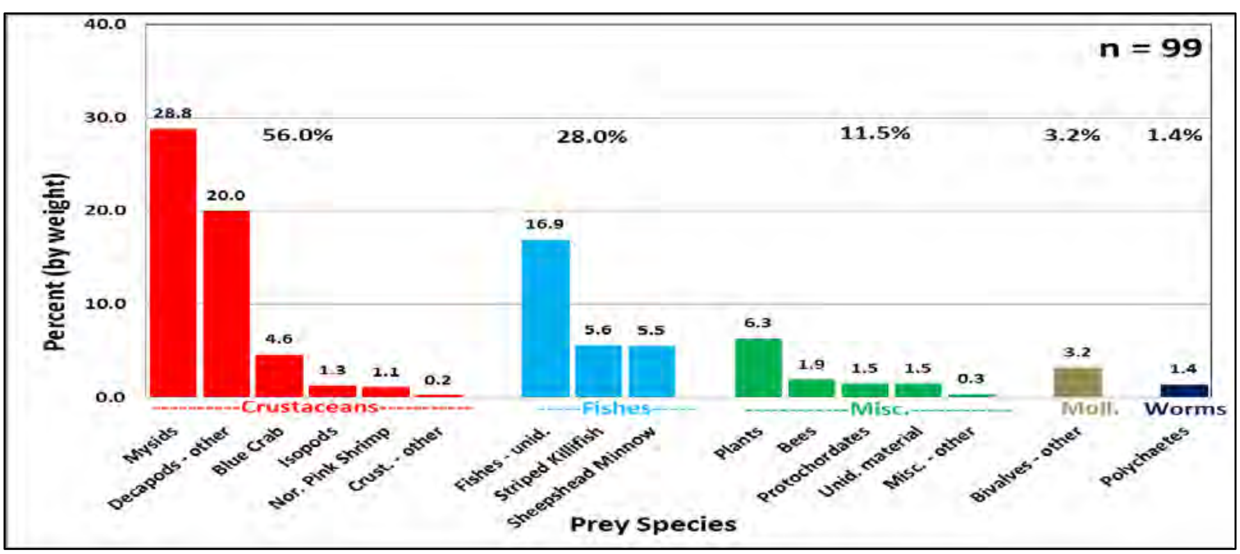


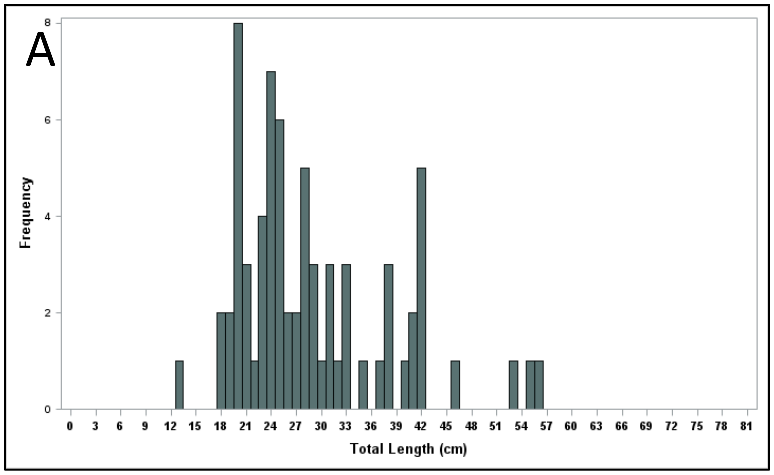
Figure E72. VIMS Trammel Net Survey White Perch diet summary (2004-2005).

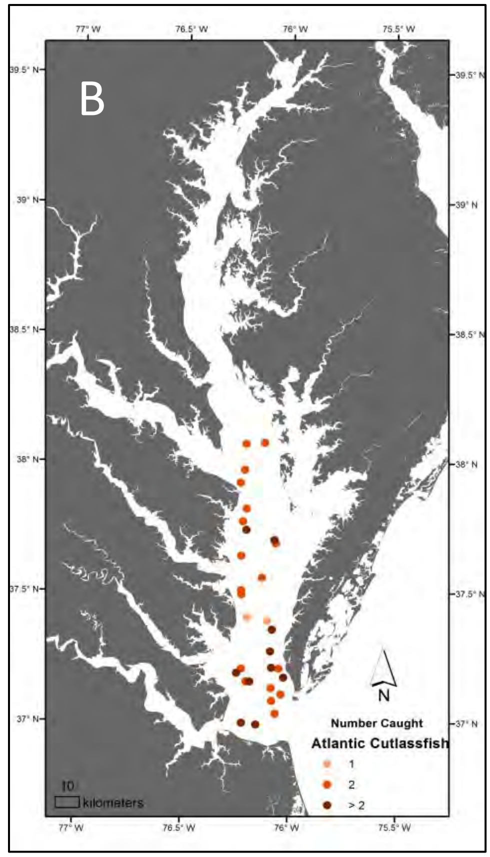


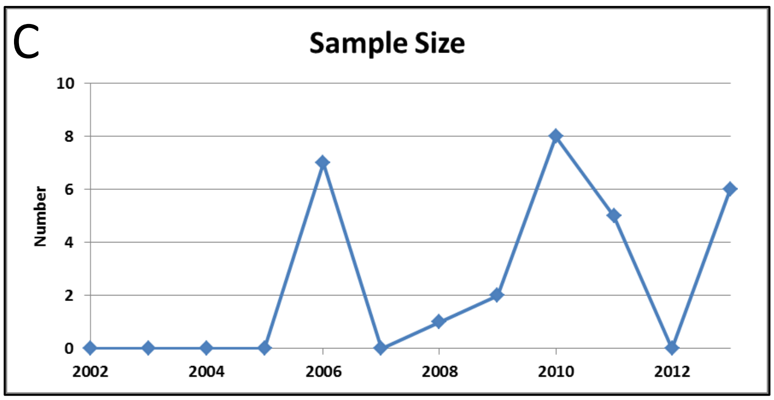
Polyhaline Fishes

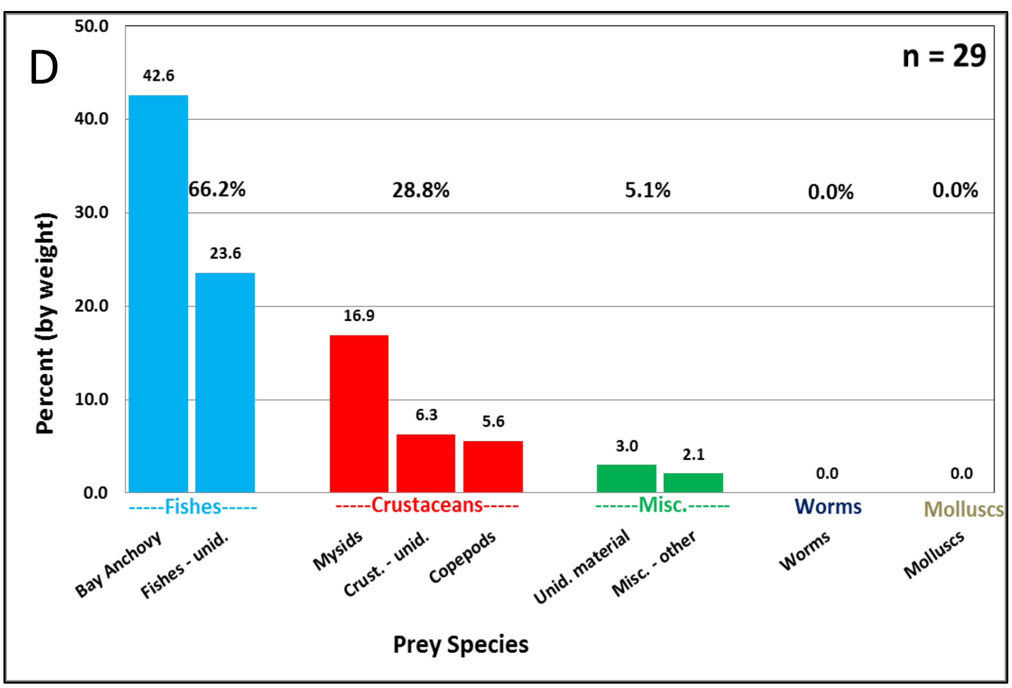
Atlantic Cutlassfish

Figure E73. ChesMMAP Atlantic Cutlassfish length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), and food habits percentages for all data combined for years 2002-2013 (D).



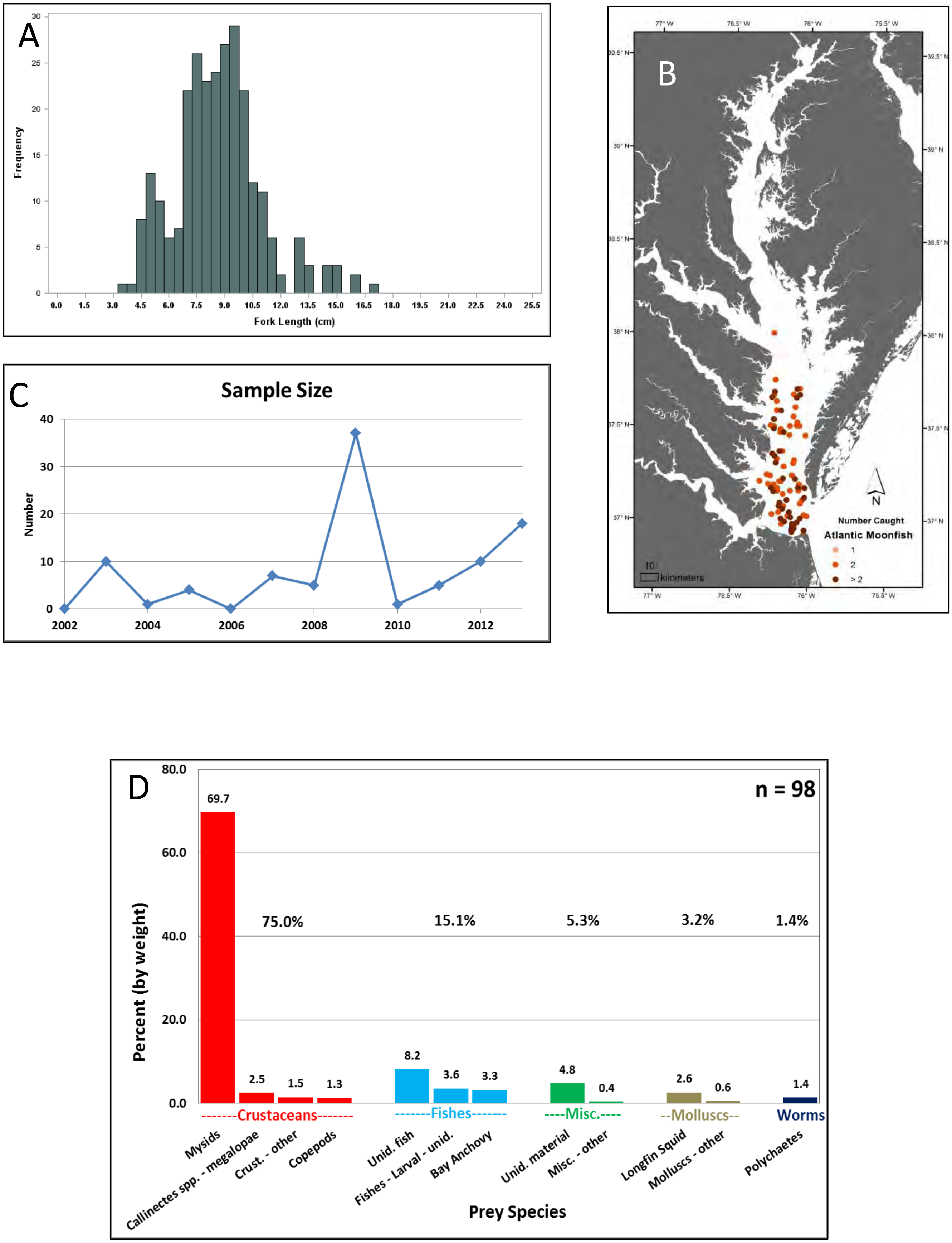






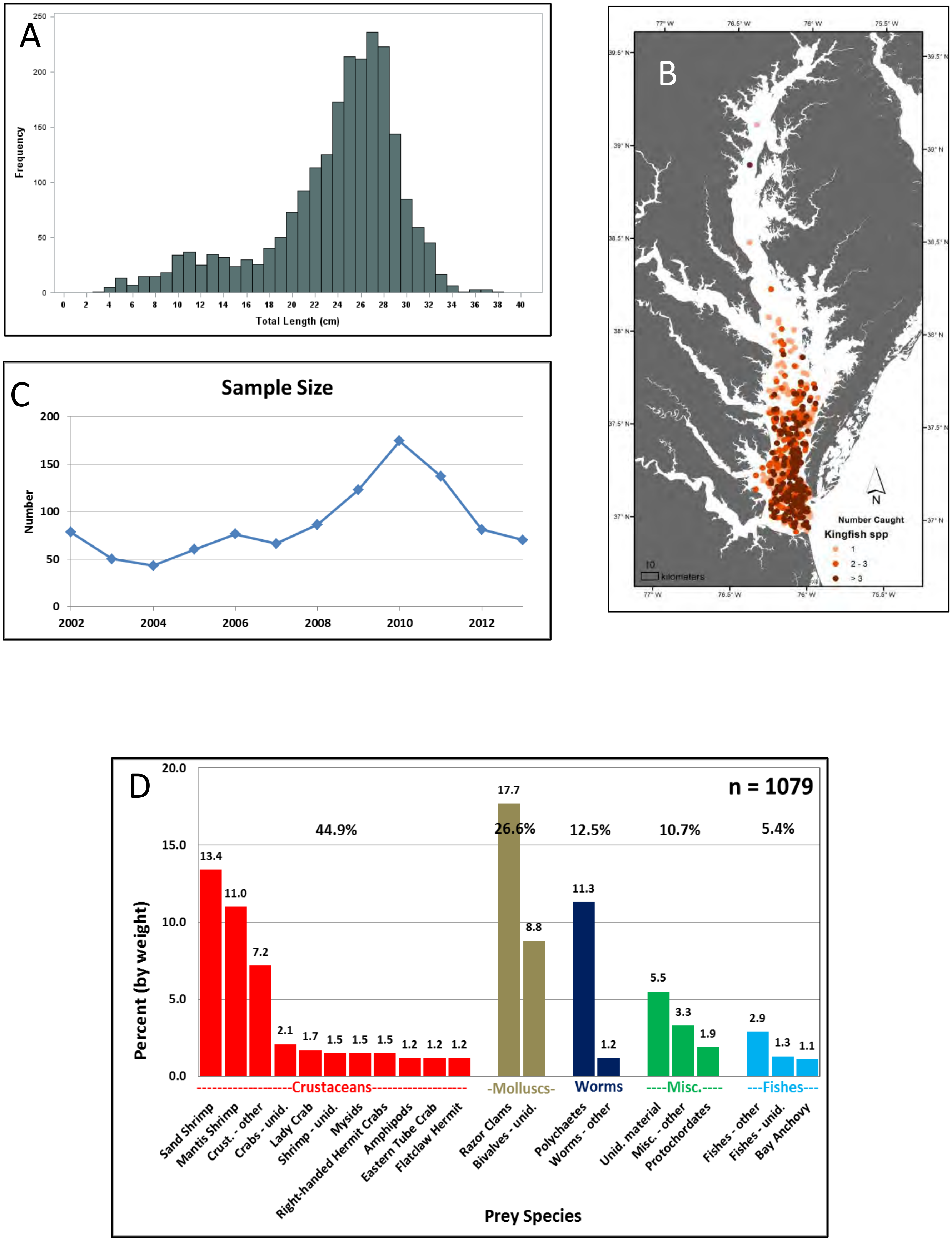
Atlantic Moonfish

Figure E74. ChesMMAP Atlantic Moonfish length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), and food habits percentages for all data combined for years 2002-2013 (D).



Kingfish

Figure E75. ChesMMAP Kingfish length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), and food habits percentages for all data combined for years 2002-2013 (D).



Kingfish

Figure E76. ChesMMAP Kingfish diet summaries by year and major taxa, with data pooled over all sample months and areas.

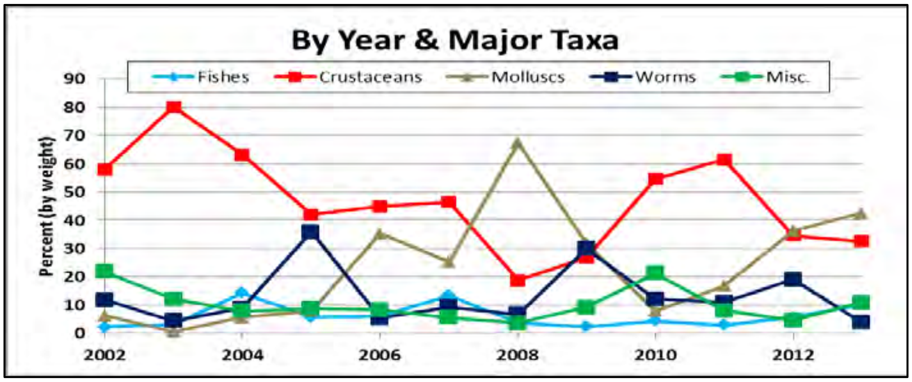
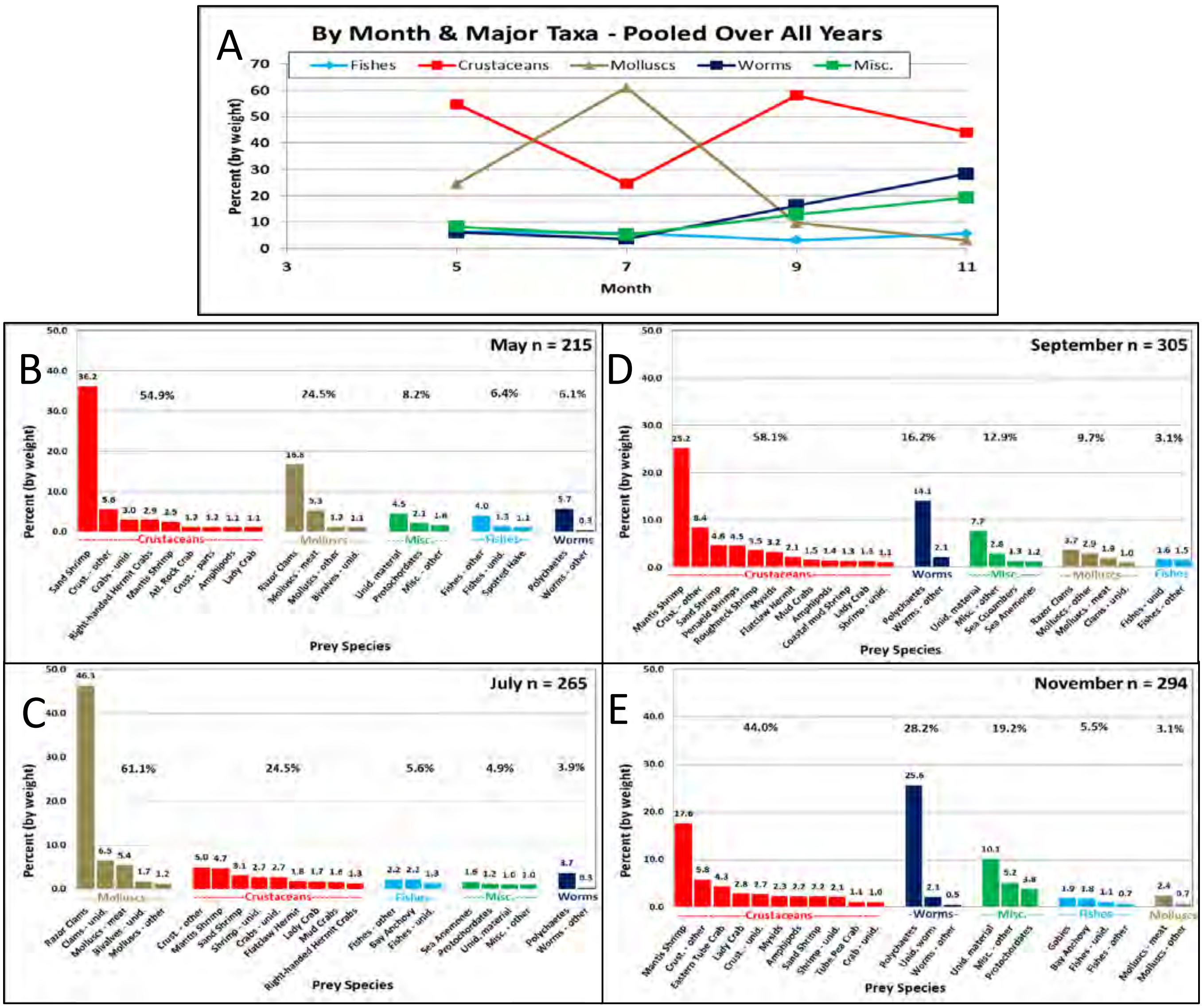
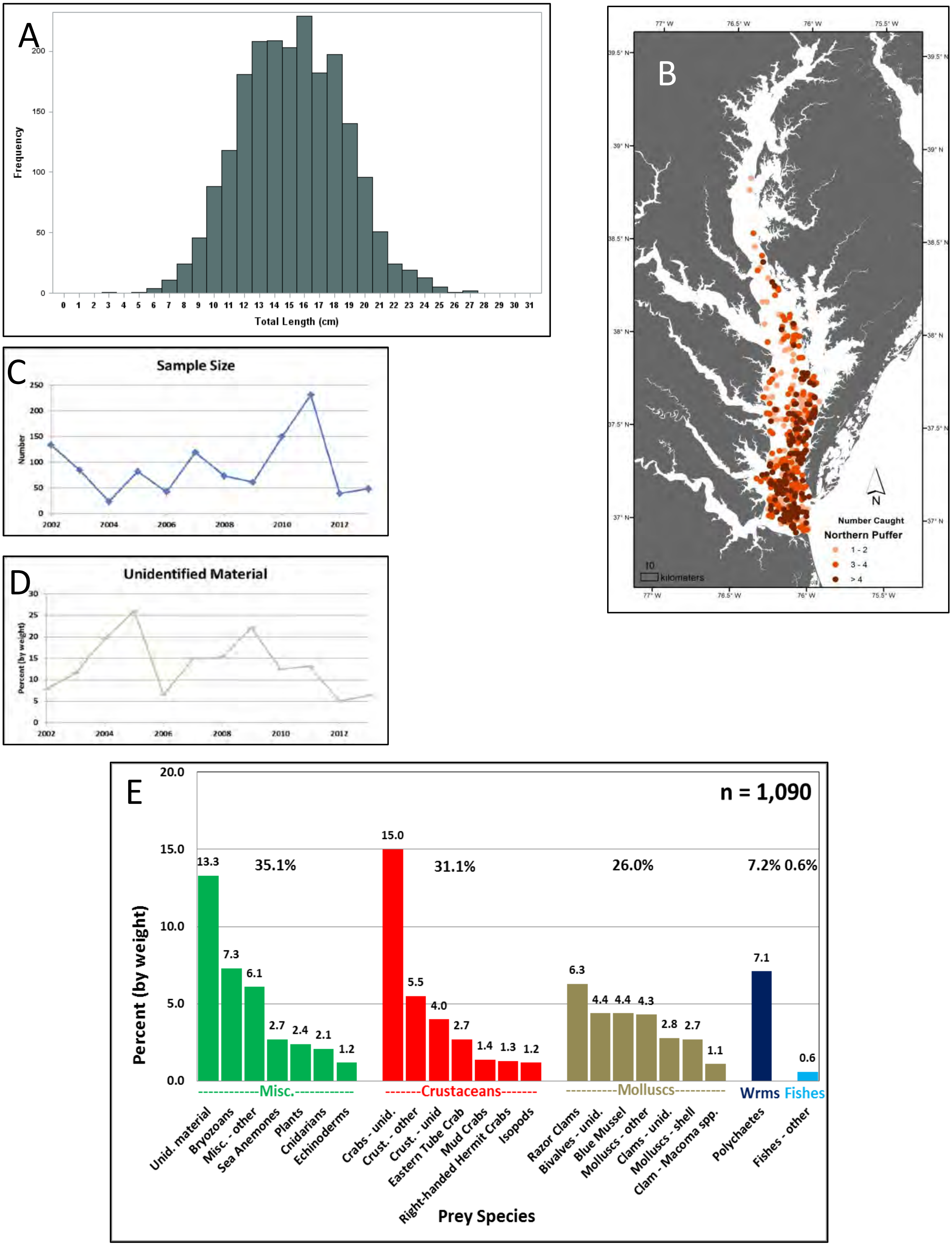


Figure E77. ChesMMAP Kingfish diet summaries by month, with data pooled over all sample years (2002-2013), for prey types summed over major taxa (A), and by species within major taxa for May (B), July (C), September (D), and November (E).



Northern Puffer

Figure E78. ChesMMAP Northern Puffer length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), yearly percentage of unidentifiable matter in stomachs (D), and food habits percentages for all data combined for years 2002-2013 (E).



Northern Puffer

Figure E79. ChesMMAP Northern Puffer diet summaries by year and major taxa, with data pooled over all sample months and areas.

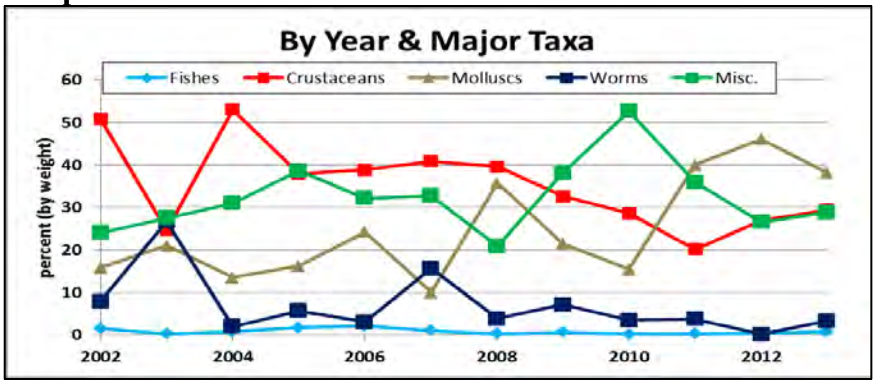
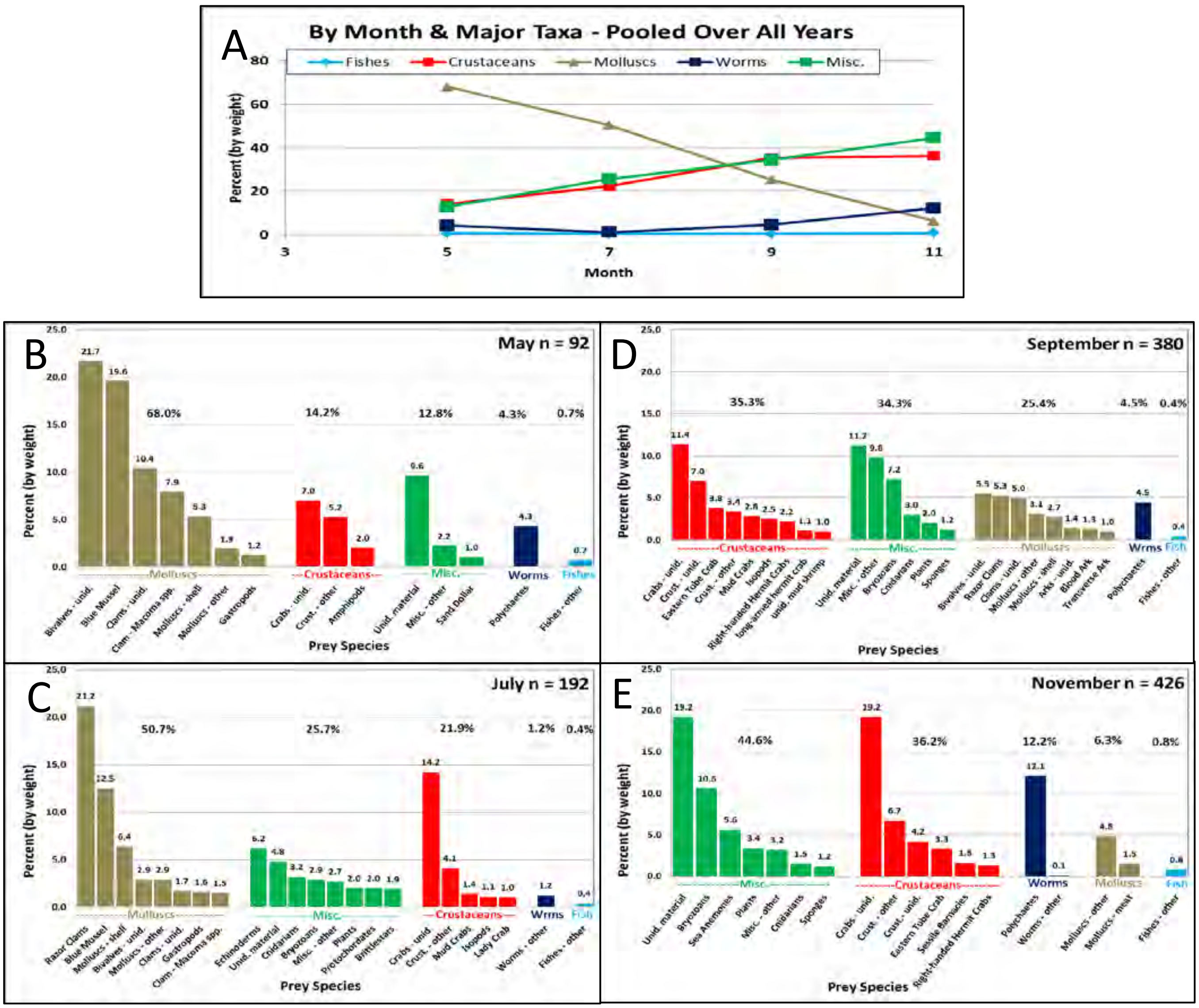
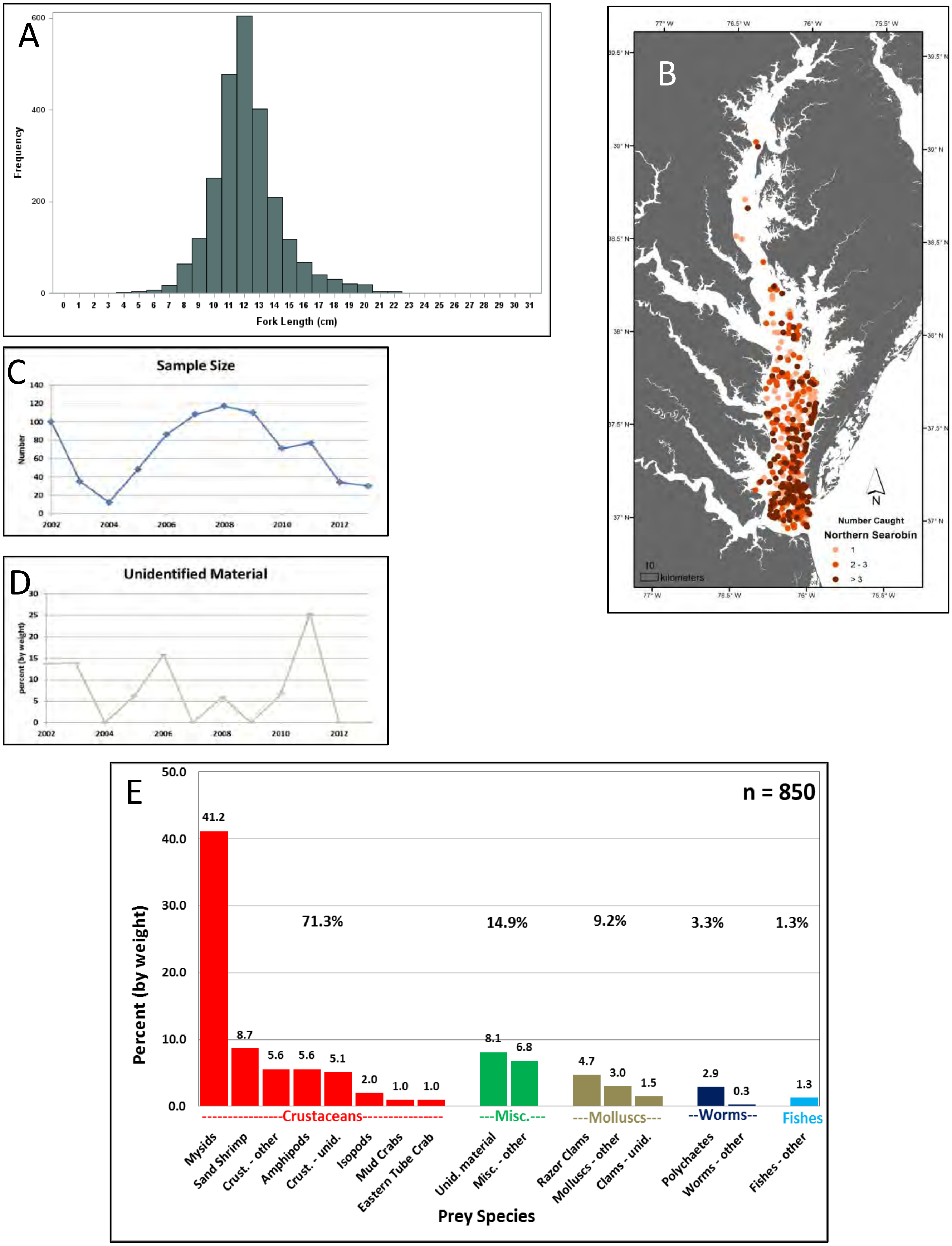


Figure E80. ChesMMAP Northern Puffer diet summaries by month, with data pooled over all sample years (2002-2013), for prey types summed over major taxa (A), and by species within major taxa for May (B), July (C), September (D), and November (E).



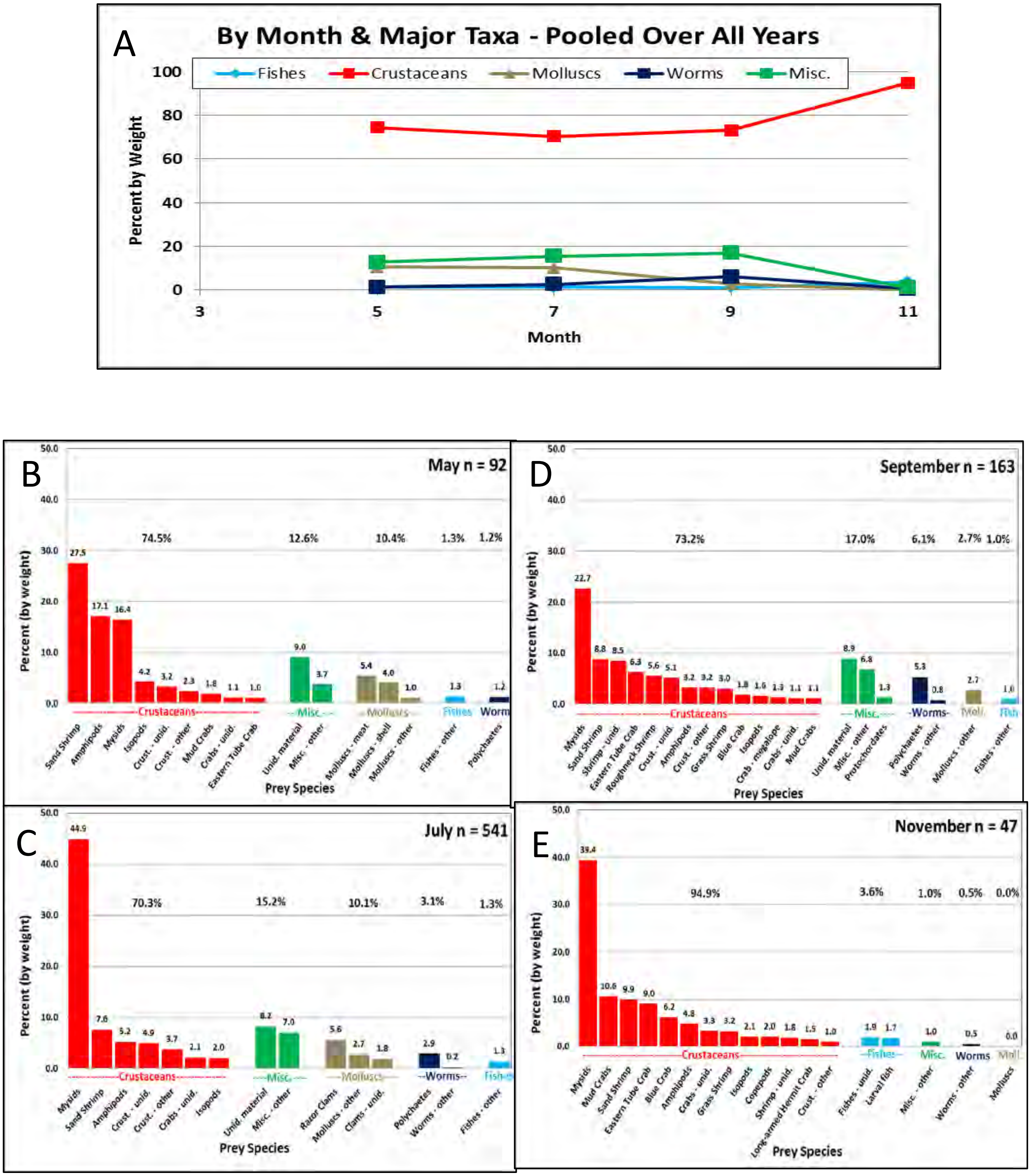
Northern Searobin

Figure E81. ChesMMAP Northern Searobin length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), yearly percentage of unidentifiable matter in stomachs (D), and food habits percentages for all data combined for years 2002-2013 (E).



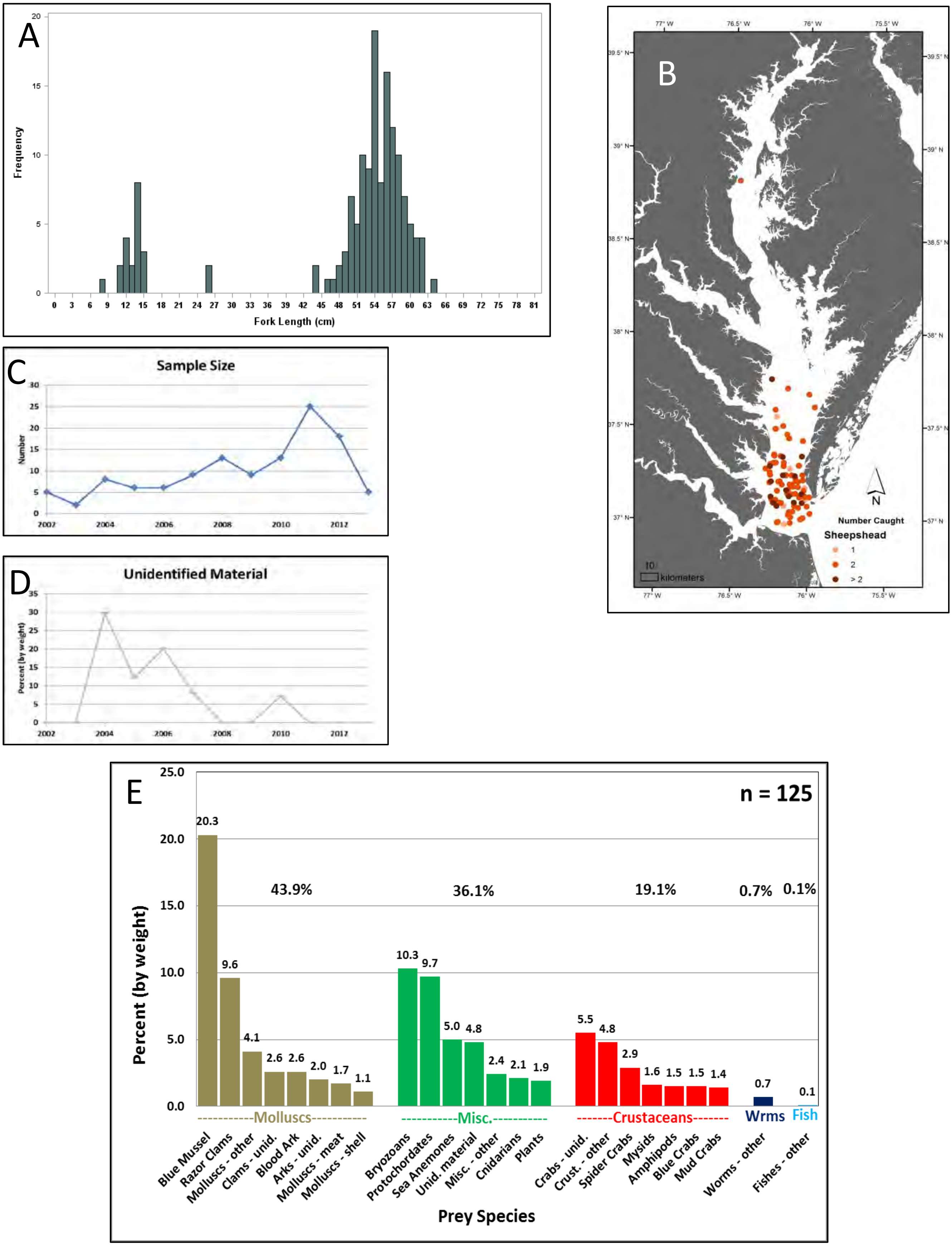
Northern Searobin

Figure E82. ChesMMAP Northern Searobin diet summaries by month, with data pooled over all sample years (2002-2013), for prey types summed over major taxa (A), and by species within major taxa for May (B), July (C), September (D), and November (E).



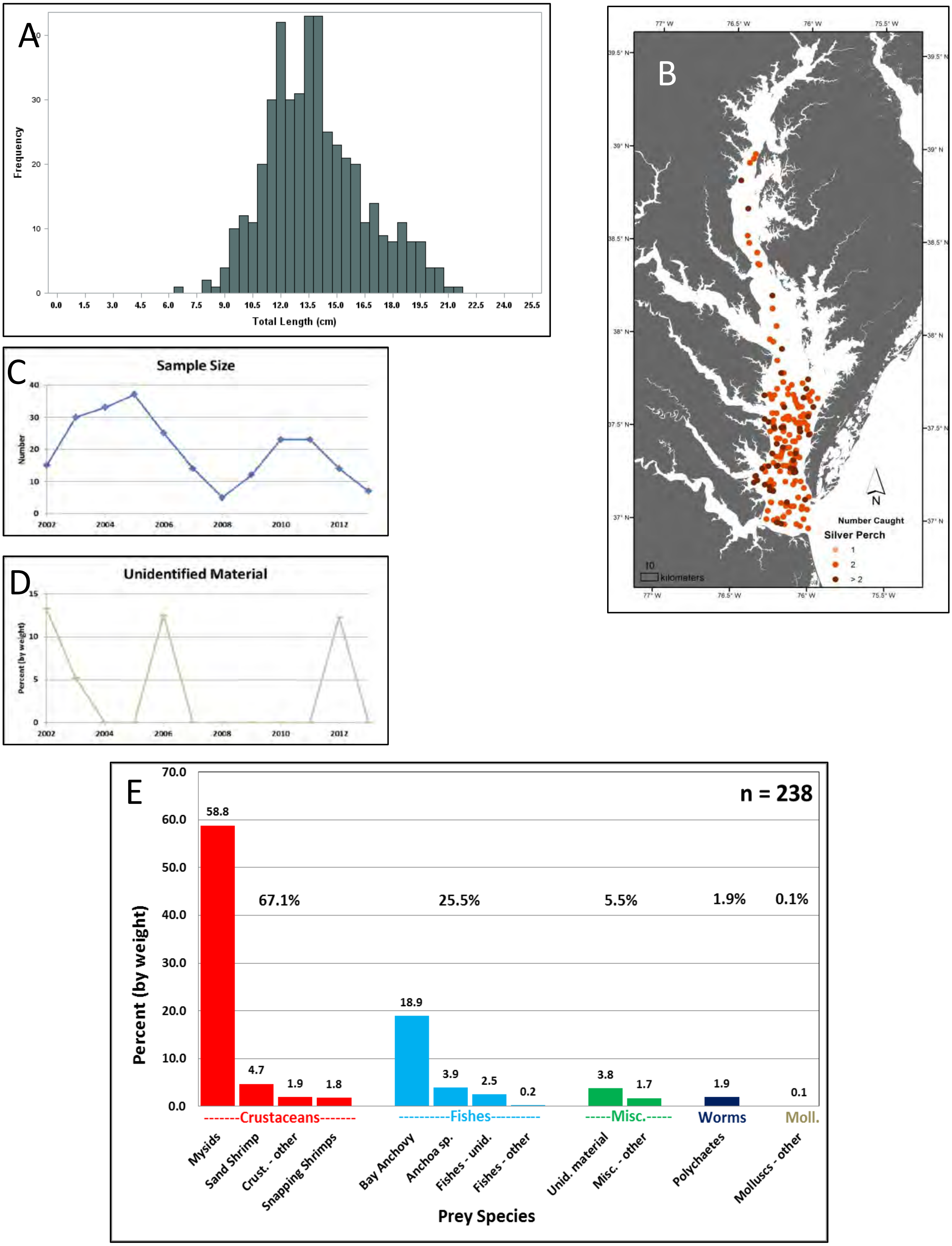
Sheepshead

Figure E83. ChesMMAP Sheepshead length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), yearly percentage of unidentifiable matter in stomachs (D), and food habits percentages for all data combined for years 2002-2013 (E).



Silver Perch

Figure E84. ChesMMAP Silver Perch length frequency (A), capture locations (B), number of stomachs analyzed yearly (C), yearly percentage of unidentifiable matter in stomachs (D), and food habits percentages for all data combined for years 2002-2013 (E).



Silver Perch

Figure E85. CHESFIMS Silver Perch diet summaries with data pooled over all sample years, areas, and sizes.

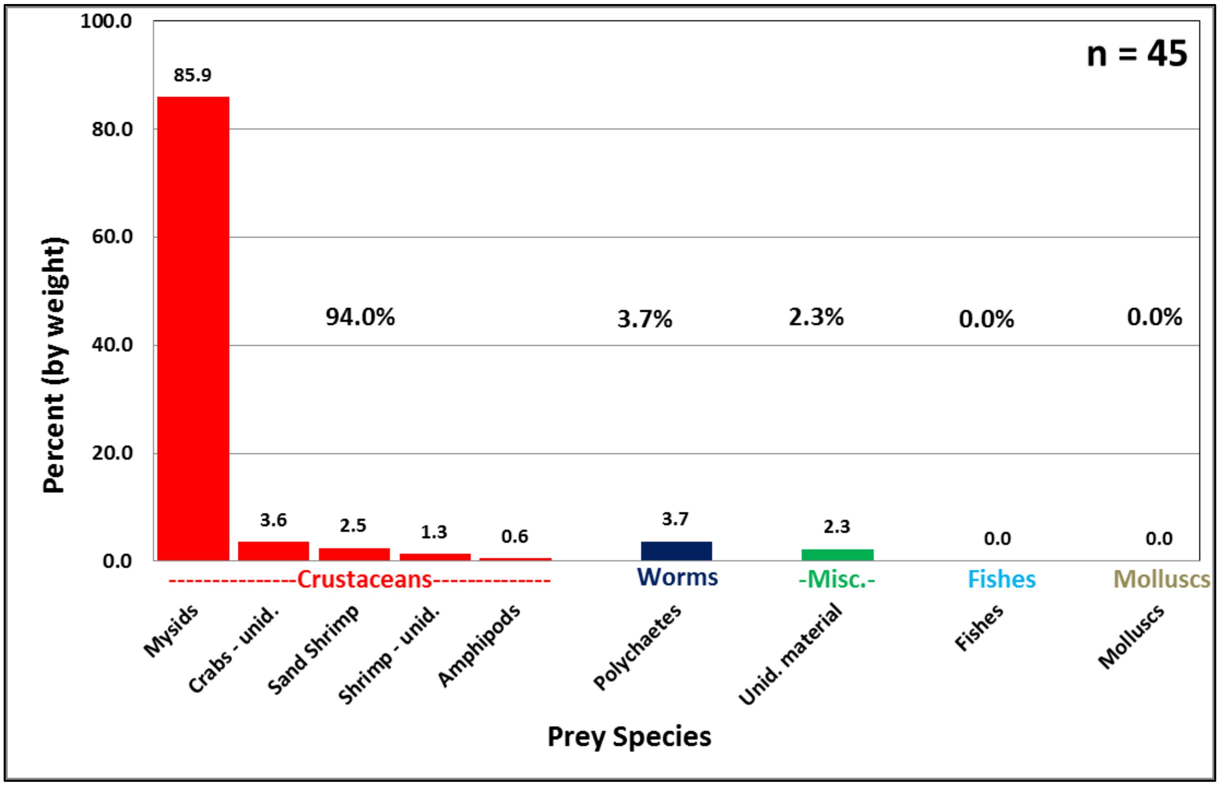


Figure E86. VIMS Juvenile Fishes Trawl Survey Silver Perch diet summaries with data pooled over all sample years, areas and sizes.