

This article was downloaded by: [Rutgers University]

On: 08 June 2013, At: 09:14

Publisher: Taylor & Francis

Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



## Fisheries

Publication details, including instructions for authors and subscription information:  
<http://www.tandfonline.com/loi/ufsh20>

### Shrinking the Haystack: Using an AUV in an Integrated Ocean Observatory to Map Atlantic Sturgeon in the Coastal Ocean

Matthew J. Oliver <sup>a</sup>, Matthew W. Breece <sup>a</sup>, Dewayne A. Fox <sup>b</sup>, Danielle E. Haulsee <sup>a</sup>, Josh T. Kohut <sup>c</sup>, John Manderson <sup>d</sup> & Tom Savoy <sup>e</sup>

<sup>a</sup> College of Earth, Ocean and Environment, University of Delaware, 700 Pilottown Rd., Lewes, DE, 19958

<sup>b</sup> Department of Agriculture and Natural Resources, Delaware State University, 1200 N. DuPont Hwy., Dover, DE, 19901

<sup>c</sup> Institute of Marine and Coastal Sciences, Rutgers University, 71 Dudley Rd., New Brunswick, NJ, 08901

<sup>d</sup> Ecosystems Processes Division, NEFSC/NMFS/NOAA, James J. Howard Marine Laboratory, Highlands, NJ, 07732

<sup>e</sup> Connecticut Department of Energy and Environmental Protection, 79 Elm St., Hartford, CT, 06106

Published online: 13 May 2013.

**To cite this article:** Matthew J. Oliver, Matthew W. Breece, Dewayne A. Fox, Danielle E. Haulsee, Josh T. Kohut, John Manderson & Tom Savoy (2013): Shrinking the Haystack: Using an AUV in an Integrated Ocean Observatory to Map Atlantic Sturgeon in the Coastal Ocean, *Fisheries*, 38:5, 210-216

**To link to this article:** <http://dx.doi.org/10.1080/03632415.2013.782861>

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: <http://www.tandfonline.com/page/terms-and-conditions>

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae, and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand, or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

# Shrinking the Haystack: Using an AUV in an Integrated Ocean Observatory to Map Atlantic Sturgeon in the Coastal Ocean

**Matthew J. Oliver**

College of Earth, Ocean and Environment, University of Delaware, 700 Pilottown Rd., Lewes, DE 19958. E-mail: moliver@udel.edu

**Matthew W. Breece**

College of Earth, Ocean and Environment, University of Delaware, 700 Pilottown Rd., Lewes, DE 19958

**Dewayne A. Fox**

Department of Agriculture and Natural Resources, Delaware State University, 1200 N. DuPont Hwy., Dover, DE 19901

**Danielle E. Haulsee**

College of Earth, Ocean and Environment, University of Delaware, 700 Pilottown Rd., Lewes, DE 19958

**Josh T. Kohut**

Institute of Marine and Coastal Sciences, Rutgers University, 71 Dudley Rd., New Brunswick, NJ 08901

**John Manderson**

Ecosystems Processes Division, NEFSC/NMFS/NOAA, James J. Howard Marine Laboratory, Highlands, NJ 07732

**Tom Savoy**

Connecticut Department of Energy and Environmental Protection, 79 Elm St., Hartford, CT 06106

**ABSTRACT:** *Physical processes in the coastal Mid-Atlantic create a complex and dynamic seascape. Understanding how coastal fishes respond to this complexity has been a major motivation in establishing coastal biotelemetry arrays. Most coastal arrays maximize the probability of fish detection by positioning hydrophones near geophysical bottlenecks. The development of a real-time ocean observatory allows for synchronous mapping of dynamic hydrographic structures important to coastal fishes. These observations provide important context for interpreting the impact of oceanographic features on the behavior of telemetered animals. In a proof-of-concept mission, we deployed a Slocum glider in a real-time ocean observatory to demonstrate how mobile listening assets could be dynamically reallocated in response to the mesoscale physics of the coastal ocean. The Slocum glider detected four Atlantic Sturgeon *Acipenser oxyrinchus oxyrinchus* that were in a shallow, well-mixed, and relatively warm and fresh water mass in a region of historic Atlantic Sturgeon bycatch.*

## INTRODUCTION

Passive acoustic biotelemetry is a widely used tool for understanding the distribution of marine organisms. Acoustic transmitters placed on or inside an animal transmit coded

## Encogiendo el pajar: utilización de un Vehículo Autónomo Submarino en un Observatorio Oceánico Integral para Mapear el Esturión del Atlántico en el Océano Costero

**RESUMEN:** *los procesos físicos que ocurren en zona costera del Atlántico medio generan un paisaje complejo y dinámico. La comprensión de cómo los peces costeros responden a tal complejidad ha sido una motivación importante para establecer un arreglo de biotelemedría en la franja costera. Muchos de los arreglos costeros maximizan la probabilidad de detectar peces mediante el uso de hidrófonos cerca de los cuellos de botella geofísicos. El desarrollo de un observatorio oceánico de monitoreo en tiempo real permite un mapeo sincrónico de estructuras hidrográficas dinámicas que son relevantes para los peces costeros. Estas observaciones bindan el contexto para interpretar el impacto que tienen ciertos rasgos oceanográficos en el comportamiento de animales rastreados mediante telemetría. En una misión diseñada para probar este concepto, se desplegó el deslizador Slocum en un observatorio oceánico para demostrar cómo los aparatos móviles de monitoreo pueden ser reubicados de forma dinámica en respuesta a procesos físicos de mesoescala que ocurren en el océano costero. El deslizador Slocum detectó cuatro especímenes de esturión del Atlántico *Acipenser oxyrinchus oxyrinchus* encontrados en una masa de agua fresca, somera y relativamente cálida en una región en la que históricamente el esturión del Atlántico ha sido parte de la captura incidental.*

messages to listening arrays, allowing researchers to reconstruct movement patterns of individuals and cohorts. Many passive acoustic biotelemetry studies focus fixed listening arrays near coastal embayments or at geophysical bottlenecks along known migration routes (Jackson 2011). For example, participants in the Atlantic Cooperative Telemetry (ACT) Network, Ocean Tracking Network, and the Pacific Ocean Shelf Tracking Project maintain thousands of passive hydrophones, most of which are closely associated with geographical boundaries in the near-shore coastal environment. Geographic boundaries concentrate telemetered animals near the arrays and increase the probability of their detection. Comparatively few arrays extend to the continental shelf away from geographic barriers, which reduces the probability of detecting telemetered animals. However, within the coastal ocean there are dynamic hydrographic structures that are known to concentrate marine fauna. Sea surface temperature and chlorophyll *a* fronts serve to aggregate forage species and

their predators (Fiedler and Bernard 1987; Palacios et al. 2006). In the Mid-Atlantic coastal ocean, these complex fronts along with other dynamic hydrographic processes appear to influence habitat associations in the ocean for several coastal species such as Longfin Inshore Squid *Loligo pealeii*, Butterfish *Pep-tilus triacanthus* and Summer Flounder *Paralichthys dentatus* (Manderson et al. 2011).

Autonomous underwater vehicles (AUVs) are natural additions to fixed listening arrays (Curtin et al. 1993; Grothues 2009). AUVs have been used in coastal embayments and estuaries to measure fine-scale movements and distributions of telemetered organisms (Grothues et al. 2010). For example, an AUV was used to map the fine-scale movements of Atlantic Sturgeon *Acipenser oxyrinchus oxyrinchus* on their suspected Hudson River spawning grounds (Grothues et al. 2008). AUVs can also be adaptively routed in a changing seascape, allowing researchers to strategically place the listening platforms in specific hydrographic features. In a demonstration mission, we show how AUVs fitted with hydrophones could be dynamically reallocated in relation to hydrographic features to detect telemetered organisms in the coastal ocean. AUVs deployed in an operational observatory provide a synergistic link between coastal ocean dynamics and telemetered organisms that improves our understanding of the distribution and behaviors of coastal species.

### An Integrated Ocean Observatory

Participants in the ACT Network currently have active transmitters in 859 Atlantic Sturgeon and maintain ~400 receivers in Mid-Atlantic embayments and nearshore environments (L. Brown, Delaware State University, personal communication). The ACT Network forms a regional backbone of telemetry receivers and is collocated with the Mid-Atlantic Regional Association Coastal Observing System (MARACOOS), which is the regional component of the U.S. Integrated Ocean Observing System focused on the coastal waters between Cape Hatteras, North Carolina, and Cape Cod, Massachusetts. Weather, high-frequency radar, satellite, and AUV observations are integrated into an ensemble of ocean models in the Mid-Atlantic Bight to support real-time and forecast-based ocean products (<http://maracoos.org>). The synthesis of these observations and models in near real-time provides the infrastructure to understand and map a dynamic coastal system. Furthermore, these observations have been shown to significantly improve habitat models of Mid-Atlantic organisms (Manderson et al. 2011; Palamara et al. 2012). Real-time oceanographic observations combined with the ACT Network provide a critical link for understanding the distribution of coastal fauna.

Teledyne-Webb Research Slocum glider AUVs are the main platform for gathering in situ data in the MARACOOS region. These battery-powered gliders are buoyancy driven and can maintain a presence in the ocean for approximately 30 days, allowing them to measure the mesoscale physics and optics of the coastal ocean. Gliders convert changes in vehicle buoyancy into forward motion by angling their nose upward or downward,

thus “gliding” on laterally mounted wings in a “sawtooth” pattern (Schofield et al. 2007). Gliders and other AUVs are being increasingly utilized and are a stable platform for a variety of in situ observations. For example, between 2005 and 2011, there were 71 Slocum glider missions by the partners of the MARACOOS observatory. These gliders were deployed for a total of 1,150 days while traveling 24,121 km (Figure 1).

### Atlantic Sturgeon

Atlantic Sturgeon are one of nearly 60 telemetered species in the Mid-Atlantic region (VEMCO, personal communication, Denise King) and were recently listed as endangered throughout most of their range (National Oceanic and Atmospheric Administration [NOAA] 2012). Atlantic Sturgeon historically occupied major river systems between Hamilton Inlet, Labrador, Canada (Backus 1951), and the St. Johns River, Florida (Vladykov and Greeley 1963). Atlantic Sturgeon spend the vast majority of their life in coastal marine waters, but little is known about this phase in their life history (Atlantic Sturgeon Status Review Team 2007). In the late fall, bycatch of Atlantic Sturgeon in commercial fisheries is highest as they move through the coastal oceans of the Mid-Atlantic region (Stein et al. 2004b). Pop-up satellite transmitters on Atlantic Sturgeon show that they use waters within ~100 km of the coastline during their migration (Erickson et al. 2011). However, the location errors inherent in pop-up satellite transmitters are too large to associate Atlantic Sturgeon with specific coastal hydrographic features during their migration. Acoustic biotelemetry provides location information with high enough spatial resolution to associate their movements with coastal hydrography.

### Demonstration Mission

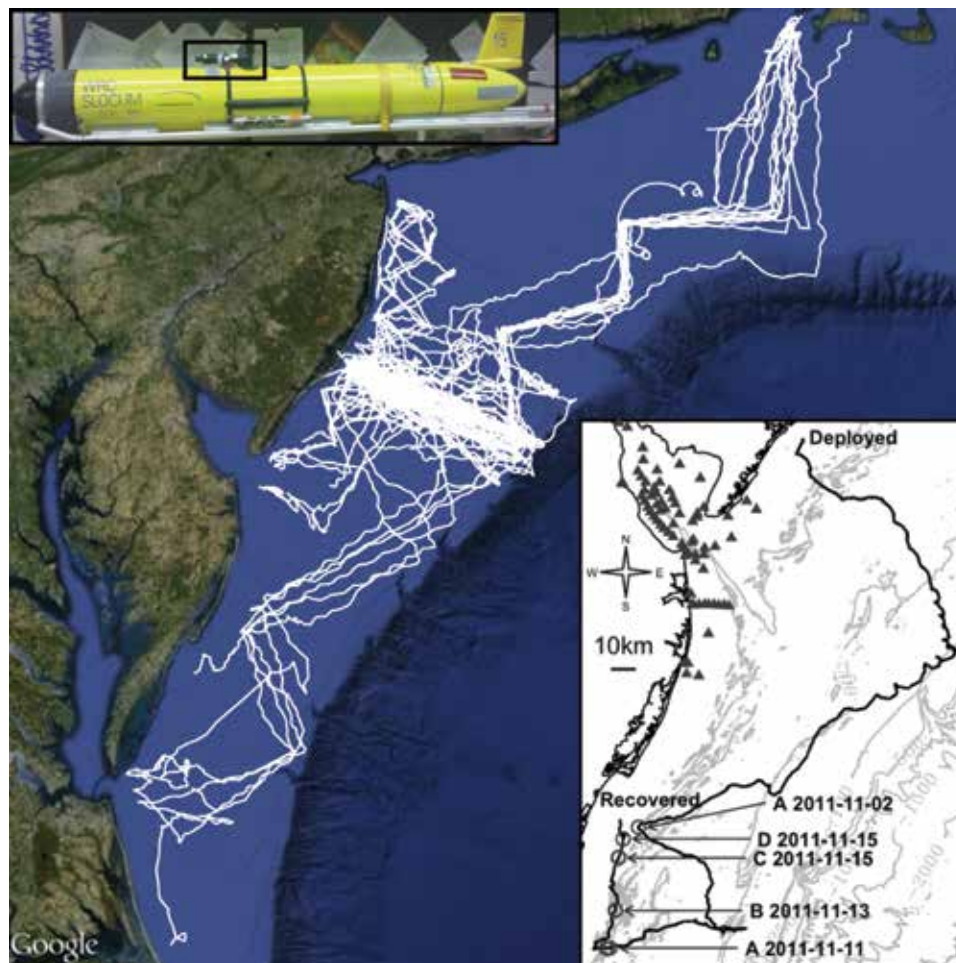
In this study, we mounted a VEMCO Ltd. (Bedford, Nova Scotia) Mobile Transceiver (VMT) on the glider’s exterior dorsal surface (Figure 1). The VMTs are small, lightweight acoustic transceivers that record the coded acoustic messages transmitted by telemetered organisms. Though a single dorsal mount is not ideal, through collaborations among the University of Delaware, VEMCO Ltd., and Teledyne-Webb Research (Falmouth, Massachusetts), we integrated two receivers into the dorsal and ventral hull of the glider to maximize the listening capability of the transceiver–glider system for future missions. Our purpose in this limited demonstration is to show how AUVs could be positioned in a dynamic coastal ocean and in the context of an ocean observatory to detect and map Atlantic Sturgeon.

## RESULTS

### Glider Deployment

On October 18, 2011, we deployed a Slocum glider carrying a VMT off the coast of southern New Jersey (Figure 1). The glider’s first task was to carry the VMT on a cross-shelf transect to collect in situ data for MARACOOS and then return to focus on the nearshore coastal region where bycatch of Atlantic Sturgeon has been recorded (Stein et al. 2004a). The glider





**Figure 1.** Tracks of the 71 Slocum glider missions between 2005 and 2011 (white lines) show the potential to develop mobile listening assets in the Mid-Atlantic. A VMT was attached to the dorsal side of a Slocum glider (upper inset) and deployed for 1 month. Telemetered Atlantic Sturgeon were detected in nearshore coastal waters along the Delmarva Peninsula (lower inset). Triangles represent the location of ACT hydrophones during the glider deployment.

was recovered just south of Chincoteague Island, Virginia, on November 18, 2011, having traveled 671 km. The water column on the first offshore leg of the glider was stratified, with higher salinities in the deep, offshore water (Figure 2). On October 28–30, 2011, a storm brought high winds and cool temperatures that increased the mixing of the water column and reduced overall water column stratification. The water column remained vertically well mixed for the remainder of the glider mission. A nearshore freshwater plume was recorded by the glider, just south of Delaware Bay. Between November 2 and 18, 2011, we detected 4 of the 859 telemetered Atlantic Sturgeon registered with the ACT Network during this glider deployment (A–D in Figures 1–3, Table 1). All detections were near the 25-m isobath along the Delmarva Peninsula. Notably, we detected fish A on November 2, and again on November 11, 56.8 km to the southwest. The first detection event for fish A consisted of only three transmissions over a period of 120 s. During that time, the glider traveled horizontally approximately 20 m, from a depth of 10 m to the surface, where it connected with the MARACOOS glider operations center at Rutgers University. Unfortunately, this scheduled surfacing event likely lifted the dorsally mounted VMT out of the water, ending our detection of fish A on November 2, 2011. The glider's second encounter with fish A, on

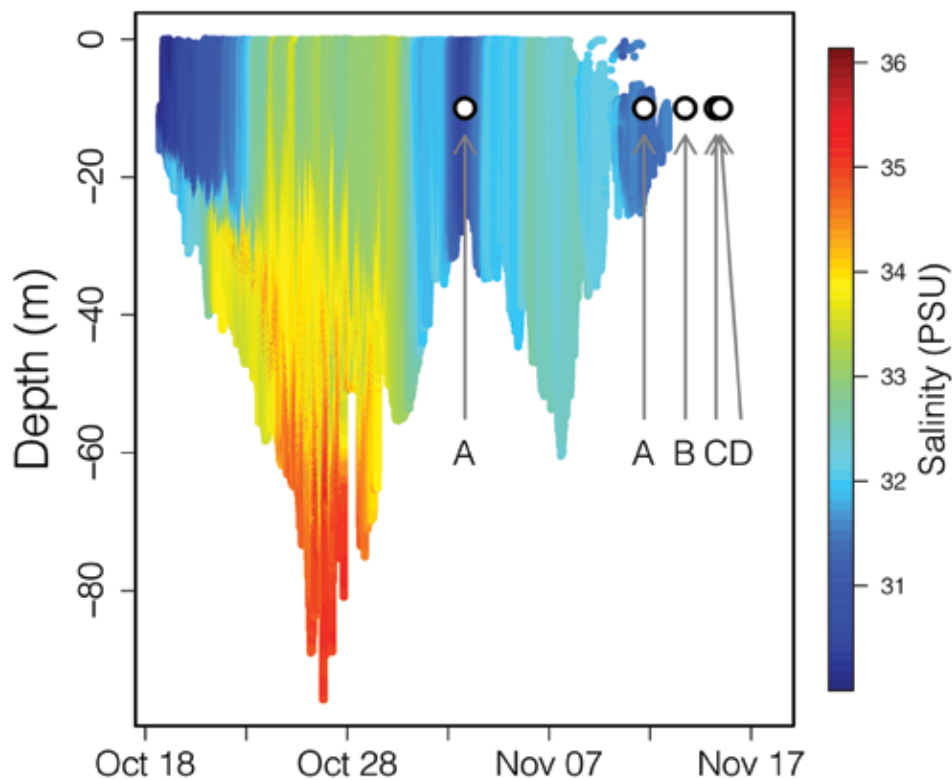
November 11, 2011, consisted of 19 detections over a period of 3.78 h. During this period, the glider traveled 2.02 km and did not make a scheduled surfacing. The salinity measured by the glider during its detection of fish A ranged between 30 and 31 practical salinity units (PSU; Figure 2). Detections from fish B, C, and D lasted less than 1 h while the glider was in power-saving mode toward the end of its deployment. All detections were verified as authentic by VEMCO Ltd. In power-saving mode, the science computers were powered down and did not take frequent oceanographic measurements. All of the detections for these fish were in waters deeper than 16 m and it is possible that the glider body was shadowing the dorsally mounted VMT from receiving transmissions from the bottom-associated Atlantic Sturgeon until the glider was at depth.

### Detected Atlantic Sturgeon

Participants in the ACT Network provided the metadata for the Atlantic Sturgeon detected by the glider. Fish A was a 42-kg, 160-cm male that was originally captured April 13, 2009, off the coast of Delaware. This individual has been detected as far away as the Long Island Sound, and its last detection in the ACT Network was in Delaware Bay on October 19, 2011, before being

**Table 1. Transmitter identification, dates, total detections, and distance traveled by the glider.**

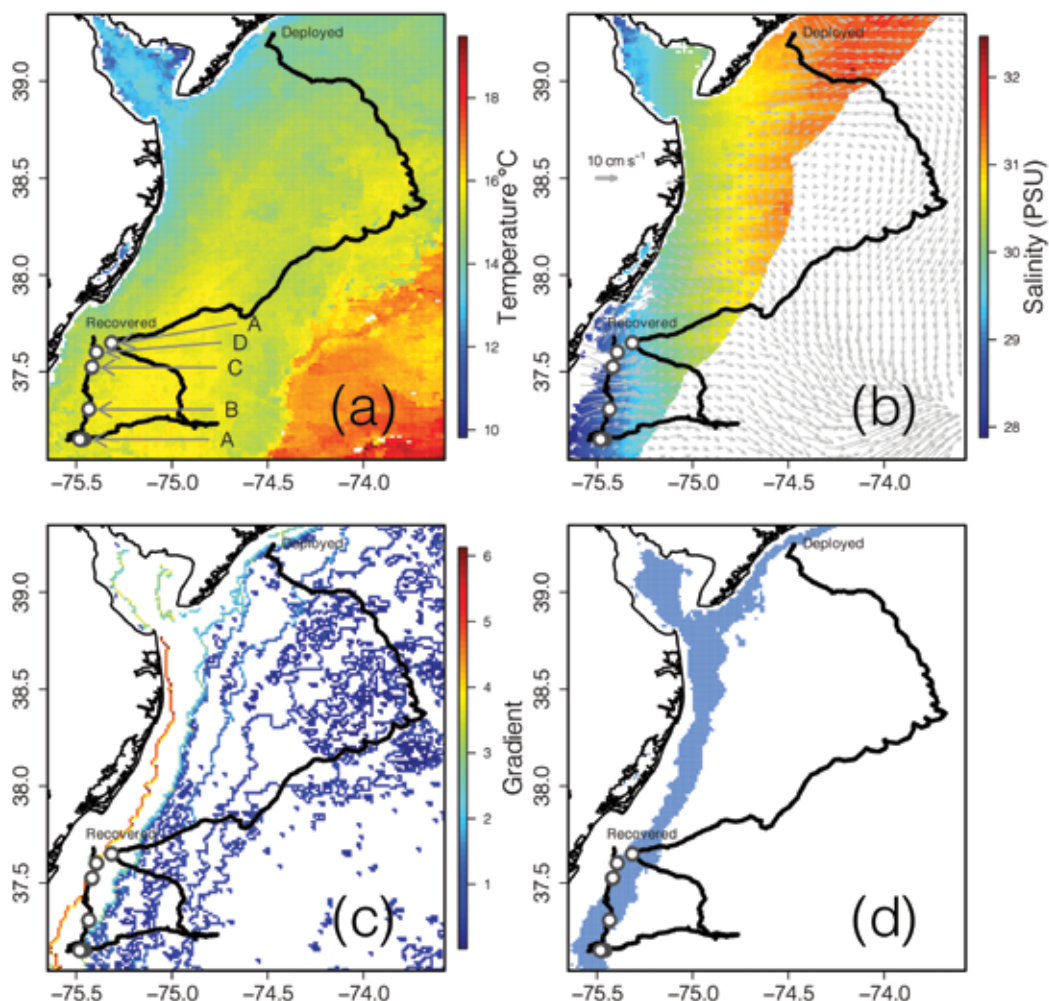
Fish	Transmitter ID	Date	No. of detections	Detection duration (h)	Distance traveled by the glider (km)
A	54839	11/2/11	3	0.03	0.02
A	54839	11/11/11	19	3.78	2.02
B	11632	11/13/11	10	0.65	0.24
C	20444	11/15/11	8	0.23	0.36
D	47914	11/15/11	3	0.11	0.18

**Figure 2. In situ salinity profiles from the glider show that Atlantic Sturgeon detections occurred in fresher, well-mixed coastal water.**

detected by the glider on November 2 and again on November 11. These detections indicate that this Atlantic Sturgeon moved south at an average rate of  $\sim 7$  km per day between October 19 and November 11. Fish B was a 39-kg, 157-cm male originally captured April 10, 2009, in the Delaware coastal ocean. This individual had been detected by the ACT Network as far away as the coast of North Carolina and was last detected by the ACT Network in Delaware Bay on September 26, 2011, before being detected by the glider on November 11, 2011. Fish C was a 43-kg, 159-cm male captured April 19, 2011. This individual was detected as far away as the Hudson River. Prior to its detection by the glider on November 15, 2011, it was last detected in the Delaware Bay on May 2, 2011. Fish D was an 18-kg, 129-cm juvenile tagged August 31, 2010, in Long Island Sound. It was last heard in Delaware Bay on May 10, 2011, before being detected by the glider on November 15, 2011.

### Satellite and High-Frequency Radar Observations

A composite of satellite and high-frequency radar surface current observations while the glider was detecting Atlantic Sturgeon between November 2 and 15, 2011 provided the spatial context for understanding their habitat associations (Figures 2A–2D). During the glider mission, sea surface temperatures of Delaware Bay were much cooler than the coastal ocean, and the warmest waters were near the shelf break, reflecting seasonal mixing of coastal waters (Castelao et al. 2008). The spatial pattern of coastal salinity reflects a typical pattern of a coastally trapped river plume from Delaware Bay (Garvine 1995). These salinity estimates from the National Aeronautics and Space Administration's MODIS-Aqua platform are in agreement with in situ measurements by the glider; however, satellite estimates of coastal salinity are  $\pm 2.2$  PSU (Geiger et al. 2011). Surface currents showed that this river plume water mass is transported offshore at a rate of  $5\text{--}13$   $\text{cm s}^{-1}$ , creating a



**Figure 3. Glider mission overlaid on the 2-week composite of (a) satellite sea surface temperature, (b) salinity, (c) water mass fronts, and (d) the unique water mass in which the glider detected the Atlantic Sturgeon (November 2–15, 2011). The horizontal banding in salinity is an artifact of the ocean color sensor design. Mean surface currents (grey arrows, b) show the average movement of surface water during fish detections.**

local convergent zone. An analysis of the water mass boundary locations and their gradient strengths derived from sea surface temperature and ocean color (Oliver and Irwin 2008) showed a complex mosaic of water masses in the coastal ocean (Figure 3c). The detections of these four telemetered Atlantic Sturgeon by the glider were clustered along the Delmarva coast in shallow (14–27 m), relatively warmer (15.1–15.7°C), and fresher waters (28–31 PSU). These individuals were also closely associated with the strongest of water mass fronts in the region (Figure 3c). Interestingly, all sturgeon detections by the glider occurred in the same coastal water mass as determined by temperature and ocean color (Figure 3d). These water masses are objectively determined against the global distribution of temperature and ocean color and are dynamic in space and time (Oliver and Irwin 2008; Irwin and Oliver 2009). This coastal water mass was nearshore and extended into the Delaware Bay and north along the coast of New Jersey.

## DISCUSSION

The recent Endangered Species Act (ESA) listing of the Atlantic Sturgeon creates significant challenges for commercial fishers and resource managers. Large-mesh, sink gillnet and otter trawl fisheries have been identified as significant sources of Atlantic Sturgeon bycatch in the coastal ocean (NOAA 2012). Ironically, the sink gillnet fishery for Monkfish *Lophius americanus* originated as bycatch in the Atlantic Sturgeon coastal intercept fishery. In the mid-1980s, sturgeon fishers began transitioning to monkfish fishing because sturgeon landings were increasingly restricted and the market for monkfish began to expand prior to the cessation of the Atlantic Sturgeon fishery in 1998 (Fox et al. 2011). It is estimated that monkfish landings are worth up to US\$55,000,000 per year (New England Fishery Management Council 2011) and are on par with the value in landings of North Atlantic Cod *Gadus morhua* (Platz et al. 2010). Bycatch in the coastal ocean appears to be a major source of Atlantic Sturgeon mortality and is cited as one of the five factors contributing to their ESA listing (NOAA 2012). Therefore, understanding how Atlantic Sturgeon orient themselves to specific hydrographic features in the coastal Mid-Atlantic is



critical for reducing interaction between sink gillnet and otter trawl fisheries.

In this study, Atlantic Sturgeon were observed in shallow, well-mixed, relatively warm freshwater that appears to be associated with the a water mass tied to Delaware Bay (Figure 2). These telemetered individuals were also very close to the edges of a distinct coastal water mass, suggesting aggregation around strong hydrographic and optical fronts. Although this demonstration mission detected only four individuals, these observations are compatible with previous studies showing that Atlantic Sturgeon remain near shore during their migration (Erickson et al. 2011) and associate with river plumes (Collins and Smith 1997). Association with coastal plumes is a reasonable expectation for an anadromous species that transitions between fresh and salt water numerous times during their life span. Clearly, more observations are needed to determine the hydrographic habitat associations of Atlantic Sturgeon in the coastal ocean.

The biotelemetry instruments on AUVs provide the capability to traverse the coastal ocean outside fixed listening arrays. Undirected, AUVs are searching for the proverbial needle in a haystack. However, real-time ocean observatories provide dynamic mapping of hydrographic features that can influence coastal fish movements. Therefore, integrating the mobility of AUVs with ocean observatories provides a much-needed component for directing mobile listening assets to hydrographic features. Dynamic maps of hydrographic features from the ocean observatory can guide the distribution of AUV receiver assets to enhance the detections of telemetered individuals as they move through the coastal ocean.

Though the introduction of AUVs as listening platforms allows for directed searches outside of the boundaries of fixed acoustic arrays, these observations are potentially more difficult to interpret because both the targets and the AUV are moving. Furthermore, the seascape itself is changing as water masses form and move through the coastal ocean. Decorrelation time- and length scales of ocean surface temperatures range from 1 to 7 days and 300 km (Abbott and Letelier 1998; Hosoda and Kawamura 2004), and advection alone is enough to confound standard surveys of fishes (Stenevik et al. 2012). In our demonstration mission, fish A was detected twice, 8 days and ~60 km apart, in the same water mass, which was probably not indicative of independent observations of Atlantic Sturgeon habitat association. Analyzing telemetry observations in a Eulerian framework leads to problems of temporal, spatial, and serial autocorrelation (Aarts et al. 2008). However, what is critical here is that all of the observations occurred in the same water mass that can be detected and tracked by the MARACOOS observatory. The MARACOOS observatory allows researchers to locate and quantify the extent of water masses in the coastal ocean and calculate the AUV sampling effort within and across water masses. Therefore, AUVs can be used in a dynamic seascape to explore the relationship between Atlantic Sturgeon and the specific water masses they encounter. We suggest that the ability to track and detect water masses that are best targeted by AUVs creates an objective Lagrangian framework for testing


factorial hypotheses about coastal habitat associations of Atlantic Sturgeon. A Lagrangian framework reduces autocorrelation problems inherent in telemetry trajectories (Aarts et al. 2008), thus simplifying analysis of habitat associations by telemetered individuals. The collaborative coupling of AUV biotelemetry within a Lagrangian framework provided by ocean observatories holds promise for understanding imperiled resources like Atlantic Sturgeon in the coastal ocean. This approach can inform management recommendations on the likely hydrographic factors that influence the timing and location of Atlantic Sturgeon encounters, which are now highly regulated under the provisions of the ESA.

## ACKNOWLEDGMENTS

These efforts were only possible with funding support provided by Charles and Pat Robertson, the DuPont Clear Into the Future Program, and NOAA-NMFS Species Recovery Grants to States and NOAA-NMFS NERO Office of Protected Resources. Ocean observing data were provided by the MARACOOS project funded through the NOAA IOOS program office (NA07NOS4730221).

## REFERENCES

- Aarts, G., M. MacKenzie, B. McConnell, M. Fedak, and J. Matthiopoulos. 2008. Estimating space-use and habitat preference from wildlife telemetry data. *Ecography* 31:140–160.
- Abbott, M. R., and R. M. Letelier. 1998. Decorrelation scales of chlorophyll as observed from bio-optical drifters in the California current. *Deep-Sea Research Part II: Topical Studies in Oceanography* 45:1639–1667.
- Atlantic States Marine Fisheries Commission (ASMFC). 2007. Special report to the ASMFC Atlantic Sturgeon Management Board: Estimation of Atlantic sturgeon bycatch in coastal Atlantic commercial fisheries of New England and the Mid-Atlantic. Atlantic States Marine Fisheries Commission, Washington, D.C.
- Atlantic Sturgeon Status Review Team (ASSRT). 2007. Status review of the Atlantic sturgeon (*Acipenser oxyrinchus oxyrinchus*). Prepared by the Atlantic Sturgeon Status Review Team for the National Marine Fisheries Service, National Atmospheric and Atmospheric Administration, Northeast Regional Office, Gloucester, Massachusetts.
- Backus, R. H. 1951. New and rare records of fishes from Labrador. *Copeia* 1951:288–294.
- Castelao, R., S. Glenn, O. Schofield, R. Chant, J. Wilkin, and J. Kohut. 2008. Seasonal evolution of hydrographic fields in the central Middle Atlantic Bight from glider observations. *Geophysical Research Letters* 35:L03617.
- Collins, M. R., and T. I. J. Smith. 1997. Management briefs: distributions of Shortnose and Atlantic Sturgeons in South Carolina. *North American Journal of Fisheries Management* 17:995–1000.
- Curtin, T. B., J. G. Bellingham, J. Catipovic, and D. Webb. 1993. Autonomous oceanographic sampling networks. *Oceanography* 6:86–94.
- Erickson, D. L., A. Kahnle, M. J. Millard, E. A. Mora, M. Bryja, A. Higgs, J. Mohler, M. DuFour, G. Kenney, J. Sweka, and E. K. Pikitch. 2011. Use of pop-up satellite archival tags to identify oceanic-migratory patterns for adult Atlantic Sturgeon, *Acipenser oxyrinchus oxyrinchus* Mitchell, 1815. *Journal of Applied Ichthyology* 27:356–365.

- Fiedler, P. C., and H. J. Bernard. 1987. Tuna aggregation and feeding near fronts observed in satellite imagery. *Continental Shelf Research* 7:871–881.
- Fox, D. A., L. M. Brown, K. W. Wark, and J. L. Armstrong. 2011. A study on the use of tie-downs and their impact on Atlantic Sturgeon, marine mammal bycatch and targeted catch in the New Jersey monkfish fishery. Completion Report NOAA Bycatch Reduction Engineering Program, Vol. EA133F-10-RQ-1160. Northeast Fisheries Science Center, Gloucester, Massachusetts.
- Garvine, R. W. 1995. A dynamical system for classifying buoyant coastal discharges. *Continental Shelf Research* 15:1585–1596.
- Geiger, E. F., M. D. Grossi, A. C. Trembanis, J. T. Kohut, and M. J. Oliver. 2011. Satellite-derived coastal ocean and estuarine salinity in the Mid-Atlantic. *Continental Shelf Research*.
- Grothues, T. M. 2009. A review of acoustic telemetry technology and a perspective on its diversification relative to coastal tracking arrays. *Tagging and Tracking of Marine Animals with Electronic Devices* 9:77–90.
- Grothues, T. M., J. Dobarro, and J. Eiler. 2010. Collecting, interpreting, and merging fish telemetry data from an AUV: remote sensing from an already remote platform. *Autonomous Underwater Vehicles (AUV) 2010 IEEE/OES*.
- Grothues, T. M., J. Dobarro, J. Ladd, A. Higgs, G. Niezgodna, and D. Miller. 2008. Use of a multi-sensored AUV to telemeter tagged Atlantic Sturgeon and map their spawning habitat in the Hudson River, USA. *Autonomous Underwater Vehicles 2008 IEEE/OES*.
- Hosoda, K., and H. Kawamura. 2004. Global space–time statistics of sea surface temperature estimated from AMSR-E data. *Geophysical Research Letters* 31:L17202.
- Irwin, A. J., and M. J. Oliver. 2009. Are ocean deserts getting larger? *Geophysical Research Letters* 36: L18609.
- Jackson, G. D. 2011. The development of the Pacific Ocean Shelf Tracking Project within the decade long Census of Marine Life. *PLoS One* 6:e18999.
- Manderson, J., L. Palamara, J. Kohut, and M. J. Oliver. 2011. Ocean observatory data are useful for regional habitat modeling of species with different vertical habitat preferences. *Marine Ecology Progress Series* 438:1–17.
- New England Fishery Management Council. 2011. Monkfish fishery management plan Amendment 5 incorporating stock assessment and fishery evaluation (SAFE). Federal Register, Vol. 76, Rules and Regulations.
- NOAA (National Oceanic and Atmospheric Administration). 2012. Endangered and threatened wildlife; notice of 90-day finding on a petition to list Atlantic Sturgeon as threatened or endangered under the Endangered Species Act (ESA). Federal Registry 77:5880–5912.
- Oliver, M. J., and A. J. Irwin. 2008. Objective global ocean biogeographic provinces. *Geophysical Research Letters* 35:L15601.
- Palacios, D. M., S. J. Bograd, D. G. Foley, and F. B. Schwing. 2006. Oceanographic characteristics of biological hot spots in the North Pacific: a remote sensing perspective. *Deep Sea Research Part II: Topical Studies in Oceanography* 53:250–269.
- Palamara, L., J. Manderson, J. Kohut, M. J. Oliver, S. Gray, and J. Goff. 2012. Improving habitat models by incorporating pelagic measurements from coastal ocean observatories. *Marine Ecology Progress Series* 447:15–30.
- Platz, T., D. Allen, and M. Claygon. 2010. Overview of the New England and Mid-Atlantic monkfish fishery. CapLog Report 2.02. Cap Log Group, LLC, Davis, California.
- Schofield, O., J. Kohut, D. Aragon, L. Creed, J. Graver, C. Halde-man, J. Kerfoot, H. Roarty, C. Jones, D. Webb, and S. M. Glenn. 2007. Slocum gliders: robust and ready. *Journal of Field Robotics* 24:473–485.
- Stein, A. B., K. D. Friedland, and M. Sutherland. 2004a. Atlantic Sturgeon marine bycatch and mortality on the continental shelf of the Northeast United States. *North American Journal of Fisheries Management* 24:171–183.
- . 2004b. Atlantic Sturgeon marine distribution and habitat use along the Northeastern Coast of the United States. *Transactions of the American Fisheries Society* 133:527–537.
- Stenevik, E. K., R. D. M. Nash, F. Vikebø, P. Fossum, and K. Bakke-plass. 2012. The effects of survey design and circulation pattern on the perceived abundance of herring larvae: a case study for Norwegian spring spawning herring (*Clupea harengus*). *Fisheries Oceanography* 21:1–10.
- Vladykov, V. D., and J. R. Greeley. 1963. Fishes of the western North Atlantic. Vol. 1(3). Sears Foundation for Marine Research, Yale University, New Haven, Connecticut. 



**FREE CATALOG!**

©2014 Forestry Suppliers, Inc. All rights reserved.

## Step up to the Pros.

The YSI Professional Plus is the one tool to have at your side. Choose the cable and the bulkhead to suit your needs, and collect your data on the ergonomic, waterproof meter. You can even go with the 4-port Quatro cable and bulkhead that holds four replaceable probes for Temp/Con, DO, and your choice of pH, ORP, Ammonium, Nitrate, or Chloride.

The Professional Plus is just one of the thousands of professional quality products we sell, each backed with our 100% Satisfaction Guarantee.

See for yourself. Scan the code, go online, or call 800-360-7788 to order your FREE catalog today.

**FORESTRY  SUPPLIERS**

Sales 800-647-5368 • [www.forestry-suppliers.com](http://www.forestry-suppliers.com)