

2012

# Exploratory Larval Fish Sampling: Kennebec River, ME



**Exploratory Larval Fish Sampling: Kennebec River, ME**



Submitted to:

Maine Dept. of Marine Resources  
21 State House Station,  
Augusta, ME 04333,

Submitted By:

Theodore Willis, PhD  
Gordon Lane  
BioDiversity Research Institute  
19 Flaggy Meadow Rd.  
Gorham, Maine 04038

Submitted on:

01 April 2012

The BioDiversity Research Institute (BRI) is a 501(c)(3) non-profit organization located in Gorham, Maine. Founded in 1998, BRI is dedicated to supporting global health through collaborative ecological research, assessment of ecosystem health, improving environmental awareness, and informing science based decision making.

*To obtain copies of this report contact:*

*BioDiversity Research Institute*

*19 Flaggy Meadow Rd.*

*Gorham, ME 04038*

*USA*

*(207) 839-7600*

*Theo.willis@briloon.org*

[www.briloon.org](http://www.briloon.org)

**FRONT PHOTO CAPTION:** Larval largemouth bass (*Micropterus salmoides*), 7 mm in length, captured in the Androscoggin River near Mustard Island on July 17, 2011. Many identification structures are highlighted in this image, including myomeres (chevron shaped muscle tissue), and melanophore pigmentation pattern (arrangement of pigment cells on head of sample). Photo credit: Gordon Lane

**SUGGESTED CITATION:** Willis, T.V. and G. Lane. 2012. Exploratory Larval Fish Sampling: Kennebec River, ME. Report BRI 2012-13 submitted to the Maine Dept. Marine Resources. Augusta, Maine. BioDiversity Research Institute, Gorham, Maine. 27 pp.

## Contents

1.0 EXECUTIVE SUMMARY .....	8
2.0 INTRODUCTION .....	8
3.0 STUDY AREA .....	9
4.0 METHODS .....	8
5.0 RESULTS .....	11
6.0 DISCUSSION .....	15
7.0 LITERATURE CITED .....	18

## List of Figures

Figure 1. ....	9
Figure 2. ....	10
Figure 3. ....	10
Figure 4. ....	12
Figure 5. ....	13
Figure 6. ....	13

## List of Tables

Table 1. ....	11
Table 2. ....	13
Table 3. ....	15

## List of Appendices

Appendix 1. ....	20
Appendix 2. ....	22
Appendix 3. ....	24
Appendix 4. ....	25
Appendix 5. ....	28

## EXECUTIVE SUMMARY

This document reports on a project to determine best methods, effectiveness and timing of deployment for capturing larval and juvenile fish in the Kennebec and Androscoggin Rivers, with specific focus on rainbow smelt (*Osmerus mordax*) and Atlantic sturgeon (*Acipenser oxyrinchus*). Four locations were targeted for larval fish sampling: one in the Androscoggin River near Mustard Island, one 0.25 km upstream of the mouth of the Eastern River, a site 0.8 km downstream from the Gardiner boat landing, and a site across the river and 0.1 km upstream of the water treatment plant in Bath. Sampling occurred once per week between July 8 and August 17.

Four types of gear were used to sample for larval fish in the Kennebec River: D-nets, surface tows, stationary plankton nets at 1 m and 2 m above the bottom, and light traps. We captured no shortnose sturgeon (*Acipenser brevirostrum*), Atlantic sturgeon (*A. oxyrinchus*) or rainbow smelt (*Osmerus mordax*) larvae between July 8 and Aug. 17. It was more than likely that the time of sampling was too late to capture rainbow smelt or shortnose sturgeon. Larval Atlantic sturgeon may have been present in the sample areas but none were captured. *Alosa spp.*, or river herring including shad, were the most abundant diadromous larval fish species found during the course of the study. The highest catches came from the Eastern River site, particularly in early July. Gardner also had an appreciable density of *Alosa* larvae in the water column during early to mid July and a few specimens were captured in the Androscoggin. White catfish (*Ameiurus catus*) were the most abundant fish captured, occurring at the Gardner, Eastern and Androscoggin sites, and light traps at the Androscoggin site caught large numbers in late July and early August. As an apparently widespread invasive species, white catfish have the potential to affect the Androscoggin and Kennebec River food webs.

Rating the four gear types used in effectiveness and efficiency, tow nets had the highest catch per unit effort (CPUE -fish per hour) across all sites and all sets, however, there was considerable variation by site. Most towed larval fish were caught in the Eastern River on one date, July 11. Conversely, stationary plankton nets caught larval fish at all locations where they were deployed. Considering total catch alone, D-nets were the most effective gear, catching an order of magnitude (100s vs. 10s) more larval and juvenile fish from the Androscoggin and Gardiner sites. D-nets also had the most diverse catches from the Androscoggin site. At the Eastern and Gardiner sites the stationary plankton net caught the widest diversity of larval fish by a narrow margin. D-nets were more labor intensive as far as separating specimens from detrital material, in many cases requiring eight hours or more to pick a quarter of the volume that filled the 2 L cod end. However, sorting was took half as long at the Gardiner site where there was less detritus in the water column. D-net sets also required returning to a site the next day. Catch per unit effort for D-nets was much lower because of the overnight sets, however fishing through the dark hours was also an advantage. Stationary plankton nets were effective, generally had higher CPUE than D-nets and processing times of two to four hours per sample, sometimes less. Tow nets were the fastest and easiest gear to deploy and pick. They also were not particularly effective, catching a low number and diversity of specimens. Light traps were generally ineffective at capturing larval fish, though this may have been due to deploying the traps on the bottom rather than suspending them from the water surface, as they are used in some applications.

## Final Report

Biodiversity Research Institute

Dr. Theodore Willis

Mar. 30, 2012

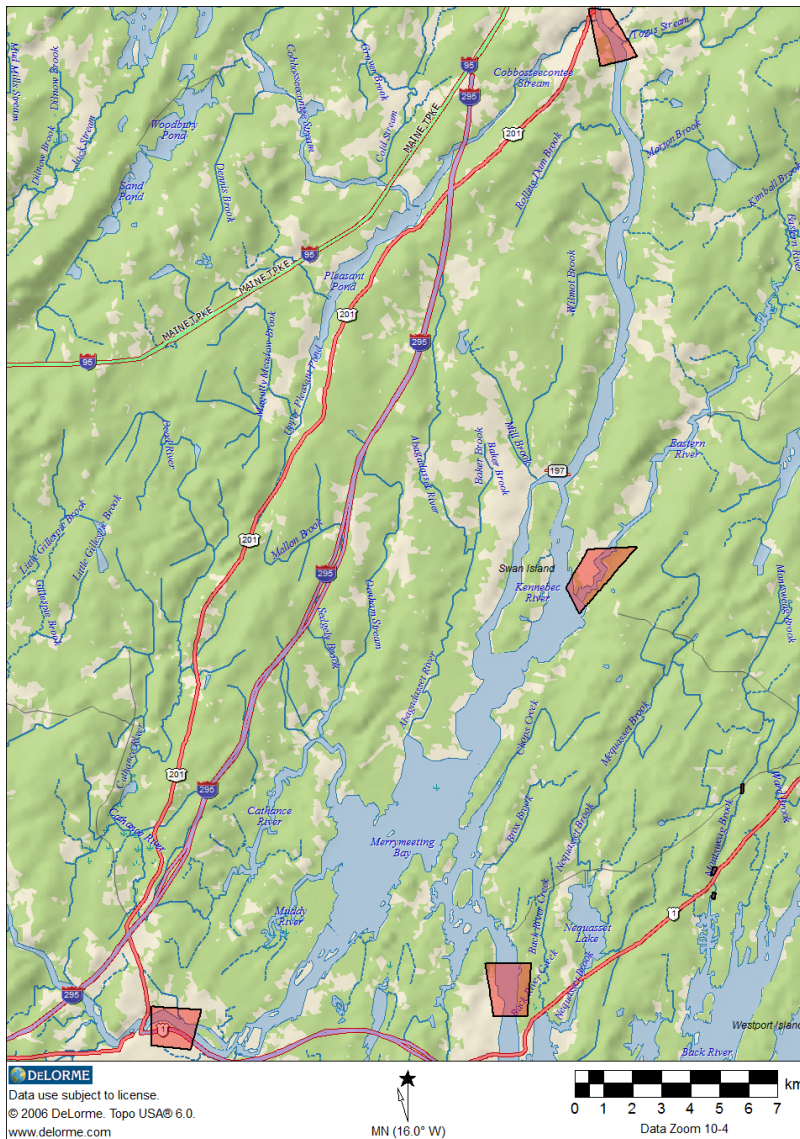
## Introduction

This document reports on a project to determine best methods, effectiveness and timing of deployment for capturing larval and juvenile fish in the Kennebec and Androscoggin Rivers, with specific focus on rainbow smelt (*Osmerus mordax*) and Atlantic sturgeon (*Acipenser oxyrinchus*). The sampling contracted to BRI augmented concurrent sampling executed by Maine DMR Bureau of Searun Fisheries in summer 2011.

## Methods

Four locations were targeted for larval fish sampling: one in the Androscoggin River near Mustard Island, one 0.25 km upstream of the mouth of the Eastern River, a site 0.8 km downstream from the Gardiner boat landing, and a site across the river and 0.1 km upstream of the water treatment plant in Bath (Fig. 1). Sampling occurred once per week between July 8 and August 17. Just after daytime high tide was considered the optimal sampling period, however, with two sites sampled per day actual sample times varied. Salinity and water temperature were recorded for each sampling event.





**Figure 1.** Map of sample sites. From top to bottom, counter-clockwise: Gardiner 19T 0438200 4878500, Eastern 19T 0438200 4878500, Bath 19T 0438200 4878500, Androscoggin 19T 0438200 4878500.

Four types of gear were used to sample for larval fish in the Kennebec River. D-nets had an opening of 0.3 m x 1.0 m, an overall length of 3 m and consisted of two mesh sizes, 600 and 1000  $\mu$  mesh netting (Fig. 2). One D-net was used per site in an overnight set ranging from 15 to 29 hrs. Modifications included two angle iron "feet" attached to the bottom bar of the net, 1 m in length. Support lines were run from the fore and aft ends of the feet to the curved top bar to prevent the net from tipping during tide changes. A net extender was used to prevent tangling during tide changes; this consisted of a 1/2" PVC pole long enough to stretch from the back of the cod end to the bottom bar of the frame, where it was connected with a PVC t-connector. Tow nets and stationary plankton nets were 0.52 m in diameter, 2 m long and made of 800 $\mu$  mesh. Both tow nets and stationary plankton nets were deployed with a General Oceanics flow counter mounted in the net mouth to facilitate calculation of volume sampled. Tow nets were towed 33 m behind the boat at approximately 2.5 knots, 15 cm below the water surface for approximately 10 minutes. Replicate upstream and downstream tows were

made back-to-back. Stationary plankton nets were set at either 1 m or 2 m above the bottom. Nets were suspended between a 50 lb mooring anchor and a 7.5 in x 20 in Go Deep Bouy with 3/8" aircraft cable; lobster bouy swivels were used to allow the nets to adjust for changes in tide and currents (Fig. 3). Sets were 40 min to 90 min in duration. Light traps consisted of transparent plastic minnow traps weighted with two red construction bricks with a 6" cylume light stick inside. Traps were set overnight in strings of five, 1.5 m apart.



**Figure 2:** Setting a D-net in the Kennebec River near Gardiner.

Various modifications to the sampling methodology were added over the course of the project. Only tows were used in Bath after the second week of sampling due to strong currents and suspended matter that tended to clog and sink the nets. The net extenders and feet, described above, were added to the D-nets after the first week to prevent laying over during tide changes or fouling of the net cod end. D-nets were tried in a variety of locations at each site until locations were found that reduced the amount of debris collected in the net. When the 2 L cod end filled with debris (e.g., leaves, twigs, sediment) a subsample (~250 ml) of the material was taken from the top and bottom of the cod end for sorting.



Material collected in the nets was fixed in either Glyofixx or an 80% alcohol, 15% ethylene glycol preservative. The net contents were sorted through within seven days. The nets used often collected significant amounts of debris, including sand and detritus. Almost all samples had large quantities of Ephemeroptera exuviae. Samples were examined under a dissecting microscope and all fish specimens transferred to new vials.

**Figure 3:** Setting a stationary plankton net in the Androscoggin River.

Specimen identification began with observations and counts of general characteristics. This included location and density of melanophores, as well as counts of fin-rays and pre-anal and post-anal myomeres. The key, Larval fish of the Great Lakes Basin was used as the primary key for determining the order and family of the specimens. Auer (1982) contained significant details of the most common species found in Maine’s rivers, including keys for both larval and yolk-sac life-stages; if a specimen’s yolk-sac was partially absorbed, both keys were consulted. In most cases, the primary features determining order were myomere counts. After determining the likely order of the specimens, a list of species documented in Maine was consulted (PEARL, 2011; note this site was decommissioned on 12/31/2011, and replaced by KnowledgeBase at <http://www.gulfofmaine.org/kb/2.0/search.html>) to guide additional family and species descriptions. Additional characteristics of the specimens were then recorded, including length of maxillae, shape of melanophores, form of urostyle, mouth shape, caudal fin shape, and morphometrics as percentages of total length. Not all characteristics were available for all species and life stages.

Potential species identifications were compared by creating a table of characteristics taken from the literature and comparing those to descriptions of the same features in the unknown specimen. Species were systematically eliminated based on notable characteristics not shared with the specimen. Positive identification was made based on the specimen sharing multiple notable characteristics with the described species.

## Results

Conditions were most similar at the three upstream sampling sites, particularly in terms of temperature and salinity. Bath had the lowest range of water temperature over the course of the study, ranging from 20.3 to 24.7 °C (68.5 to 76.5°F) (Table 1). The other three sites had a maximum water temperature near 26.1 °C (79°F) in late July and a minimum near 21.7 °C (71°F) when the study ended in late August. Salinities were highest at the Bath sample site, ranging from 4 ppt to 15 ppt. The salinity at the Androscogin site was as high as 7 ppt on the first day of sampling, after which salinities at all upstream sites was less than 4 ppt.

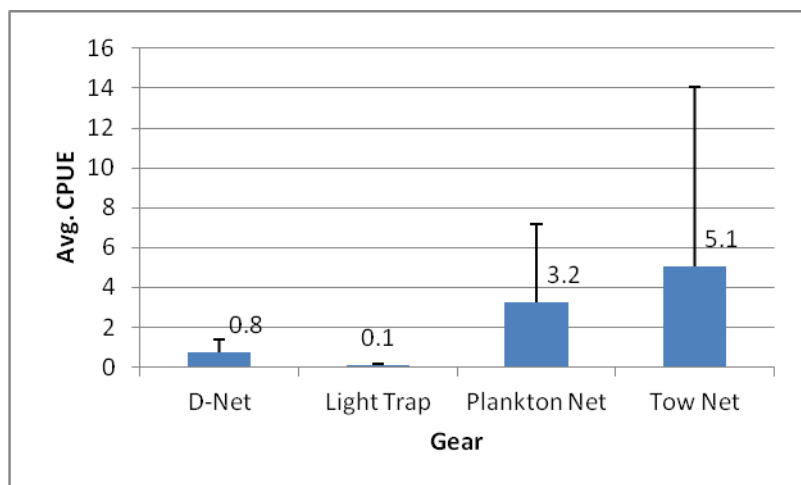
**Table 1:** Water temperature and salinity by sample date for the four sample sites.

Set Date	Water Temp (°F)				Salinity (ppt)			
	ANDO	BATH	EAST	GARD	ANDO	BATH	EAST	GARD
7/8	74.1	68.5			7	12		
7/11			75.5	75.9			2	0
7/12				78				
7/17	78.5	76.5						
7/18	78.9	73.9	77.6		2	6		
7/19		73.9	79.1	77.6		6	2	0
7/25		73.4	79.4	78.6		10	4	1
7/26	77.1		76.7	74.9	1		1	1
7/27	75				1			
8/1		71.4	77.3	77.2		12	2	1
8/2			75.9	76.4			2	3
8/3	75.2				1			
8/8		69	74.8	75.2		15	3	1

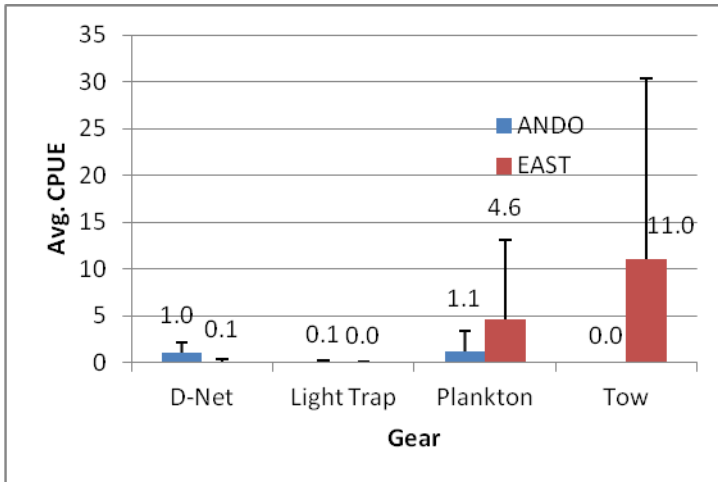
8/9	76.8		76.3	75.8	0	1	1
8/10	73				1		
8/15			72.8	73.4		3	0
8/16	71.5		71.6	71.3	0	0	0
8/17	70.6	70.6			0	4	

One of the goals of this study was to determine if diadromous fish species, particularly shortnose sturgeon (*Acipenser brevirostrum*), Atlantic sturgeon (*A. oxyrinchus*), or rainbow smelt (*Osmerus mordax*), were present in any of the sample areas. We found no larvae of these species between July 8 and Aug. 17 in the areas sampled. A second goal was to evaluate a diversity of larval fish gear for effectiveness and efficiency. Overall, tow nets had the highest catch per unit effort (CPUE) across all sites and all sets (Fig. 4). However, there was considerable variation by site. Most towed larval fish were caught in the Eastern River on one date, July 11 (Table. 2). Stationary plankton nets were the second most efficient gear, catching larval fish at all locations where they were deployed (Fig. 5 & 6). (Stationary plankton nets, D-nets and light traps were deployed in Bath in the first two weeks of the study only because of strong currents and the possibility of losing the gear.) Like the tow nets, the stationary plankton nets were most effective at the Eastern River site.

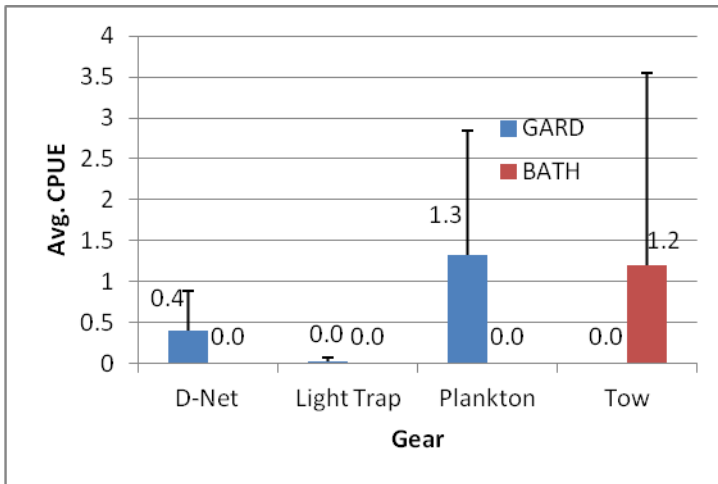
Summarizing the data as raw numbers of larval fish captured, the D-net was the most effective gear by far. At the Androscoggin and Gardiner sites D-net catches were an order of magnitude higher than those of the other gear (Table 2). White catfish were particularly vulnerable to capture in D-nets and were found in abundance during the last week of July (App. 1). Shad were also prevalent in the D-net catch from the Androscoggin during the last week of July.



**Figure 4:** Combined catch per unit effort (fish per hour) of larval fish for each gear type across Androscoggin, East and Gardner sites. Error bars are 95% CI.



**Figure 5:** Catch per unit effort of larval fish for each gear type deployed in Androscoggin and Eastern sites. Error bars are 95% CI.



**Figure 6:** Catch per unit effort of larval fish for each gear type deployed in Gardener and Bath sites. Error bars are 95% CI.

**Table 2:** Number of larval fish captured by date and gear, separated by site.

Location	Set Date	D-Net	Light Trap	Plankton Net	Tow Net	Grand Total
ANDO	7/8	4		9		13
	7/17	12	10			22
	7/18					
	7/26	57	2			59
	7/27					
	8/2	29	2			31
	8/3					
	8/9	4	1			5
	8/10					
	8/16	1				1
	8/17					
	<b>ANDO Total</b>		<b>107</b>	<b>15</b>	<b>9</b>	

<b>BATH</b>	7/8			1		1
	7/17					
	7/18					
	7/19					
	7/25					
	8/1					
	8/8				1	1
	8/17					
<b>BATH Total</b>				<b>1</b>	<b>1</b>	<b>2</b>
<b>EAST</b>	7/11			25	10	35
	7/18	5				5
	7/19					
	7/25	12				12
	7/26			1		1
	8/1	2	1			3
	8/2				1	1
	8/8					
	8/9					
	8/15		1			1
8/16						
<b>EAST Total</b>		<b>19</b>	<b>2</b>	<b>26</b>	<b>11</b>	<b>58</b>
<b>GARD</b>	7/11		1			1
	7/12			3		3
	7/19	3		4		7
	7/25	33				33
	7/26					
	8/1	9	2			11
	8/2					
	8/8					
	8/9	1				1
	8/15		1			1
8/16			1		1	
<b>GARD Total</b>		<b>46</b>	<b>4</b>	<b>8</b>		<b>58</b>
<b>Grand Total</b>		<b>172</b>	<b>21</b>	<b>44</b>	<b>12</b>	<b>249</b>

*Alosa spp.*, or river herring including shad, were the most abundant diadromous larval fish species found during the course of the study. The highest density of larval river herring production was found in the Eastern River site, particularly in early July (Table 3). Gardner also had an appreciable density of *Alosa* larvae in the water column during early to mid July and a few specimens were captured in the Androscoggin. For all three sites the highest *Alosa* concentrations were deeper than 1 m from the surface and above 1 m off the bottom, based on lower catches in the D-net and tow net than the stationary plankton net. Confirmed specimens of *Alosa sapidissima* were captured in plankton or tow net gear at the Androscoggin site on July 9, and at the Gardiner



site on July 19. Confirmed specimens of *A. pseudoharengus* were captured in plankton or tow gear at the Eastern site on July 11 and the Gardiner site on July 12 and Aug. 16. *A. aestivalis* may have been present also with *A. pseudoharengus*, but the state of decomposition of some samples prevented their positive identification (App. 3). Confirmed specimens of *A. sapidissima* were captured in D-net sets from the Androscoggin sites on July 8, July 17 and July 26.

**Table 3:** Average density of *Alosa spp* in one m<sup>3</sup> of water, by site and date. All Net gear is the average of plankton and tow gear.

Location	Set Date	Plankton Net	Tow Net	All Net gear
ANDO	7/8	0.002	0	0.001
	7/18	0	0	0
	7/27	0	0	0
	8/3	0	0	0
	8/10	0	0	0
	8/17	0	0	0
	EAST	7/11	14.459	0.027
7/19		0	0	0
7/26		0	0	0
8/2		0	0.003	0.002
8/9		0	0	0
8/16		0	0	0
GARD		7/12	2.379	0
	7/19	0.029	0	0.014
	7/26	0	0	0
	8/2	0	0	0
	8/9	0	0	0
	8/16	0.002	0	0.001

## Discussion

No diadromous fish of the *Acipenser* or *Osmerus* genera were found during the sampling in 2011. This is not to say that these species were not present or that natal or spawning habitat were not sampled. Indeed, we observed many sturgeon jumping in our sample areas, particularly in the Androscoggin, and with less frequency near Gardiner. Our conclusions may be a reflection of timing of the study. Rainbow smelt spawn shortly after ice out, which would have placed any individuals captured by this study at approximately two months old. The gear used relies on larval fish behaving essentially like plankton, moving with the tides and current. By July it was possible that smelt were no longer vulnerable to the gear used. Rainbow smelt peak spawning occurs between April and May at temperatures of 4 - 9°C (Buckley 1989). The sampling occurred at temperatures well beyond this. In fact, the upper lethal temperature for rainbow smelt is 18°C, 6°C lower than the coolest temperatures we recorded at the Androscoggin, Eastern or Gardiner sites at the start of the study. In summary, Rainbow Smelt were likely no longer in the area, if they frequented these sites at all.

The same may be true of shortnose and Atlantic Sturgeon. Shortnose sturgeon are early spring spawners, migrating upstream into freshwater tidal river reaches in April, or around water temperatures of 8 – 9°C, whereas Atlantic sturgeon have a June to July spawning season and tend to remain in oligohaline sections (Gilbert 1989). Consequently, it was much more likely that the sampling would have encountered Atlantic sturgeon larvae rather than shortnose sturgeon. Observations from Maine DMR estimates that there may be shortnose sturgeon spawning habitat near Waterville or Augusta in the Kennebec. There is less information available regarding Atlantic sturgeon spawning habitat. Preferred spawning habitat for both sturgeon species is described as usually rock, rubble or hard clay with little sand or silt, in relatively fast flowing sections (Gilbert 1989). The Eastern River site would not contain appropriate spawning habitat because of the silty nature of substrates there. The Gardner site would have appropriate habitat, as well as sections of river upstream from the Androscoggin site. Bath may not have had appropriate spawning habitat based on the brackish and relatively deep waters at that sampling location. Larval behavior may also have affected our chances of capturing sturgeon larvae. Yolk-sac sturgeon actively swim, rising up into the current, presumably for dispersal purposes, for the first nine to ten days after hatching, then settle into a more benthic life style, making more extensive use of crevices and cover (Gilbert 1989). In conclusion, Atlantic sturgeon were the more likely of the three target species to be captured, and then within a relatively short two week window after hatching. The Androscoggin and Gardner sites were most likely to harbor Atlantic sturgeon larvae.

Anadromous fish in the genera *Alosa* were caught in numbers at three of four sites and in three of four gear deployed. *Alosa* were identifiable based on a characteristic melanophore pattern that appeared on the venter (ventral area between the operculum). *A. sapidissima* had a characteristic bottleneck pattern, whereas *A. pseudoharengus* and *A. aestivalis* were more tapered. With the combination of myomere counts and melanophore pattern alewife were distinguishable from blueback herring, but with damaged specimens (e.g., headless, decayed, broken, curled) the ID could only be resolved to river herring.

The Androscoggin River site produced the most *A. sapidissima*. A remnant run of American shad exists in the Androscoggin. These fish will not use the Brunswick fish ladder so it is logical that if any spawning were taking place, it would occur in the river reaches below the dam. Our findings confirm that shad are spawning in the Androscoggin, though our results do not provide insight into survival of those larvae. One American shad was caught at the Gardner site. Alewife and river herring were also captured in numbers at the Androscoggin, Eastern and Gardner sites. All three locations have significant river herring runs. All river herring headed to Brunswick Dam fishway had to pass through the Androscoggin site. It is very likely that many river herring, especially blueback herring, spawn below the dam, as blueback herring are rarely caught in the fish ladder. Mill stream in Dresden is an actively harvested site that collects circa 600 bushel (~ 72,000) river herring annually. Mill stream has at least two significant falls of 1 m height or more, both within the tributary's first km. Consequently, some spawning probably occurs in the Eastern River and some larvae are likely washed into the Eastern shortly after hatching, if not during the egg stage. The Gardner site is a half km downstream from Togus Stream, which leads to Togus Pond. Although alewife do not currently have access to the lake, DMR has stocked the lake with alewife since 2009.

It may be noteworthy that *Alosa* were caught in large batches rather than an evenly distributed catch over time. This could indicate that shad and river herring were demonstrating coordinated movement or drift downstream, possibly in schools or in *en mass*. Many of the specimens were in poor shape once picked from the



net contents. The warm water temperatures at or above 25°C may have accelerated decomposition once fish were caught in the nets. Middle and late July temperatures were above the preferred temperature envelope for river herring and shad (Weiss-Glanz et al. 1986, Bozeman & VanDen Avyle 1989, Taylor 2009), which may have triggered downstream migration in search of a more preferable temperature regime.

White catfish (*Ameiurus catus*) were the most abundant fish captured during the study. D-net sets at Gardner, Eastern and Androscoggin sites, and light traps at the Androscoggin site caught large numbers in late July and early August. White catfish spawning appeared to have occurred throughout the Kennebec watershed and at least up to Brunswick Dam. As an apparently widespread invasive species, white catfish have the potential to affect the Androscoggin and Kennebec River food webs.

Another objective of the study was to compare the effectiveness of different larval fish gear. D-nets caught the most fish during the six weeks of sampling by a large margin. At the Androscoggin site the D-net catch was also the most diverse. At the Eastern and Gardiner sites the stationary plankton net caught the widest diversity of larval fish by a narrow margin. Two additional considerations when comparing gear is how much time was required to process the sampled material and resources (fuel & time) used to set and pull the gear. D-nets were extremely labor intensive as far as separating specimens from detrital material that also ends up in the nets. In many cases, a complete sample was not collected from the D-nets because the amount of material required sub-sampling the top and bottom of the 2L cod end cup. Two 475 ml (16 oz) jars, i.e., the top and bottom subsamples, required eight hours or more to fully pick through. Also, D-net sets required returning to a site the next day. Catch per unit effort was much lower because of the overnight sets. D-nets did have the advantage of sampling overnight compared to the other gear. In locations where detritus collection was minimal, i.e., Gardiner, D-nets were arguably the most effective gear.

Stationary plankton nets were effective, generally had higher CPUE than D-nets and processing times of two to four hours per sample, sometimes less. Sets right at slack tide or in eddies could result in the net turning knife-edge to the current and failing to collect any material. In high current locations the stationary plankton nets could fill up with detrital matter. In one case this weighted a net down and dragged the buoy underwater. For this reason setting stationary plankton nets overnight may not be advisable; however mid-water column sets may work, as the majority of detritus seemed to be closer to the river bottom.

Tow nets were the fastest and easiest gear to deploy and pick. They also were not particularly effective and caught a low number and diversity of specimens. Light traps were generally ineffective at capturing larval fish, though this may have been due to deploying the traps on the bottom rather than suspending them from the water surface, as they are used in some applications. However, because all of the sites were in flowing river habitat surface sets may not have been possible.

There were subtle differences in either the gear or how the gear was set during the study. There were two types of D-nets, a multi-filament woven 1 mm mesh net and a woven monofilament net with a slightly smaller mesh size. The larger mesh, multi-filament net caught more larval fish. Stationary plankton nets were set within 1 m of the bottom and at 2 m above the river bed. The net suspended at 1 m caught more larval fish than the 2 m net. Tows were made in the upstream and downstream direction. Towing against the flow of water caught marginally more larval fish.

## References

- Bozeman, E.L., Jr., and M.J. VanDen Avyle. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (South Atlantic) --alewife and blueback herring. U.S. Fish Wildl. Serv. Biol. Rep. 82 ( 11.111). U.S. Army Corps of Engineers, TR EL-82-4. 17 pp.
- Buckley, J. L. 1989. Species profiles: life histories and environment; requirements of coastal fishes and invertebrates (North Atlantic) --rainbow smelt. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.106). U.S. Army Corps Engineers, TR EL-82-4. 11 pp.
- Gilbert, C.R. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Mid-Atlantic Bight)--Atlantic and shortnose sturgeons. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.122). U.S. Army Corps of Engineers TR EL82-4. 28 pp.
- Taylor, K., (Shad and River Herring Plan Development Team). 2009. Amendment 2 to the Interstate Fishery Management Plan For Shad and River Herring (River Herring Management). Government Printing Office, Washington.
- Weiss-Glanz, L.S., J.G. Stanley, and J. R. Moring. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (North Atlantic) --American shad. U.S. Fish Wildl. Serv. Biol. Rep. 82 (11.59). U.S. Army Corps of Engineers, TR EL-82-4. 16 pp.

## Larval ID

- Auer, N.A. (1982). *Identification of larval fishes of the Great Lakes basin with emphasis on the Lake Michigan drainage* (Great Lakes Fishery Commission Special Publication 82-3). Ann Arbor, Michigan.
- Becker, G. C. (1983). *Fishes of Wisconsin*. Madison, WI: University of Wisconsin Press. Retrieved from <http://www.seagrant.wisc.edu/greatlakesfish/becker.html>.
- Bigelow, H.B., & Schroeder, W.C. (1953). *Fishes of the Gulf of Maine* (Fishery Bulletin 74). Washington, DC: United States Government Printing Office. Retrieved from: <http://www.gma.org/fogm/Default.htm>.
- Bigelow, H.B., & Schroeder, W.C. (2002). *Fishes of the Gulf of Maine* (3rd ed.). Washington, DC: Smithsonian Institution Press.
- Buynak , G.L, & Mohr Jr., H. W. (1978). Larval development of the redbreast sunfish (*Lepomis auritus*) from the Susquehanna River. *Trans. Am. Fish. Soc.*, 107, 600-604.
- Fahay, M. P. (1983). Guide to the early stages of marine fishes occurring in the western North Atlantic Ocean, Cape Hatteras to the southern Scotian Shelf. *Journal of Northwest Atlantic Fishery Science*, 4, 3-423. Retrieved from: <http://journal.nafo.int/J04/vol4.html>.
- Fahay, M. P. (2007). *Early Stages of Fishes in the Western North Atlantic Ocean (Davis Strait, Southern Greenland, and Flemish Cap to Cape Hatteras)*. Dartmouth, Nova Scotia: Northwest Atlantic Fisheries Organization. Retrieved from: <http://www.nafo.int/publications/frames/fahay.html>.
- FishBase Consortium. (2011). FishBase. Available at <http://www.fishbase.org>.
- Fish, M. P. (1931). *Contributions to the early life histories of sixty-two species of fishes from Lake Erie and*

*its tributary waters*. Washington, D.C.: U.S. Government Printing Office. Retrieved from: <http://fishbull.noaa.gov/47-1/fish.pdf>.

LarvalBase Project. (2006). LarvalBase. Available at <http://www.larvalbase.org>.

Lippson, A.J., & Moran, L. (1974). *Manual for Identification of Early Developmental Stages of Fishes of the Potomac River Estuary* (Maryland Department of Natural Resources Publication PPSP-MP-13). Baltimore, Maryland: Environmental Technology Center, Martin Marietta Corporation. Retrieved from <http://esm.versar.com/pprp/bibliography/sec5.htm>.

Loos, J.J., & Fuiman, L.A. (1977). Subordinate taxa of the genus *Notropis*: A preliminary comparative survey of their developmental traits. In *Proceedings of the first symposium of freshwater larval fish* (Olmsted, L.L., ed.). Charlotte, N.C. Retrieved from <http://repositories.lib.utexas.edu/handle/2152/16>.

Mansueti, R. (1958). *Eggs, larvae and young of the striped bass, *Roccus saxatilis** (Contribution No. 112). Solomons, Maryland: Maryland Department of Research and Education. Retrieved from: <http://aquaticcommons.org/4867/1/112.pdf>.

Methven, D. A. (1985). Identification and development of larval and juvenile *Urophycis chuss*, *U. tenuis*, and *Phycis chesteri* (Pisces, Gadidae) from the Northwest Atlantic. *J. Northw. Atl. Fish Sci.*, 6, 9-20.

PEARL. (2011). Maine Fish Checklist. Retrieved from [http://pearl.maine.edu/windows/biodiversity/fish\\_checklist.htm](http://pearl.maine.edu/windows/biodiversity/fish_checklist.htm).

Pennsylvania Natural Heritage Program. (n.d.) Bridle Shiner (*Notropis Bifrenatus*). Retrieved from: <http://www.naturalheritage.state.pa.us/factsheets/11313.pdf>.

Sigler, W.F., & Sigler, J.W. (1987) *Fishes of the Great Basin: A Natural History*. Reno, NV: University of Nevada Press.

Snyder, D.E. (1979). Myomere and vertebra counts of the North American cyprinids and catostomids. In *Proceedings of the third Symposium on Larval Fish* (Hoyt, R.D., ed.). Bowling Green, KY. Retrieved from: <http://repositories.lib.utexas.edu/handle/2152/17>.

University of California. (2011). California Fish Species. Retrieved from: <http://calfish.ucdavis.edu/species>.

U.S. Fish and Wildlife Service. (1978). *Development of Fishes of the Mid-Atlantic Bight* (WS/OBS-78/12). Solomons, Maryland: Chesapeake Biological Laboratory. Retrieved from: [http://docs.lib.noaa.gov/rescue/NOAA\\_E\\_DOCS/Coastal\\_Services\\_Center\\_docs](http://docs.lib.noaa.gov/rescue/NOAA_E_DOCS/Coastal_Services_Center_docs).

Vásquez-Yeomans, L. (2002). *Preliminary Guide to the Identification of the Early Life History Stages of Atherinopsid Fishes of the Western Central North Atlantic* (NOAA Technical Memorandum NMFS-SEFSC-482). Miami, FL: National Marine Fisheries Service.

**Appendix 1:** Fish captured, sorted by gear and location.

Location	Common_Name	D-Net	Light Trap	Plankton Net	Tow Net	Grand Total
<b>ANDO</b>	alosid	2				2
	American eel	2				2
	American shad	27		1		28
	brown bullhead	1				1
	common carp			2		2
	largemouth bass	1				1
	mummichog			1		1
	redbreasted sunfish		1	1		2
	river herring	1				1
	spottail shiner			2		2
	three-spine stickleback			1		1
	unk	8				8
	unk killifish			1		1
	white catfish	57	14			71
yellow bullhead	6				6	
<b>ANDO Total</b>		<b>105</b>	<b>15</b>	<b>9</b>		<b>129</b>
<b>BATH</b>	fourbeard rockling			1	1	2
<b>BATH Total</b>				<b>1</b>	<b>1</b>	<b>2</b>
<b>EAST</b>	alewife			1	6	7
	alosid	2		6		8
	common carp			2	1	3
	mummichog		1			1
	river herring	1		9	3	13
	spottail shiner		1		1	2
	unk			2		2
	unk catfish			1		1
	unk perch			1		1
	white catfish	6				6
	white perch	3		4		7
yellow bullhead	7				7	
<b>EAST Total</b>		<b>19</b>	<b>2</b>	<b>26</b>	<b>11</b>	<b>58</b>
<b>GARD</b>	alewife		1	4		5
	American shad			1		1
	pumpkinseed	2				2
	redbreasted sunfish	2	2	1		5
	sea lamprey		1	1		2
	unk	1				1
	unk shiner			1		1

white catfish	41			41
<b>GARD Total</b>	<b>46</b>	<b>4</b>	<b>8</b>	<b>58</b>

**Appendix 2:** General categories of specimens sampled sorted by location and gear.

Location	Specimen	D-Net	Light Trap	Plankton Net	Tow Net	Grand Total
<b>ANDO</b>	Amphipod	7	5	6	7	25
	Clam	6	1			7
	Eel	2				2
	Egg	5	1	4	5	15
	Elver	2				2
	Fish Lice	2		3	3	8
	Fragment	5				5
	Insects	8	5	6	6	25
	Juvenile fish	75	15	4		94
	Larval Fish	3		1		4
	Leech	5	1			6
	Mite	1	1		2	4
	Mysid			1		1
	none			3	3	6
	Snail	1			1	2
	Unknown specimen	2			2	4
	Yolk-sac larvae			4		4
<b>ANDO Total</b>		<b>124</b>	<b>29</b>	<b>32</b>	<b>29</b>	<b>214</b>
<b>BATH</b>	Amphipod	4	2	5	6	17
	Crab		1			1
	Crayfish	2	1	2		5
	Egg		1			1
	Fish Lice		1		5	6
	Insects		1		2	3
	Larval Fish			1	1	2
	Mysid	3	2	5	6	16
	none				1	1
	Snail		1	2		3
	Spider				2	2
	Unknown specimen	1	1	1		3
<b>BATH Total</b>		<b>10</b>	<b>11</b>	<b>16</b>	<b>23</b>	<b>60</b>
<b>EAST</b>	Amphipod	9	6	9	3	27
	Clam	2				2
	Crayfish	3	1	1		5
	Egg	3				3
	Fish Lice	2		3	4	9
	Fragment			1		1
	Insects	4	6	7	3	20

	Juvenile fish	16		1		17
	Larval Fish	3		17	10	30
	Leech	1				1
	Mysid		1	3	7	11
	none			4	1	5
	Snail	1				1
	Unknown specimen	3			1	4
	Adult fish		1			1
	Yolk-sac larvae		1	2	1	4
<b>EAST Total</b>		<b>47</b>	<b>16</b>	<b>48</b>	<b>30</b>	<b>141</b>
<b>GARD</b>	Ameocyte		1	1		2
	Amphipod	5	6	2	4	17
	Clam	2				2
	Eel		1			1
	Egg	1		4	1	6
	Fish Lice			5	2	7
	Insects	5	6	8	7	26
	Juvenile fish	33	2			35
	Larval Fish	3		5		8
	Leech	4		1		5
	Mite			1	2	3
	Mysid			1	1	2
	none			1	2	3
	Snail	2			2	4
	Spider	1				1
	Yolk-sac larvae		1	2		3
<b>GARD Total</b>		<b>56</b>	<b>17</b>	<b>31</b>	<b>21</b>	<b>125</b>

**Appendix 3:** Density of *Alosa* spp. in the water column at three sites per m<sup>3</sup>. Alewife corresponds to specimens that were positively identified to *A. pseudoharengus*. The river herring category consists of specimens that could not be positively identified to either *A. pseudoharengus* or *A. aestivalis*, but were not *A. sapidissima* larvae. The shad category consists of specimens that were positively identified to *A. sapidissima*.

Location	Set Date	alewife		river herring		shad	
		Plankton	Tow	Plankton	Tow	Plankton	Tow
ANDO	7/8	0	0	0	0	0.002	0
	7/18	0	0	0	0	0	0
	7/27	0	0	0	0	0	0
	8/3	0	0	0	0	0	0
	8/10	0	0	0	0	0	0
	8/17	0	0	0	0	0	0
EAST	7/11	0.904	0.021	8.133	0.006	0	0
	7/19	0	0	0	0	0	0
	7/26	0	0	0	0	0	0
	8/2	0	0	0	0.003	0	0
	8/9	0	0	0	0	0	0
	8/16	0	0	0	0	0	0
GARD	7/12	2.379	0	0	0	0	0
	7/19	0	0	0	0	0.029	0
	7/26	0	0	0	0	0	0
	8/2	0	0	0	0	0	0
	8/9	0	0	0	0	0	0
	8/16	0.002	0	0	0	0	0



**Appendix 4:** Set date and time, gear, hours (hr:min) after last tide change before set, and total soak time for the four sampling locations.

Location	Gear	Set Date	Set Time	Time since tide	Duration	
ANDO	D-Net	7/8/2011	22:12	2:06	20:13	
		7/17/2011	20:14	3:59	22:51	
		7/26/2011	17:15	6:30	16:39	
		8/2/2011	17:05	0:49	15:00	
		8/9/2011	18:51	0:14	17:30	
		8/16/2011	18:18	2:06	14:47	
		7/8/2011	23:00	2:54	1:17	
		23:10	3:04	1:20		
		7/18/2011	18:21	1:35	1:37	
	Plankton Net	7/27/2011	9:22	1:52	0:53	
		10:25	2:55	0:45		
		8/3/2011	7:36	3:03	1:01	
		8:49	4:16	0:54		
		8/10/2011	11:36	4:05	1:03	
		12:53	1:08	0:55		
		8/17/2011	8:38	4:12	1:20	
		10:14	5:48	0:55		
		Tow Net	7/8/2011	23:20	3:14	0:10
			23:48	3:42	0:10	
7/18/2011	18:30		1:44	0:10		
18:45	1:59		0:10			
7/27/2011	9:28		1:58	0:10		
10:28	2:58		0:10			
8/3/2011	7:42		3:09	0:10		
8:52	4:19		0:10			
8/10/2011	11:42		4:11	0:10		
12:56	1:11		0:10			
BATH	D-Net	8/17/2011	8:43	4:17	0:10	
		10:17	5:51	0:10		
	D-Net	7/8/2011	19:00	0:28	0:56	
		7/17/2011	22:58	2:16	17:32	
	Plankton Net	7/8/2011	19:38	1:06	0:42	
		7/19/2011	15:00	5:15	1:50	
	Tow Net	7/8/2011	19:48	1:16	0:10	
		7/18/2011	15:20	0:08	1:00	
		15:40	0:28	0:10		
		7/25/2011	9:38	1:24	0:10	

			9:59	1:45	0:10
		8/1/2011	15:01	1:05	0:10
			15:23	1:27	0:10
		8/8/2011	8:59	1:00	0:10
			9:20	1:21	0:10
		8/17/2011	12:19	3:01	0:10
			12:44	3:26	0:10
<b>EAST</b>	<b>D-Net</b>	7/11/2011	11:25	0:25	4:45
		7/18/2011	23:45	0:38	0:14
		7/25/2011	11:56	1:52	22:53
		8/1/2011	17:30	1:40	15:37
		8/8/2011	10:58	1:19	0:45
		8/15/2011	16:55	1:13	21:33
	<b>Plankton Net</b>	7/11/2011	12:02	1:02	0:58
			12:17	1:17	0:57
		7/19/2011	17:10	5:33	0:50
			18:08	0:29	0:40
		7/26/2011	10:22	5:16	0:52
			11:26	0:27	0:56
		8/2/2011	8:42	4:31	0:53
			9:53	5:42	0:50
		8/9/2011	11:16	0:33	0:57
			12:26	1:43	1:04
		8/16/2011	12:29	2:06	1:20
			13:57	3:34	1:14
	<b>Tow Net</b>	7/11/2011	12:24	1:24	0:10
			12:42	1:42	0:10
		7/19/2011	17:15	5:38	0:10
			18:13	0:34	0:10
		7/26/2011	10:29	5:23	0:10
			11:36	0:37	0:10
		8/2/2011	8:47	4:36	0:10
			9:56	5:45	0:10
		8/9/2011	11:21	0:38	0:10
			12:29	1:46	0:10
		8/16/2011	12:37	2:14	0:10
			14:03	3:40	0:10
<b>GARD</b>	<b>D-Net</b>	7/19/2011	2:07	2:02	18:27
		7/25/2011	13:57	3:19	0:11
		8/1/2011	19:10	2:40	21:40
		8/8/2011	12:39	2:27	2:42

		8/15/2011	15:08	4:29	18:23
	<b>Plankton Net</b>	7/12/2011	18:39	6:07	1:23
			18:44	6:12	1:29
		7/19/2011	0:09	0:04	0:50
			20:10	1:56	0:47
		7/26/2011	13:41	2:08	0:49
			14:42	3:09	0:44
		8/2/2011	13:21	1:44	0:56
			14:28	2:51	0:52
		8/9/2011	14:54	3:41	0:58
			16:00	4:47	0:55
		8/16/2011	9:09	4:34	0:52
			10:10	5:35	0:54
	<b>Tow Net</b>	7/12/2011	18:52	6:20	0:10
			19:10	0:05	0:10
		7/19/2011	20:17	2:03	0:10
			21:13	2:59	0:10
		7/26/2011	13:48	2:15	0:10
			14:46	3:13	0:10
		8/2/2011	13:28	1:51	0:10
			14:32	2:55	0:10
		8/9/2011	14:59	3:46	0:10
			16:04	4:51	0:10
		8/16/2011	9:13	4:38	0:10
			10:16	5:41	0:10

**Appendix 5:** *Alosa* specimens highlighting diagnostic pigmentation pattern on the venter (ventral surface between the gill arch), and along the abdomen. Numbers on each photo corresponds to an ID code in the database.

