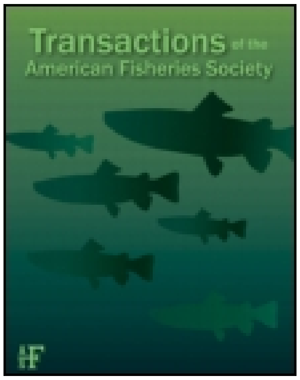

Transactions of the American Fisheries Society
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/utaf20

Consequences of Incidental Otter Trawl Capture on Survival and Physiological Condition of Threatened Atlantic Sturgeon

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Published online: 25 Jul 2013.

To cite this article: Jeffrey W. Beardsall, Montana F. McLean, Steven J. Cooke, Brian C. Wilson, Michael J. Dadswell, Anna M. Redden & Michael J. W. Stokesbury (2013) Consequences of Incidental Otter Trawl Capture on Survival and Physiological Condition of Threatened Atlantic Sturgeon, Transactions of the American Fisheries Society, 142:5, 1202-1214, DOI: 10.1080/00028487.2013.806347

To link to this article: http://dx.doi.org/10.1080/00028487.2013.806347

Transactions of the American Fisheries Society 142:1202–1214, 2013

ISSN: 0002-8487 print / 1548-8659 online
DOI: 10.1080/00028487.2013.806347

ARTICLE

Consequences of Incidental Otter Trawl Capture on Survival and Physiological Condition of Threatened Atlantic Sturgeon

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Abstract
Atlantic Sturgeon *Acipenser oxyrinchus* aggregate in Minas Basin in the inner Bay of Fundy, Nova Scotia, during summer, presumably to feed on abundant intertidal invertebrates. The Atlantic Sturgeon aggregation is composed of multiple stocks from Canada and the USA. Government agencies from both nations have recently recognized Atlantic Sturgeon as threatened or endangered due to overfishing and habitat degradation. Little is known about the fate of Atlantic Sturgeon that are captured as bycatch in fisheries targeting other species, making it difficult to determine the extent to which bycatch is contributing to the Atlantic Sturgeon population's decline. To characterize the effects of otter trawl capture and release on Atlantic Sturgeon, we calculated a minimum survival rate for fish after catch and release by using acoustic telemetry, and we examined physiological indicators of stress. The minimum postrelease survival rate from otter trawl capture events was high (94% survival). Results also demonstrated that the magnitude of blood lactate in trawl-captured fish relative to experimental control fish increased with longer handling times. Trawl capture and handling did not cause significantly elevated levels of blood glucose or cortisol relative to those of controls. Minimization of handling time (i.e., time on deck) should be a priority in trawl fisheries that capture Atlantic Sturgeon as bycatch. Future studies should attempt to quantify the postcapture behavior of these fish to better understand whole-organism condition after fisheries encounters.

Atlantic Sturgeon *Acipenser oxyrinchus* are migratory anadromous fish. Overfishing and habitat degradation (i.e., dams and river pollution) from 1980 to 1990 resulted in a dramatic decrease in commercial landings of Atlantic Sturgeon, which prompted regulatory action from fishery management agencies (Dadswell 2006). The Atlantic Sturgeon fishery in the United States was closed in 1998, and the marine fishery in Canada was closed in 2002, although regulated fisheries still operate in

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Received August 30, 2012; accepted May 8, 2013
Published online July 25, 2013

the Saint John and St. Lawrence rivers (Dadswell 2006; DFO 2011). The Canadian government recognizes the Atlantic Sturgeon as a threatened species (COSEWIC 2011); in the USA, the species was declared endangered in 2012 (NOAA 2012). The Atlantic States Marine Fisheries Commission (ASMFC 2007) and the Atlantic Sturgeon Status Review Team (ASSRT 2007) cited fishery bycatch as one of the largest continuing threats to the recovery of Atlantic Sturgeon populations.

Estimates from New England and mid-Atlantic fisheries indicate that between 3,298 and 8,977 Atlantic Sturgeon were incidentally captured and released as bycatch each year between 2001 and 2006 (ASMFC 2007). Observer programs estimate that trawling fisheries captured between 45,000 and 90,000 kg of Atlantic Sturgeon bycatch annually between 1989 and 2000. Fish and shrimp otter trawls operating north of North Carolina during 1988–2004 are estimated to have produced low levels of immediate bycatch mortality (0–0.2%), but these may be underestimates of true mortality due to the short tow times and cool water temperatures. Observer data are limited for southern fisheries because there is no observer coverage in U.S. federal waters between North Carolina and Florida (ASSRT 2007). Shrimp and whelk trawl fisheries in Georgia accounted for 39% of Atlantic Sturgeon recaptures from an Altamaha River tagging project, although immediate mortality of these Atlantic Sturgeon was not observed (Collins et al. 1996). Southern trawl fisheries typically use longer tow times and occur in warmer waters than northern trawl fisheries; thus, they are likely associated with higher bycatch mortality rates (ASSRT 2007).

The ASMFC estimated trawling bycatch mortality of 5% along the entire coast for stock assessment purposes, but this mortality rate has not been verified for trawling fisheries that incidentally capture Atlantic Sturgeon by using long tow times in warm water temperatures. Due to slow growth rates and late maturity, Atlantic Sturgeon populations can sustain minimal (i.e., <4%) incidental mortality from fishery activity (Boreman 1997). Hence, an understanding of the level of mortality associated with trawling capture and release as well as potential sublethal consequences is critical for identifying and refining management strategies that would enable the population to recover. However, to our knowledge, there are no studies of postrelease mortality or sublethal physiological disturbances associated with trawl capture for any acipenserid species.

Atlantic Sturgeon are incidentally captured by benthic otter trawl and intertidal brush weir commercial fisheries in the Minas Basin, Bay of Fundy, Canada. An aggregation of Atlantic Sturgeon enters Minas Basin (the inner Bay of Fundy estuary) in late May or early June each year during coastal migration, presumably to feed on abundant intertidal invertebrates (McLean et al. 2013). Gravid females are rarely captured in Minas Basin, but there is an abundance of maturing juveniles, usually between 90 and 150 cm FL (Wehrell 2005; Dadswell 2006). Recent DNA analyses indicate that approximately 60% of the Atlantic Sturgeon in Minas Basin were from the Saint John River stock, 32–34% were from the Kennebec River stock, and 1–2% were from the Hudson River stock (Wirgin et al. 2012). During late spring and summer, the Minas Basin groundfish and pelagic fisheries operate using benthic otter trawls and fish weirs. Atlantic Sturgeon are not targeted, but they are the fifth most common species captured in otter trawls (Wehrell 2005).

Although there is a variety of ways in which to document postrelease mortality (e.g., net-pens, tank studies, or mark–recapture), electronic tagging tools (i.e., biotelemetry and biologging) have become popular in recent years because researchers have used them to study unrestrained fish in their natural environment (reviewed by Donaldson et al. 2008). In nearshore coastal marine waters, acoustic telemetry in particular has become the tool of choice for studies of postrelease mortality. Acoustically tagged fish that are released can either be tracked manually (e.g., Cooke and Philipp 2004; Butcher et al. 2010) or by using fixed hydrophones (e.g., Roberts et al. 2011; Yergey et al. 2012). Physiological endpoints (e.g., blood chemistry) can be used to understand the sublethal consequences of fisheries interactions or to understand the mechanistic basis for mortality (Cooke et al. 2008a, 2013).

Trawl bycatch and mortality studies have been performed on non-acipenserid fish, such as elasmobranchs. A study of Spiny Dogfish *Squalus acanthias* suggested that blood acidosis resulting from lactate production and high venous CO_2 partial pressure were potential risk factors after trawl capture (Mandelman and Farrington 2007a, 2007b). Blood acidosis was greatest immediately after trawl capture. Immediate posttrawl mortality from 45-min tows did not occur (0/34 fish), and the only mortalities reported by Mandelman and Farrington (2007a) occurred during laboratory confinement after trawl capture and transport. Mandelman and Farrington (2007b) also reported 29% mortality in Spiny Dogfish after bycatch treatment and a 72-h confinement in sea-pens. These results suggest that delayed mortality resulting from trawl bycatch is moderate but is lower than the assumed 50% mortality previously used by Spiny Dogfish fishery management authorities (Mandelman and Farrington 2007b). Confinement of wild Spiny Dogfish in sea-pens is potentially stressful, and therefore it may have contributed to delayed mortality (Mandelman and Farrington 2007b). Gathering of survival data without the use of confinement is a critical step in developing accurate estimates of delayed mortality (Donaldson et al. 2008). Studies that have simulated capture by benthic trawl in the laboratory have reported that behavioral impairments and physical damage (i.e., net abrasion) may also contribute to immediate and delayed mortality in trawl capture events (Davis 2005; Davis and Ottmar 2006). Clearly, interaction with trawls has the potential to yield mortality or cause physiological alterations in Atlantic Sturgeon.

In this study, we used acoustic telemetry to determine minimum survival estimates for Atlantic Sturgeon that were captured by otter trawl or intertidal brush weir and then released. We also investigated the physiological response of Atlantic Sturgeon to capture by benthic otter trawl and intertidal brush weir. Whole-blood glucose, lactate, and plasma cortisol levels were measured, as these parameters are good indicators of stress; they respond to a variety of stressors in sturgeon species, including capture events, confinement, hypoxia, and salinity stress (Lankford et al. 2003; Baker et al. 2005, 2008; Wuertz et al. 2006; Webb et al. 2007; Falahatkar et al. 2009; Allen et al. 2011; Kieffer et al. 2011). Atlantic Sturgeon that were captured by the intertidal brush weir were treated as minimally stressed samples and were used to provide a relative context for survival and physiological endpoints under conditions of minimal stress.

METHODS

Capture sites.—Minas Basin is a summer-warm (∼18°C) macrotidal estuary in the inner Bay of Fundy and has the highest recorded tides in the world (Bousfield and Leim 1959), resulting in strong tidal currents and high productivity. Atlantic Sturgeon were captured by otter trawl in Minas Basin and by intertidal brush weir near Five Islands, Nova Scotia (Figure 1). Minas Basin is a well-mixed estuary, and salinity at both capture sites is approximately 25‰ (Bousfield and Leim 1959). Water temperatures were measured at each capture site. Trawl capture temperatures were collected from June 1 to October 6, 2011, by using a HOBO temperature logger (Onset Computer Corp., Cape Cod, Massachusetts) located in Minas Basin at Kingsport (Figure 1, location 6). Weir temperature data were collected at each tide during which the weir was inspected for Atlantic Sturgeon. Fishing was performed under Scientific License to Fish Number 322595 from the Department of Fisheries and Oceans Canada. All tagging and blood collection procedures were performed under Acadia University Animal Care Committee Protocol Number 07-11.

Weir capture.—Between June 1 and June 19, 2011, two or more researchers tended a brush weir along with the operator of the weir. The weir net was approximately 1.5 km long, with a bend in the middle, giving the weir the appearance of a "V" opening toward the shore. The top of the net stood approximately 2.5 m high from the benthic substrate; at high water, the weir was approximately 8–9 m below the surface. The lower 1 m of the weir net was constructed by using spruce tree brush. During each low tide, four to five large-sized pools (∼0.5–1.0 m deep) on the inner walls of the weir were inspected for Atlantic Sturgeon. Pools were inspected while water was draining from the weir to minimize confinement stress in weir samples. This intertidal fish weir was assumed to apply a low capture stress level because the fish are retained in relatively large pools of water and are able to fully submerge their bodies and gills. Atlantic Sturgeon were observed exploring the pool in a calm manner and did not appear agitated in any way until they were corralled by using a small beach seine. Due to these factors, we considered weir capture to be a minimal-stress treatment.

Weir-captured Atlantic Sturgeon were corralled and netted by using a small beach seine and were pulled onto dry land.

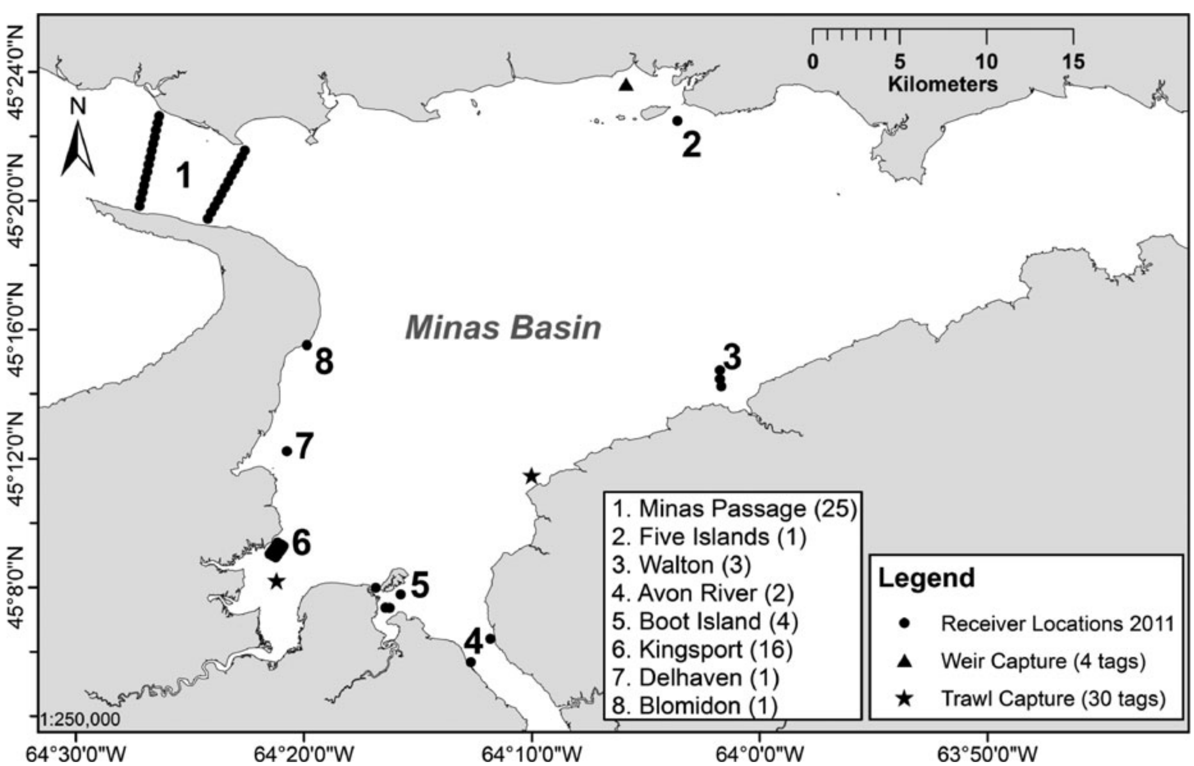

FIGURE 1. Map of capture sites for Atlantic Sturgeon and the positions of acoustic receiver stations deployed in Minas Basin and Minas Passage, Bay of Fundy, Nova Scotia, Canada, in 2011.

Handling time was recorded from the second the fish reacted to corralling procedures to the second the blood sample was obtained. Atlantic Sturgeon were placed in the supine position on a moistened plastic ground sheet, where blood samples were drawn (procedure described below). After blood sampling, fish were tagged in the dorsal musculature with conventional dart tags (Floy Tag & Manufacturing, Inc., Seattle, Washington) and a FishID SST-1 PIT tag (Destron Fearing, South St. Paul, Minnesota). A DNA sample was obtained from a pelvic fin punch. Fish that were large enough (>100 cm FL) for a transmitter implant were anesthetized in a large polyvinyl chloride tube containing the anesthesia bath; a VEMCO/Amirix V16P acoustic transmitter (VEMCO/Amirix, Halifax, Nova Scotia) was then surgically implanted in the coelomic cavity (described below). After surgery, the fish were released into the nearest pool for recovery. Fish that were too small for acoustic tagging were released into the nearest pool without anesthesia or surgery.

Otter trawl capture.—Between June 29 and September 4, 2011, five trawling excursions were conducted aboard the 13-m fishing vessel *Terry & Sandy*. Each excursion consisted of five to eight tows conducted between 0800 and 2100 hours Atlantic Standard Time. Benthic trawls were conducted using a 24-m box-trawl net with a stretched mesh size of 14 cm. The net was equipped with modified rock hopper equipment and two 200-kg metal doors. Tows were conducted at 4 km/h between 5- and 10-m depths from the surface. Tows were 50–60 min in duration.

After the net was landed, the catch was released from the cod end, and the fish were held in a catch box that was located at the stern of the boat. Handling time was recorded from the second the net was landed on deck to the second the blood sample was obtained. Atlantic Sturgeon catches ranged from 1 to 12 fish/tow. Atlantic Sturgeon were sampled for blood prior to administration of anesthetic. As above, fish that were large enough had a VEMCO/Amirix V16P transmitter surgically implanted in the coelomic cavity. Fish that were too small for acoustic tagging were released immediately after blood sampling.

Blood sampling.—Blood was sampled from Atlantic Sturgeon via caudal venipuncture. Fish were placed in a supine position in the catch box, and a 21-gauge, 3.81-cm (1.5-in) needle (Becton-Dickinson, Franklin Lakes, New Jersey) was then inserted immediately posterior to the anal fin. A 3.0-mL blood sample was drawn using a 4.0-mL, lithium-heparinized Vacutainer (Becton-Dickinson) and was immediately placed in a 50:50 water–ice slurry. Blood samples were stored in the slurry for 2 h or less prior to centrifugation. Storage of blood samples in water–ice slurry for less than 8.5 h does not affect lactate and cortisol (Clark et al. 2011). Samples were spun for 5 min at 3,300 $\times$ g using a field centrifuge (Portafuge; LW Scientific, Lawrenceville, Georgia). Blood plasma was drawn from the top of each Vacutainer, deposited into two plastic vial aliquots (~1.0 mL each), and then frozen in a liquid nitrogen dry shipper for later laboratory analyses.

Acoustic transmitter surgery.—Atlantic Sturgeon (>100 cm FL) underwent a surgical procedure to implant acoustic transmitters. The incision site, surgical tools, and transmitters were disinfected using 10% Betadine solution, followed by a saline rinse. Before surgery, each Atlantic Sturgeon was placed in a large polyvinyl chloride cradle tipped at a 45° angle. A stock solution of tricaine methanesulfonate (MS-222) at 10 mg/L was mixed with 20 L of fresh seawater. The fish was placed dorsal side up, with its head and gills fully submerged in the anesthesia bath. Slowed opercular beats and unresponsiveness to a stimulus (shake of the tail) were used as indicators that the anesthesia had taken effect. The fish was removed from the cradle and placed into a supine position on a moistened tarpaulin. A 3–4-cm incision was made on the ventral surface to the left or right of the *linea alba*. The incision was generally made posterior to the pelvic girdle, roughly halfway between the anus and pelvic girdle. Transmitters were inserted into the abdominal cavity and pushed anteriorly approximately 4 cm. Incisions were closed with a horizontal mattress suture by using sterile, absorbable 1/0 Ethilon monofilament nylon sutures (Johnson & Johnson, Markham, Ontario) with a reverse cutting edge. Surgeries lasted 2–4 min (excluding anesthesia and recovery time). All Atlantic Sturgeon were held in a recovery tank (~700 L) after surgery to allow sufficient time for the anesthetic to wear off and then were released into the same area where they had been captured. Holding times varied between 5 and 25 min depending on when the fish regained its ability to maintain dorsoventral orientation.

Anesthesia and implantation procedures had the potential to influence postrelease behavior and survival, but the internal tagging approach was deemed to be better for long-term (i.e., months) tracking than external tags, which potentially could be shed. Each transmitter was uniquely coded and programmed to emit signals at a frequency of 69.0 kHz at randomly determined intervals varying from 30 to 90 s (VEMCO/Amirix). Estimated tag life varied from 1,581 to 1,633 d (~4 years) after deployment. Acoustic signals were decoded and archived to memory by VEMCO/Amirix VR2W acoustic receiver stations (Figure 1) when tags were transmitting within range (generally up to 400–500 m depending on environmental conditions; J. Broome, Acadia Centre for Estuarine Research, unpublished data). Data from the receiver stations were then downloaded, providing unique identification information, depth, temperature, and a time stamp.

Minimum survival estimate.—Minimum survival was determined by using 53 fixed-place receiver stations distributed among eight locations throughout Minas Basin (Figure 1). Receiver stations were deployed by the Acadia Centre for Estuarine Research (ACER), the Acadia University Coastal Ecology Laboratory, and the Ocean Tracking Network (OTN) located at Dalhousie University (see Cooke et al. 2011). Receiver station coverage was designed for multispecies tracking studies in this system. Briefly, receiver stations covered eight locations at least 7 km apart, and each location contained either one receiver station or multiple stations (Table 1). Any release mortality study that uses telemetry must have strict nonsubjective criteria for evaluating the fates of fish (Yergey et al. 2012). If a transmitter

TABLE 1. Summary of Atlantic Sturgeon capture method (W = intertidal brush weir; T = otter trawl) and acoustic tracking data, including detection locations (number of receiver stations at each location is given in parentheses) for each unique identification number (ID) of Atlantic Sturgeon tagged in Minas Basin during summer 2011. Double asterisks (**) indicate possible mortalities given the number of locations visited, maximum distance between detections, and mean depth for all detections.

				Detection location								
Fish ID	Capture method	Maximum distance between detections (km)	Mean depth (m) ± SD for all detections	Minas Passage (25)	Walton (3)	Avon River (2)	Delhaven (1)	Kingsport (16)	Blomidon (1)	Boot Island (4)	Five Islands (1)	Total number of locations visited
15525	W	24.9	11.5 ± 3.8						X		X	2
15517	W	26.0	8.1 ± 3.8	X				X			X	3
15516	W	33.5	7.5 ± 4.5	X			X	X	X			4
15520	W	36.2	7.4 ± 3.9		X	X		X		X		4
15561**	T	0.0	4.8 ± 0.2		X							1
15543**	T	0.9	9.0 ± 2.7					X				1
15558	T	1.3	31.0 ± 2.2	X								1
15553	T	5.3	25.2 ± 5.1	X								1
15533	T	6.9	13.1 ± 3.7	X								1
15532	T	13.4	NA	X					X			2
15546	T	13.6	7.5 ± 3.5			X		X				2
15557	T	13.6	30.8 ± 5.6	X					X			2
15549	T	20.5	10.8 ± 3.4				X	X				2
15560	T	29.9	9.7 ± 2.9		X			X				2
15545	T	30.3	30.4 ± 4.8	X			X					2
15565	T	30.4	12.2 ± 10.6	X	X							2
15554	T	30.6	23.2 ± 19.1	X	X							2
15552	T	33.5	7.5 ± 6.8		X	X						2
15562	T	35.2	4.6 ± 2.4	X		X						2
15536	T	35.9	10.3 ± 4.5	X	X							2
15538	T	4.3	36.5 ± 4.3	X			X	X				3
15539	T	30.7	9.0 ± 3.4			X	X	X				3
15548	T	33.6	7.0 ± 4.9	X		X		X				3
15567	T	25.4	6.6 ± 2.3		X		X	X		X		4
15541	T	29.6	5.3 ± 3.0	X		X		X	X			4
15544	T	33.4	22.8 ± 18.5	X	X	X					X	4
15550	T	33.5	6.7 ± 11.7	X		X	X	X				4
15535	T	35.2	8.0 ± 7.0	X		X	X	X				4
15540	T	35.2	12.7 ± 10.6	X		X	X	X				4
15551	T	35.2	8.2 ± 6.5	X	X			X		X		4
15537	T	35.6	11.6 ± 7.7	X	X		X	X				4
15563	T	35.7	14.6 ± 14.7	X	X		X	X				4
15559	T	36.2	7.8 ± 3.5	X	X	X	X					4
15534	T	35.1	10.1 ± 8.2	X	X	X	X	X	X	X		7

was identified at two different locations by at least two receiver stations over the course of 5 months (June–October 2011), that particular fish was considered to have survived the capture-and-release event. If a fish was detected in only one location, then the mean swimming depth for all detections and the maximum distance traveled between two receiver stations were used to determine whether the fish was alive at the time of detection. Two curtains of receiver stations were deployed approximately 5.5 km apart in the Minas Passage location by ACER and OTN in an attempt to detect all tagged fish that exited or entered Minas Basin (Figure 1). Minas Basin is a turbid environment, with strong tidal currents (e.g., Minas Passage) that can affect the performance of acoustic transmission. Fish may have avoided detection due to poor signal reception. Fish that were detected in one or more locations may have visited other locations, but poor acoustic reception resulted in a failure to identify the fish. Due to these factors, our data can only represent a minimum survival estimate.

Physiological measurements.—Whole-blood glucose and lactate measurements were obtained prior to plasma separation. Whole-blood glucose was measured by using a One-Touch blood glucose meter (LifeScan, Inc., Milpitas, California) and manufacturer-recommended test strips. Whole-blood lactate was measured by using a Lactate Pro handheld lactate monitor (Arkray, Inc., Kyoto, Japan) and compatible test strips. Each test required approximately 250 μL of whole blood. Accuracy and validity of these two field measurement devices for use with fish blood were demonstrated by Cooke et al. (2008b).

Plasma cortisol was measured by using a Cortisol Enzyme Immunoassay (EIA) Kit (Enzo Life Sciences, Catalogue Number 900-071) according to the manufacturer's instructions. This EIA kit was validated by Sink et al. (2008) for use on blood plasma from four teleost fish species (e.g., Channel Catfish *Ictalurus punctatus*, Largemouth Bass *Micropterus salmoides*, Pirapatinga [Red-Bellied Pacu] *Piaractus brachypomus*, and Golden Shiner *Notemigonus crysoleucas*). Each sample was assayed in duplicate by using a twofold dilution factor, and an average optical density reading was used to calculate cortisol concentration from a standard curve ($R^2 > 0.92$). The intra-assay CV was 17.98%, and the interassay CV was 24.01%.

Statistical analyses.—All variables were assessed for normality using the Shapiro–Wilk test. Comparisons between weir captures and trawl captures were evaluated by using *t*-tests with the Welch df correction for unequal variances (Zar 2010). Outliers were kept in the analyses, and nonnormal variables were analyzed by using the nonparametric Mann–Whitney *U*-test. Relationships between physiological variables and handling time were evaluated by using simple linear regression (type III sums of squares; Zar 2010). Non-normal variables were normalized with $\log(y + 1)$ transformation for regression analyses (Zar 2010). An alpha level of 0.05 was used for all tests. All statistical analyses were conducted using the R programming interface (R Development Core Team 2011).

RESULTS

Minimum Survival Estimate

In total, 19 Atlantic Sturgeon were captured by the intertidal brush weir and 44 fish were captured by the otter trawl. Immediate mortality from weir or trawl capture was not a factor because all fish were released alive. Thirty-four of the 63 fish captured during this study were tagged with an acoustic transmitter. Four of the 34 tagged fish were captured by using the intertidal brush weir, and the remaining 30 tagged fish were captured with the benthic otter trawl. Weir- and trawl-captured fish did not significantly differ in their days at large, days tracked, number of locations visited, or number of receiver stations visited. The number of days at large in the study system was 53 ± 34 d (mean ± SD) for all 34 tagged fish, and the number of days tracked during that period was 14 ± 15 d. The number of locations visited was 3 ± 1 (mean ± SD), and the number of receiver stations visited was 14 ± 8. Twenty-nine of the 34 tagged Atlantic Sturgeon were identified in at least two locations over the course of their Minas Basin migration; hence, we considered them to be survivors of the capture–tag–release event (Table 1). For those 29 fish, the number of days tracked was 17 ± 15 d (mean ± SD). During the course of 1 d, fish 15538 and 15557 were detected at three and five locations, respectively. In each case, the last location of detection was the Minas Passage, which suggests that these fish swam directly for Minas Passage after the capture–tag–release event, visiting at least two other locations on the way to Minas Passage.

Fish 15558, 15553, and 15533 were detected at only one location but over relatively large distances within that location and at depths similar to those of confirmed survivors. These three fish were also considered to be survivors of the capture–tag–release event. Over the course of 1 d, fish 15558 was detected by three receiver stations up to 1.3 km apart in Minas Passage (Table 1). Fish 15558 was swimming at a mean depth of 31 ± 2.2 m (mean ± SD) below the surface, over a benthos that varied between 110 and 120 m in depth, suggesting that this fish was actively swimming through Minas Passage at a depth typical of other confirmed surviving Atlantic Sturgeon (Table 1). Fish 15553 and 15533 were detected by both curtains of receiver stations in Minas Passage. Fish 15553 was detected on seven receiver stations up to 5.3 km apart over the course of 2 d (Table 1). Fish 15553 was detected at a depth of 25 ± 5.1 m (mean ± SD), suggesting that this fish was swimming in the middle of the water column through Minas Passage, and it maintained residency near Minas Passage for 2 d before exiting to the outer Bay of Fundy. Fish 15533 was detected at 10 receiver stations up to 6.9 km apart within Minas Passage (Table 1); this fish exited Minas Passage for 77 d and then returned to the passage on day 78 posttagging. This detection pattern suggests that fish 15533 maintained residency outside of Minas Basin and visited Minas Passage at least once after the capture–tag–release event.

For all 32 surviving Atlantic Sturgeon, the shortest maximum distance between detections was 1.3 km, and the greatest maximum distance between detections was 36.1 km. Among survivors, the maximum distance between detections averaged 26.9 ± 10.9 km (mean ± SD). These distances indicate that survivors were actively swimming to cover such distances and then were identified in suspected migration locations, feeding locations, or both.

Two fish that were captured in the benthic otter trawl had detection patterns that were inconsistent with confirmed surviving fish. Fish 15561 was detected by one receiver station for approximately 20 min at a nearly constant depth of 4.8 m off the coast of Walton, Nova Scotia (Figure 1; Table 1). During the remainder of the study, this fish was not identified anywhere else in Minas Basin or as passing through Minas Passage. Fish 15543 was identified by 11 receiver stations in the Kingsport receiver array over the course of 3 d. The maximum distance between detections was 927 m, and the depth profile varied closely with tidal patterns, suggesting that the tag was laying stationary on the benthic substrate. Based on these detection patterns, we cannot conclude that fish 15561 and 15543 were swimming into different locations typical of Atlantic Sturgeon.

Physiological Condition

Blood samples that were collected with handling times greater than 8.3 min (500 s) were excluded from comparisons

TABLE 2. Mean (±SD; with N in parentheses) FL, handling time, lactate, glucose, and cortisol for Atlantic Sturgeon that were captured by intertidal brush weir or 50–60-min trawls in Minas Basin during summer 2011. Fork length, lactate, glucose, and cortisol means were calculated from samples collected with less than 8.33 min (500 s) of handling time (modified handling time). Significant differences in means between capture methods using t-test with Welch correction for parametric comparisons, or Mann–Whitney U-test for nonparametric comparisons indicated with double asterisks (**$P < 0.05$).

Capture method	FL (cm)	Unmodified handling time (min)	Modified handling time (min)	Lactate (mmol/L)	Glucose (mmol/L)	Cortisol (ng/mL)
Weir	112 ± 27 (16)	3.52 ± 2.62** (17)	3.12 ± 2.10** (16)	1.0 ± 0.4** (16)	3.1 ± 0.8 (15)	5.765 ± 2.729 (9)
Trawl	124 ± 15 (21)	12.29 ± 10.00** (44)	4.48 ± 2.10** (21)	3.2 ± 1.0** (21)	3.3 ± 0.4 (21)	5.578 ± 4.784 (21)

between capture methods; this was done to remove the confounding bias of handling time in trawl samples (henceforth, the data set with greater handling times excluded is referred to as "modified handling time"). This reduced the weir and trawl sample sizes to 16 and 21 fish, respectively (Table 2). Water temperatures from June 1 to October 6, 2011, ranged from 10.7°C to 22.1°C at the capture sites. The temperature averaged 16.4 ± 1.9°C (mean ± SD). Shapiro–Wilk tests revealed that handling time and lactate data for weir captures were non-normally distributed ($W = 0.85$ and 0.56, respectively; $P < 0.05$). Cortisol data for trawl captures were also non-normally distributed ($W = 0.84$, $P < 0.05$).

Significant differences in mean modified handling time between capture methods were detected using the t-test with the Welch correction ($t = 2.10$, df = 30.11, $P = 0.044$). There was no significant difference in FL between capture methods ($t = 0.82$, df = 19.4, $P = 0.42$). Whole-blood glucose was not significantly different between trawl- and weir-captured fish ($t = 0.59$, df = 19.98, $P = 0.56$; Figure 2). The Mann–Whitney U-test indicated that whole-blood lactate was significantly elevated after trawl capture relative to weir capture ($W = 809.5$, $P < 0.001$; Figure 2), but plasma cortisol was not significantly different between trawl- and weir-captured fish ($W = 112.5$, $P = 0.43$).

Effect of Handling Time on Physiological Stress

Unmodified handling time was used to evaluate the effect of handling time on physiological measures of stress. Unmodified handling time had a significant positive correlation with blood glucose and lactate in trawl-captured fish (glucose: $F = 8.68$, df = 1, 42, $P = 0.005$, $R^2 = 0.17$; lactate: $F = 35.32$, df = 1, 41, $P < 0.001$, $R^2 = 0.46$; Figure 3). Unmodified handling time was not significantly correlated with plasma cortisol in either capture treatment, and it was not a significant predictor of glucose or lactate in weir-captured fish (glucose: $F = 0.33$, $P = 0.58$; lactate: $F = 4.00$, $P = 0.06$).

DISCUSSION

There was a high minimum survival rate (94%) for Atlantic Sturgeon that were captured by the otter trawl. Confirmed survivors spent, on average, 56 d in Minas Basin and were tracked for 27% of the days spent in the basin. Five fish (14%) were detected for one to three consecutive days before leaving Minas

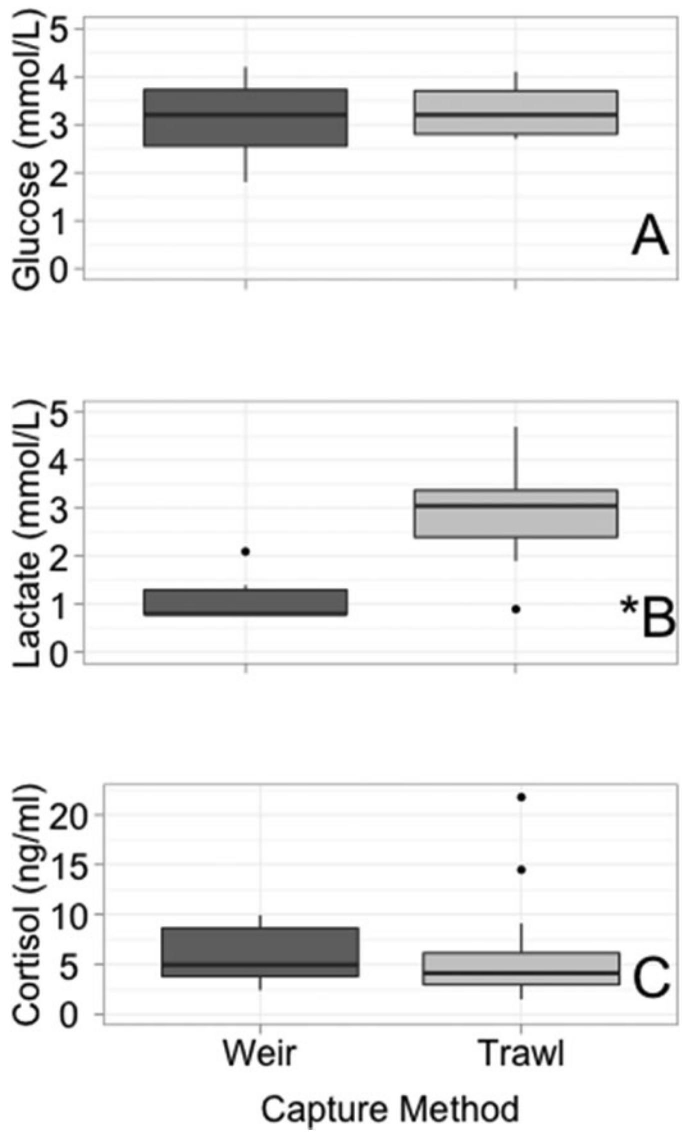

FIGURE 2. Box plots showing **(A)** blood glucose, **(B)** blood lactate, and **(C)** plasma cortisol for Atlantic Sturgeon that were captured by intertidal brush weir or 50–60-min trawls in Minas Basin, Nova Scotia. Blood lactate was significantly higher in trawl-captured fish (Shapiro–Wilk $W = 809.5$, *$P < 0.001$). Boxes contain data from the first to third quartiles; the horizontal bar within each box represents the median; and whiskers indicate 1.5 times the interquartile range. Outliers are displayed as black shaded circles.

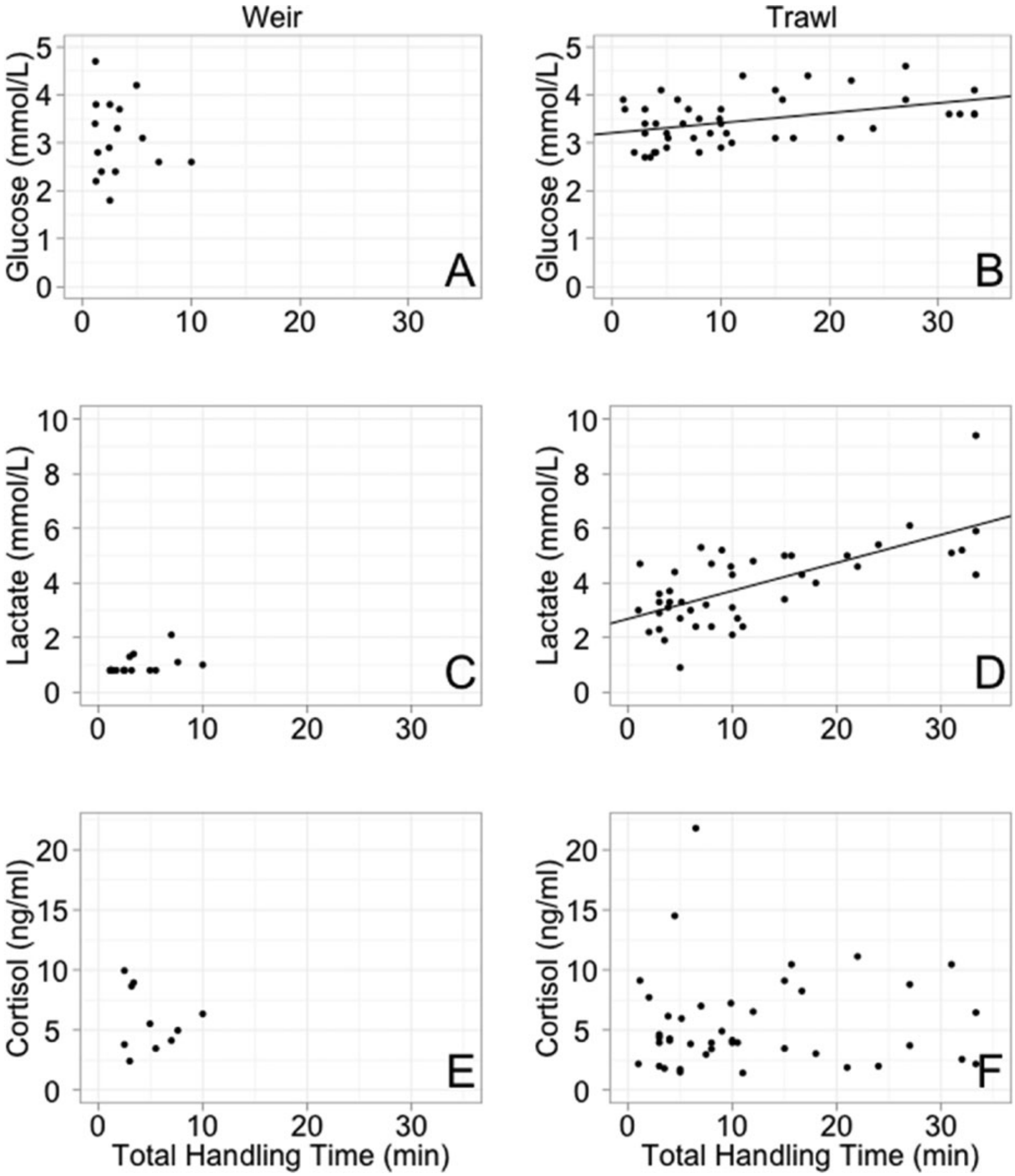

FIGURE 3. Scatter plots of blood glucose (mmol/L), lactate (mmol/L), and cortisol (ng/mL) in relation to total handling time (min) for Atlantic Sturgeon that were captured by **(A)**, **(C)**, **(E)** intertidal brush weir or **(B)**, **(D)**, **(F)** 50–60-min otter trawls in Minas Basin, Nova Scotia. Linear regression lines are shown for significant linear relationships between glucose ($y = 3.21 + 0.021x$, $R^2 = 0.17$, $P < 0.05$) or lactate ($y = 2.68 + 0.103x$, $R^2 = 0.46$, $P < 0.05$) and total handling time of trawl-captured fish.

Passage for the remainder of the year, but they were still considered survivors of the trawl bycatch event. Fifty-three acoustic receiver stations passively monitored tagged fish at eight locations in Minas Basin. Tagged survivors were identified at several locations or were detected at one location with relatively long distances between receiver station detections and at depths typical of confirmed survivors (i.e., fish that were identified at more than one location). These characteristics allowed us to conclude that tagged survivors were actively swimming through receiver station coverage rather than passively drifting via tidal currents.

The fate of two Atlantic Sturgeon that were captured by benthic otter trawl was considered uncertain because they were only detected in one location over a short period of time, with relatively small distances between detections and relatively low depth variability in comparison with tagged survivors. It is possible that the two fish did survive the capture–tag–release event, but acoustic transmission failed to identify these particular fish in other locations; the obvious signal-mitigating factors are turbidity, mixing layers, and tidal currents. The surgically implanted acoustic transmitters could have also been rejected and shed by the fish (Jepsen et al. 2002). The worst possible outcome would be that the two fish were mortalities due to stress associated with the capture–tag–release event.

Our biotelemetry results provide a strong argument for high survival rates in Atlantic Sturgeon that were released after intertidal weir or otter trawl bycatch. Pacific Sockeye Salmon *Oncorhynchus nerka* released immediately after beach seine or angling bycatch during their upriver migration maintained a high (>95%) 24-h survival as determined using radio biotelemetry (Donaldson et al. 2011). However, angled Sockeye Salmon held in net-pen recovery for 24-h had ~80% survival, and survival to their natal tributory varied from 3% for angling capture with 24-h net-pen recovery, up to 52% for seine capture with immediate release. Although the species and study system are quite different from those in the present study, the results of Donaldson et al. (2011) provide context for short-term postrelease survival studies. Survival to natal watersheds is confounded with migratory stress in salmon (Wendelaar-Bonga 1997); therefore, 24-h survival rates provide the most relevant context. Long-term postrelease studies in open marine environments are rare and typically require expensive electronic tag technology (Graves et al. 2002; Campana et al. 2009). Stokesbury et al. (2011) used pop-up archival tag technology to estimate postrelease mortality of Atlantic Bluefin Tuna *Thunnus thynnus* in an experimental catch-and-release fishery. Generalized results from that study found that long-term (30-d) postrelease mortality was approximately 5% (95% confidence interval = 1.6–15.6%). The Stokesbury et al. (2011) study provides evidence that pop-up archival tag technology can be used to evaluate postrelease mortality in ocean environments; this technology may be able to provide insight on bycatch discard mortality rates in Atlantic Sturgeon.

Mandelman and Farrington (2007b) reported that the 72-h posttrawl capture mortality rate for Spiny Dogfish was 29%. This mortality rate is relatively high compared with the posttrawl capture mortality rate in Atlantic Sturgeon. In lieu of biotelemetry, Mandelman and Farrington (2007b) used a 72-h holding period in net-pens to assess Spiny Dogfish mortality, and the confinement likely contributed to their high mortality rates; however, this comparison between results of the two studies emphasizes the resiliency of Atlantic Sturgeon to capture and tagging stress. Across many species and fishery types, postrelease mortality less than 10% is typically considered “low” (Muoneke and Childress 1994), although acceptable incidental mortality rates are largely dependent on life history, fishing effort, population size, and other factors.

Our data indicate that 60-min trawl bycatch events have a relatively small impact on postrelease survival of Atlantic Sturgeon. It is also important to note that these are conservative minimum survival rates because the tracked fish also experienced the extra stress of anesthesia and surgery. Boreman (1997) calculated that Atlantic Sturgeon populations can sustain only very low incidental mortality, and our results suggest that bycatch mortality in Minas Basin fisheries is low and close to sustainable levels.

Our experimental trawls were relatively long and were conducted in summer water temperatures—capture conditions that are in contrast to those used in current postrelease mortality estimates for Atlantic Sturgeon (ASSRT 2007). The present study’s conditions are likely closer to southern state commercial shrimp and whelk trawling conditions. Shrimp and whelk trawl fisheries also experience bycatch of Atlantic Sturgeon, but postrelease mortality estimates for those fisheries are uncertain at best. It is likely that the shrimp and whelk trawl fisheries in southern states are using smaller mesh sizes than were used in the present study, thus causing greater entanglement for large fish such as Atlantic Sturgeon. Environmental conditions can vary greatly between Minas Basin and southern state fisheries; thus, our results are only an educated guess for postrelease mortality of Atlantic Sturgeon in other estuarine or marine environments.

Multiple encounters with commercial fishery gears may also pose a risk to Atlantic Sturgeon throughout their range. Commercial trawlers that target flounder in Minas Basin typically try to avoid Atlantic Sturgeon aggregation sites (G. Travis, Minas Basin commercial fisherman, personal communication), but the Atlantic Sturgeon is still the fifth most common bycatch species in Minas Basin. Genetic studies have revealed that the Minas Basin Atlantic Sturgeon aggregation is composed of river stocks from the Gulf of Maine, the Saint John River, and the St. Lawrence River (Wirgin et al. 2012), which suggests that these fish will migrate through other commercial fishing zones where they are susceptible to encounters with larger trawlers and gillnet fisheries. Physiological data from our study do not suggest that 1-h trawl capture poses a risk of long-term physiological disruption (i.e., elevated cortisol levels and possible immune suppression or impaired osmoregulation; Fast et al. 2008), but a longer trawl duration, a greater mass of catch, or capture by gill net may increase the risk of greater physiological disruption (Mandelman and Farrington 2007b; Baker et al. 2008). Physical exhaustion (i.e., high blood lactate) after a 1-h trawl capture suggests that there is postrelease behavior disruption, and repeated bycatch events may compound postrelease behavior disruptions and interfere with migration to spawning or feeding sites.

The connection between disturbances in physiological stress responses and postrelease mortality is still unclear for many capture events (Davis et al. 2005). Exposure of fish to increased water temperatures after capture is usually associated with increased mortality (Davis et al. 2005; Crossin et al. 2008), but physiological variables that respond to increased temperature and are associated with increased mortality differ between studies and are likely dependent on the species and environment

(Davis 2005; Crossin et al. 2008). Effort must be placed into selecting appropriate physiological measures for the risks of specific fishery bycatch, and those physiological data must be associated with postrelease mortality in order for such data to have value for stakeholders in commercial fishery regulation (Davis 2002; Young et al. 2006; Cooke et al. 2013).

The 1-h trawl captures were associated with increased blood lactate concentrations relative to weir captures. This indicates that capture in a 1-h trawl tow is associated with higher levels of anaerobic ATP production, resulting in increased blood lactate. This result was expected due to the forced swimming activity that occurs while the fish attempts to escape the trawl net. High blood lactate has also been identified in other studies investigating the effects of trawl capture on the secondary stress response in Spiny Dogfish. Mandelman and Farrington (2007a) reported moderate increases in blood lactate concentration, and the lowest blood pH values were observed immediately after trawl capture.

Lactic acid production is often associated with low intracellular pH (metabolic acidosis), but in reality there are several metabolic pathways (e.g., aerobic glycolysis, glycogenolysis, etc.) that produce more intracellular protons during exhaustive exercise (Robergs et al. 2004). Studies of exhaustive exercise in several fish species have identified venous CO_2 partial pressure as being associated with the lowest blood pH measurements (Wood et al. 1977; Wilkes et al. 1981; Wood 1991; Mandelman and Farrington 2007a). Although lactate production may not be the only causative factor in metabolic acidosis, studies have found that high lactate measurements are associated with low blood pH measurements in many species, including sturgeon (Wood et al. 1977; Turner et al. 1983; Nonnotte et al. 1993). Correlation between lactate and blood pH and the fact that there are field-ready tools for measuring blood lactate are good reasons to utilize lactate as an indicator of metabolic acidosis during bycatch events. However, identifying the causative factors associated with acidosis in commercial bycatch events will inform fisheries on how to mitigate bycatch stress and potential physiological and behavioral consequences (Wood et al. 1983).

Lactate measurements in weir-captured fish were commonly below the detection limit of the field meter (0.8 mmol/L). This result indicates that Atlantic Sturgeon are not engaging in excessive burst swimming behavior during the weir capture event. Low lactate measurements also indicate that oxygen supply was adequate in the weir tidal pools early in the weir capture event. Oxygen supply might become inadequate for Atlantic Sturgeon if the weir pool is particularly warm, if the fish remain in the weir pool for an extended period of time, if there is a high oxygen demand from a large biomass of fish in the weir pool, or a combination of these factors. It is also important to note that our weir blood samples were collected from fish that were completely submerged in tidal pools; higher blood lactate measurements would be expected for fish captured in relatively shallow tidal pools.

Sturgeon species tend to have reduced disturbances in physiological stress responses relative to other teleost species (Barton et al. 2000). Resting cortisol measures are typically around 1–5 ng/mL for various sturgeon species (Barton et al. 2000; Lankford et al. 2003; Baker et al. 2005, 2008). Plasma cortisol in sturgeon shows small to moderate increases after confinement, emersion (air exposure), capture, and handling stressors. Barton et al. (2000) found no physiological responses to acute handling procedures as indicated by cortisol levels in *Scaphirhynchus* spp. sturgeons, but they did find that 1–4 h of confinement resulted in a four- to sevenfold increase (~8–14 ng/mL) in plasma cortisol. Lankford et al. (2003) reported that brief emersion resulted in a relatively large cortisol response (19 ng/mL) in young-of-the-year Green Sturgeon *Acipenser medirostris*, and Baker et al. (2005) found that a 1-h exposure to 30-mm HgO_2 levels resulted in increased cortisol levels (21 ng/mL) in Atlantic Sturgeon and Shortnose Sturgeon *Acipenser brevirostrum*. These results demonstrate that severe stressors can cause increased plasma cortisol in sturgeon species. Minor stressors that may produce large cortisol responses in most teleost fish do not produce large cortisol responses in sturgeon species, except perhaps in young individuals.

Baker et al. (2008) reported that Lake Sturgeon *Acipenser fulvescens* that were captured using 24-h gill-net soaks (22.86-cm [9-in] stretched mesh size) responded with a 25-fold increase (50 ng/mL) in blood cortisol relative to resting levels. Results from the present study suggest that capture by weir or 50–60-min benthic trawls does not produce significant disruptions in plasma cortisol relative to other capture methods, such as 24-h gill-net soaks. A 50–60-min trawl capture event might not be a sufficient stressor to evoke a moderate cortisol response in subadult or adult Atlantic Sturgeon; more likely, measureable cortisol responses to capture events occur after a period greater than 1 h. Holding studies after a 50–60-min trawl capture are needed to clarify cortisol response dynamics after trawl bycatch. It is important to note that cortisol measures in our study were considerably variable but were consistent with values that are typically reported as resting or minimally stressed levels in sturgeon.

Handling time was a significant predictor of blood lactate and glucose concentrations in trawl-captured Atlantic Sturgeon. Longer handling times were associated with increased lactate and glucose concentrations, indicating that handling time is a significant stressor in addition to the 1-h trawl capture. Experimental trawl tows were 50–60 min in duration; thus, it is likely that some fish experienced relatively long trawl interactions, whereas other fish were caught several minutes before the net was hauled in. The increase in lactate with handling time suggests that air exposure and restraint may have a greater effect on lactate buildup than the interaction with the trawling net itself. This result was expected because air exposure is known to increase lactate production and to lower blood pH levels achieved through exhaustive exercise alone (Ferguson and Tufts 1992). The moderate correlation between blood glucose and handling time also suggests a stronger glucogenic response to the combined stress of capture and handling.

Interestingly, handling time was not a significant predictor of physiological stress after weir capture. This result could be attributable to the low-stress nature of weir capture events, and thus the Atlantic Sturgeon possessed physiological adaptations to cope with subsequent 8-min handling events without major deviations in metabolic and primary stress responses. This result might also be related to shorter handling times for weir-captured fish. Larger catch sizes in trawl gear create an inherent difficulty in obtaining blood samples from trawl-captured fish relative to weir-captured fish. Because of this, it was difficult to minimize handling times for trawl-captured fish; thus, the fish that were sampled with this gear typically had longer handling times. If handling times for weir-captured fish had been longer, there likely would have been a moderate correlation between handling time and physiological variables.

Although handling is highly likely to be a significant stressor, there is latency in the physiological indicators measured in this study. Cooke et al. (2008b) demonstrated a 10–30-min latency period for blood glucose and lactate to reach maximum levels in Bahamian Bonefish *Albula vulpes* after capture. Longer periods of handling provide the time necessary for physiological indicators to respond to the capture event but not necessarily to the handling stress. Physiological data presented in this study provide a relative index of capture stress at the time of capture regardless of response latency. It is presumed that after the fish are released, physiological factors will soon peak and then begin to normalize (Cooke et al. 2013). The time required for physiological condition to normalize after capture (i.e., recovery time) can vary from as little as approximately 2 h to greater than 24 h depending on the physiological factor and the species examined (Danylchuk et al. 2007; Cooke et al. 2008b). The duration of this recovery time has implications for the physiological and behavioral fitness of the recovering fish (Hoolihan et al. 2011).

Short-term behavioral deficits have been demonstrated in several species exposed to different types of capture techniques. Fish that are angled to exhaustion and exposed to air for short periods sometimes display short-term impaired behaviors such that predator avoidance or typical parental behaviors are not readily engaged (Danylchuk 2007; Hanson et al. 2007). Northern Rock Sole *Lepidopsetta polyxystra*, Atlantic Halibut *Hippoglossus hippoglossus*, Walleye Pollock *Theragra chalcogramma*, and Sablefish *Anoplopoma fimbria* also exhibited reduced startle behaviors and reduced sensitivity to mechanical stimuli after simulated trawling (Davis and Ottmar 2006). Capture by many gear types has similar physiological effects across species, but the most common effect is increased lactate concentration. During recovery from physical exhaustion, a surplus of oxygen must be delivered to tissues so that the fish can cope with the reduction demand of lactate ions. This leads to a deficit in oxygen available for normal behavior, thus inhibiting movements such as startle reactions and antipredation behaviors. Physical exhaustion is a key determinant in postrelease behavior; therefore, it is possible that the behavioral impairments seen in other species could also be present in Atlantic Sturgeon after trawl capture.

These results collectively indicate that postrelease mortality associated with 1-h trawl capture is minimal for Atlantic Sturgeon but that this capture event is also a moderate stressor. Prompt handling of Atlantic Sturgeon trawl bycatch should be a priority in trawl fisheries because significant correlations exist between relatively long handling times (i.e., >10 min on deck) and increased blood lactate. Minimization of physical exhaustion (as indicated by lactate production) may help to mitigate potential postrelease mortality and the behavioral impairments that arise as a result of metabolic or respiratory acidosis. Other fisheries that use different trawling gear, that trawl for longer than 60 min, or that leave fish on deck for longer than 10 min may risk higher rates of postrelease mortality. Larger catch sizes may also increase stress and mortality, so fisheries with a bycatch of large, heavy individuals (i.e., Atlantic Sturgeon or other fish) may also influence postrelease mortality rates in Atlantic Sturgeon (Mandelman and Farrington 2007b). In addition, there are very few predators of Atlantic Sturgeon in Minas Basin; therefore, the risk of predation mortality during their recovery is low. However, Atlantic Sturgeon that are captured as bycatch in other fisheries may be released in areas with an abundance of potential predators, and postrelease predation may influence mortality related to bycatch events in those situations.

Future studies of postrelease survival in Atlantic Sturgeon should investigate postrelease behaviors. Increased lactate concentrations after capture suggest that physical activity may be contributing to postrelease impairments, but there are no data to indicate the length of time required for Atlantic Sturgeon to recover from exhaustion. Such information may be valuable if Atlantic Sturgeon are released into environments where predators are a threat or in situations where the ecological timing of behaviors (e.g., spawning runs) is important. Measurement of blood pH and venous CO_2 partial pressure in addition to blood lactate will also help in identifying the extent to which respiratory and metabolic acidosis is contributing to lowered blood pH.

ACKNOWLEDGMENTS

We thank Jeremy Broome, Offshore Energy Research Association of Nova Scotia, and the Fundy Ocean Research Centre for Energy for funding, design, organization, deployment, and collection of metadata concerning the Acadia Line receiver array in Minas Passage. We are grateful to Tony Lewis for allowing us to sample Atlantic Sturgeon captured in his weir and to Glanville and Charles Travis for allowing us to sample from their otter trawl gear. In addition, we appreciate the field support provided by William Roberts, Tom Gregoire, Sierra Wehrell, and many others. Financial and in-kind support was provided by the Natural Sciences and Engineering Research Council through OTN Canada. M. J. W. Stokesbury and S. J. Cooke were supported by the Canada Research Chairs Program.

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