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Potential for use of accelerometers to monitor green sturgeon *Acipenser medirostris* (Ayres, 1854) behavior after handling

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Summary

A pilot study was conducted to test the use of accelerometer tags (coded acoustic transmitters equipped with inertial sensors) to detect changes in green sturgeon activity following gillnet capture and release. Green sturgeon *Acipenser medirostris* (Ayres, 1854) is listed as threatened under the Endangered Species Act, but is captured as bycatch in both estuarine and coastal gillnet and trawl fisheries. Measured were tail-beat activity and swimming depth of sturgeon (145-167 cm fork length) caught with gillnets in Willapa Bay, Washington during late July 2011. These data were transmitted acoustically over a period of up to 55 d to an array of 16 receivers positioned in the bay. Transmitters were either surgically implanted (n = 2) or attached externally to the dorsal scutes (n = 2). In spite of the small number of fish tagged, over 4,800 data transmissions were obtained, with three fish detected over more than 46 d and in estuaries up to 55 km from the release site. Breakpoint regression analysis indicated that the accelerometers could be used to document discrete changes in activity of the fish after handling. Use of this technology could therefore allow the identification of fishing methods that are most harmful to protected species.

1 | INTRODUCTION

As is the case for many sturgeon species, green sturgeon (*Acipenser medirostris*) is of conservation concern. Two genetically-distinct metapopulations exist along the west coast of North America: the Southern distinct population segment (DPS) spawns in the Sacramento River, California and the northern DPS spawns in the Rogue and Klamath rivers of Oregon and northern California (Moser et al., 2017). The southern DPS is considered threatened, and the northern DPS a species of concern, under the U.S. Endangered Species Act (ESA) (Adams, Grimes, Hightower, Lindley, & Moser, 2007). Recent estimates indicate that the number of spawning adults in the Sacramento River ranges from 336 to 1236 individuals annually and that a similar number or fewer occur in each of the Klamath and Rogue river systems (Moser et al., 2017). The small population size and limited spawning area make green sturgeon susceptible to catastrophic losses, in addition to effects of natural mortality (Adams et al., 2007; Lindley et al., 2008).

Green sturgeon is amongst the most marine-oriented of all sturgeon species, making the species susceptible to a gamut of fisheries. In the first year of life, green sturgeon can enter estuarine waters, and as sub-adults this sturgeon makes extensive coastal migrations, typically in nearshore habitats less than 100 m depth (Lindley et al., 2011; Moser et al., 2017). This behavior results in exposure to capture in both marine trawl and estuarine gillnet fisheries. Green sturgeon are regularly intercepted in the trawl fishery for California halibut (*Paralichthys californicus*), but occur less often in other trawl fisheries prosecuted off the coast of Oregon and Washington (Moser et al., 2017). Green sturgeon also occurs regularly in tribal and commercial gillnet fisheries for salmon in the Klamath River, Columbia River, Willapa Bay, and Grays Harbor estuaries. With protection from the ESA, green sturgeon by catch is now legally retained only in tribal subsistence fisheries in U.S. waters (Moser et al., 2017).

Unfortunately there is little information regarding either direct or indirect effects of gillnet capture on green sturgeon. A study of gear effects on white sturgeon indicated that 4.8% caught in drift gillnets and 6.2% caught in set gillnets were dead at the time of net retrieval (Robichaud, English, Bocking, & Nelson, 2006). In that study, fish captured using the two gear types were held in surface net pens for three

days after capture to assess post-release mortality, which was 0% for drift gillnets and 46.9% in set gillnets. Measurements of plasma cortisol in white sturgeon also indicated that stress effects from capture vary with fish size and gear type (unpublished data, J. North, Oregon Department of Fish and Wildlife). For example, fish caught in overnight gillnet sets exhibited higher stress responses than those caught in trawls or gillnet sets of shorter (1.4 h) duration.

We conducted a pilot study to test how well acoustic transmitters equipped with inertial sensors (accelerometer tags) can document changes in green sturgeon activity following gillnet capture and release. Accelerometer tag data correlated well with tailbeat frequency, tail beat amplitude, and overall dynamic body acceleration in lake sturgeon (*A. fulvescens*) held in a large flume (Thiem et al., 2015). These tags have also been used to document activity patterns in large elasmobranchs and sturgeon in the wild (Lowe, Holland, & Wolcott, 1998; Semmens, Payne, Huveneers, Sims, & Bruce, 2013; Watanabe, Lydersen, Fisk, & Kovacs, 2012; Watanabe, Wei, Du, Li, & Miyazaki, 2013; Watanabe et al., 2008). Moreover, accelerometer data have been used to quantify capture and release effects in other fish species (Broell, Taylor, Litvak, Bezanson, & Taggart, 2016; Brownscombe et al., 2013). Accelerometers can provide movement information at both low (mortality) and high (specific spawning or feeding movements) resolution (Payne et al., 2011). However, it is key to establish the correct interval of accelerometer readings, tag position on the fish body, type of accelerometer used, and to control for the regularity of detections (i.e., number and proximity of acoustic receivers).

2 | MATERIALS AND METHODS

2.1 | Fish capture and tagging

Previous telemetry studies have documented the seasonal presence of green sturgeon in numerous estuaries along the Washington and Oregon coasts (Lindley et al., 2008). In Willapa Bay, Washington, green sturgeon range throughout the bay in May through October (Moser & Lindley, 2007), but there is a distinct aggregation area in the southern arm of the bay near Nahcotta, Washington. This is where we focused our efforts. Recent genetic analyses have indicated that the majority of green sturgeon captured in this area are from the southern DPS (Schreier, Langness, Israel, & Van Dyke, 2016).

For fish collection, a commercial fisherman deployed a sinking gillnet (6-8 strand monofilament) that had three joined panels of different mesh size (18.4, 21.5, and 24.8 cm). Each panel was 91.4 × 9 m and the entire net was set perpendicular to the current at flooding or slack tide in a 9-16 m deep area where green sturgeon are known to congregate. Soak times (time that the net was fully deployed) were < 20 min, and retrieval times varied depending on how many fish were caught. The net was retrieved on a hydraulic reel, sturgeon were removed and placed in a floating live car alongside the vessel both before and after tagging. The live car was 1.8 × 0.9 × 0.9 m, with both the floating (sealed) and bottom (perforated) frames made of 10 cm PVC pipe. Netting that covered the sides and the bottom was made of 4-mm braided single Olivene (HDPE) twine, knotted to form a stretch mesh size of 12.7 cm. A lead line was also used to assure full vertical extension of the net pen in the water column.

Due to the high cost of accelerometer tags, only four fish were tagged in this pilot study, two with surgical implants and two with externally attached tags. For surgical tagging, fish were positioned ventral side up on a measuring board, fin clipped for a genetic sample, and measured. Throughout the procedure, the head was covered with wet burlap to keep the fish calm and the gills were irrigated with ambient seawater. A 2-cm long incision was made just off the ventral midline and in line with the 6th ventral scute (approximately 20 cm anterior to the anus). A disinfected and rinsed transmitter was inserted into the body cavity and gently pushed posterior to the incision to prevent it from rubbing on the incision area. The incision was closed with two or three simple interrupted sutures (2-0 synthetic absorbable suture with a CP-1 cutting needle). Total fish handling time did not exceed 15 min. After tagging, fish were placed in the live car for transmitter calibration(< 80 min).

For external tagging, fish were positioned dorsal side up on a measuring board, fin clipped, and measured. Again, the head was covered with wet burlap to keep the fish calm and gills were irrigated with ambient seawater throughout the procedure. A 1-mm hole was drilled through the base of both the 8th and 9th dorsal scutes with a cordless drill, and a disinfected fluorocarbon fishing line was threaded through each hole and attached to a loop that was epoxied on each end of the transmitter. This attachment method was designed so that the transmitter would eventually wear through the scute and fall off after the study. Total fish handling time was less than 10 min. Each fish was placed in a live car alongside the vessel for transmitter calibration(< 80 min) before it was released at the site of capture.

Transmitters used in this study (Vemco Model V9AP) were cylindrical (9 × 43 mm) and weighed 6.1-g (tag burden was <0.05% body weight for the fish tagged). They were programmed to alternate between two coded signals: a depth record and an accelerometer record. Transmitters had a pressure transducer and emitted a coded high power 4-4.5 s burst at 69 kHz that contained the fish code and depth reading. For the following 20 s, acceleration measurements (ACC, m/s^2) were taken at 10 Hz/s in the x and z dimensions only, as transmitters were programmed to identify fish tailbeat as opposed to forward movement. This transmission was followed by a randomly selected 20-70 s period before the next 4-4.5 s burst that contained the fish code and mean ACC. Transmitters were programmed in this way to reduce transmission collisions and extend transmitter battery life as long as possible without losing fish activity information (transmitter life was rated at 55 d).

Each transmitter was calibrated on land by swinging it through a 30-cm arc at a rate of 1 and 2 beats/s to simulate adult sturgeon axial movements during continuous slow and fast swimming, respectively (Long, 1995). When each tag was moved at an approx. rate of 1 Hz, we obtained mean ACC values ranging 1.35-3.95 m/s^2. When the rate was increased to 2 Hz, the maximum accelerometer readings for each tag were exceeded (4.90 m/s^2). Transmitters were also calibrated for at least 10 min after attachment to the fish by recording ACC and depth transmissions while fish were videotaped

swimming alongside the vessel in the live car. An acoustic receiver (Vemco VR2W) was positioned near the live car to log transmissions. Time stamps from the receiver were synchronized with video camera time stamps.

2.2 | Tracking

Following transmitter calibration, each green sturgeon was released at the capture site, and transmitters were detected via a network of fixed site receivers (Vemco VR2W). Twelve fixed receivers were positioned throughout Willapa Bay during the entire period of transmitter life (55 d). Also active throughout the study period were receiver arrays outside of Willapa Bay at Grays Harbor and the Columbia River estuary, and arrays at other sites operated by salmonid researchers. Inside Willapa Bay, four temporary receivers were added to the array near the tagging site to insure that accelerometers would be detected if fish did not move far from the release location. These four receivers were only deployed during the first two days after sturgeon release. Range testing indicated that all of the receivers could typically detect the high power accelerometer tags at a range of at least 450 m.

2.3 | Data analysis

Raw detection data were downloaded from the receivers and appended into a single time series of detections for each fish (both depth and acceleration sensor data). The calibration period in the live car was identified from video time stamps and analyzed separately from the period after release. For the calibration period, video time stamps were used to match approximate vessel ground speed with accelerometer and depth data transmissions.

For both the complete time series and the subset of detections after release from the live car, we used a segmented regression analysis to evaluate the data. This method was chosen with the expectation that if there were a tagging effect on movement, it would be detectable as a shift in the mean accelerometer value at some point after tagging. For example, if sturgeon quickly flees the area, a period of high accelerometer readings would be followed by a period of relatively lower readings as the fish returns to normal swimming behavior.

The regression models we used were intercept-only models, effectively calculating the mean accelerometer value before and after a 'break point':

$$y = I_1\,(t < b) + I_2(t > b)$$

where I_1 and I_2 are the values of the intercept (mean response) for data prior to the break point (t < b, during which $I_2 = 0$) and after the break point (t > b, during which $I_1 = 0$). To optimize the location of the break point (b), we sequentially ran models with a break point between each pair of consecutive data points and used Akaike's information criterion (corrected for small sample size, AICc) to select among break points. The best model (the one with the lowest AICc) provided location of the optimal break point, as well as mean accelerometer value before (I_1) and after (I_2) the break point. All analyses were run in the R programming language (R Core Team, 2014).

3 | RESULTS

On 25 July 2011, one surgically implanted fish (#6164: 167 cm FL) and one externally tagged fish (#6170: 145 cm FL) were released (Table 1). These fish were captured in the same net set and the actual soak time was 19 min during a flood tide. Net retrieval was started at 13:22, and #6164 and #6170 were caught in the 18.4 cm and 24.8 cm mesh sizes, respectively. For #6164, tagging time was 8 min, and time in the live car was 80 min (total processing time 88 min). Handling time for #6170 was 5 min and it was in the live car for 78 min (total processing time 83 min).

On 26 July 2011 one externally tagged fish (#6168: 155 cm FL) and one surgically implanted fish (#6166: 161 cm FL) were released. The soak time for #6168 was 12 min during the flood tide and it was caught in the 21.6 cm mesh. Net retrieval was started at 10:10 and the fish was caught and tagged in 4 min and released after 16 min (total processing time 20 min). Soak time for #6166 was 4 min during slack high water and it was captured in the 18.4 cm mesh. Net retrieval was started at 12:25 and tagging required 10 min. This fish was released after 15 min in the live car (total processing time 25 min).

When we observed tagged fish in the live car, they did not exhibit continuous tailbeats. Instead, they were able to maintain position with only a single tailbeat every 1-11 s (0.09-1.0 Hz) and had mean ACC values ranging 0.95-2.14 m/s^2. This was because they were able to rest in low velocity areas created by the net pen. Calibration also confirmed that tags were primarily recording tailbeat activity (i.e., the y dimension was not being measured). For example, for fish #6166, mean ACC was 1.54 m/s^2 when the vessel was moving forward at 1.7 km/h, but it was 1.36 m/s^2 when the vessel was moving at 3.2 km/h. This was due to the fact that the net pen collapsed vertically at the higher speed, giving the sturgeon more low velocity areas in which to rest. Nevertheless, all fish exhibited higher mean ACC in the live car than

TABLE 1 Green sturgeon size (cm fork length, FL), tagging location, total processing time (time from start of tagging to fish release) and mean of acceleration (ACC, m/s^2) records during live car observations and after release. Standard deviations of ACC in parentheses

Fish	FL	Tag	Handling time (min)	Mean ACC in live car	*n*	Mean ACC after release	*n*
6164	167	Internal	88	0.95 (0.96)	37	0.45 (0.31)	1064
6166	161	Internal	25	1.37 (0.41)	4	0.62 (0.38)	127
6168	155	External	20	0.75 (0.38)	26	0.59 (0.15)	1046
6170	145	External	83	2.14 (1.51)	9	0.41 (0.14)	116

TABLE 2 Results from break point regression for the accelerometer (ACC) detection data both with live car detections (i.e., time of break point in hours after release into the live car) and without detections made in the live car (i.e., time of break point in hours after fish were released from the live car). Mean ACC values (m/s^2) given for the period before and after the break point for each dataset and each fish

	With live car data			Without live car data		
Fish	Break point (h)	ACC before	ACC after	Break point (h)	ACC before	ACC after
6164	1.43	1.00	0.44	1.43	1.28	0.44
6166	3.98	1.78	0.58	3.98	2.33	0.58
6168	15.41	0.74	0.59	91.2	0.50	0.60
6170	0.35	2.14	0.41	0.52	1.02	0.40

during the time they were detected after release (Table 1). Calibration also confirmed that the depth data were accurate to within 0.1 m at the surface. Transmitter specifications indicated that at depths in the estuary (typically less than 20 m), we could expect accuracy to at least ± 1.0 m (Vemco.com).

All tagged fish moved among the permanent receiver sites and three were detected for >46 d. Fish #6164 (a male from the southern DPS based on genetic analysis) moved among receiver sites in Willapa Bay until 24 August. He then left Willapa Bay and moved north to Grays Harbor, Washington for 3 d. He returned to Willapa Bay on 1 September and was detected there until 17 September, when the tag battery life expired. Throughout this period, the fish exhibited regular ACC measurements over a variety of depths (1-25 m). The sex and DPS of the other three fish were unknown. Fish #6166 also made excursions outside of Willapa Bay to the Columbia River estuary, Washington (2-17 August) and Grays Harbor where it was last detected on 11 September. Fish #6168 was detected almost daily in Willapa Bay throughout the study period and was last detected there on 12 September. We obtained the least amount of data from #6170, which was detected only on the first two days after release. However, during this period it moved between four permanent receivers and ranged in depth from 4.4-15.4 m.

Break point regression analysis indicated that the mean ACC values were higher before the break point than afterward for all fish when live car data were included in the analysis (Table 2). When live car detections were removed, this was still the case except for fish #6168. In addition, break point values were similar between datasets and all break points occurred within the first 4 h after fish were released either into the live car or into the bay for all fish except #6168 (Table 2, Figure 1). The two fish held for >80 min in the live car (#6164 and #6170) also had the shortest time to break point (Table 2). For fish #6168, there was not a single distinct minimum AIC value (Figure 2). Mean ACC values for this fish were also similar before and after the break points identified for both time series with and without live car observations (Table 2).

4 | DISCUSSION

Transmitters with accelerometers show promise for elucidating sturgeon activity patterns following handling. While a larger sample size of fish is obviously needed, our break point regression indicated that clear changes in activity were detectable in three of the four acceleration time series we obtained. We opted for non-continuous accelerometer readings to extend the battery life of the transmitters to 55 d and we obtained a long time series of activity observations (46-54 d) for all but one individual (#6170). Three tags provided acceleration measurements throughout their projected battery lives, and two were detected in estuaries outside of Willapa Bay. Traditional telemetry (acoustic pingers) has been used to assess handling effects on lake (Hondorp, Holbrook, & Krueger, 2015) and Atlantic (Balazik, 2015) sturgeon. Our data indicated that the addition of activity sensors provides a more detailed account of fish behavior and could be used to document subtle changes in behavior following capture and handling (Broell et al., 2016; Watanabe et al., 2013).

Both external and internal attachment of the accelerometer tags provided similar activity information. The short time series of data from #6170 might be the result of the fish rubbing the tag off, as has been observed in shortnose (*A. brevirostrum*) and Atlantic (*A. oxyrinchus*) sturgeons (Collins et al., 2002; Smith, Lamprecht, & Hall, 1990). Lowe et al. (1998) found that juvenile scalloped hammerhead sharks (*Sphyrna lewini*) swimming in the laboratory were affected by an external transmitter attachment, but that this was not a problem for fish released into the wild. While a larger sample size is needed, it appears that surgical implantation of the accelerometers did not affect fish behavior or accelerometer operation (Figure 1).

Sturgeon in our study experienced relatively benign levels of handling compared to some catch and release fisheries. Information is needed on the recovery times for fish that experience longer times on deck (in air) or extended soak times. Also needed is a more thorough analysis of the value of holding fish in a live car for recovery. Sturgeon mortalities have been reported in both gillnet and trawl fisheries (Collins, Rogers, & Smith, 1996; Collins, Rogers, Smith, & Moser, 2000). In addition, green sturgeon may not be able to habituate to chronic stress (such as repeated recaptures), and this type of stress has been shown to reduce metabolic scope for activity and may have direct consequences for fitness (Lankford, Adams, Miller, & Cech, 2005). Determining what type of handling results in elevated stress should be a research priority for imperiled sturgeon species.

Accelerometers such as those used in our study could provide insights into the relative effects various fishery practices have on

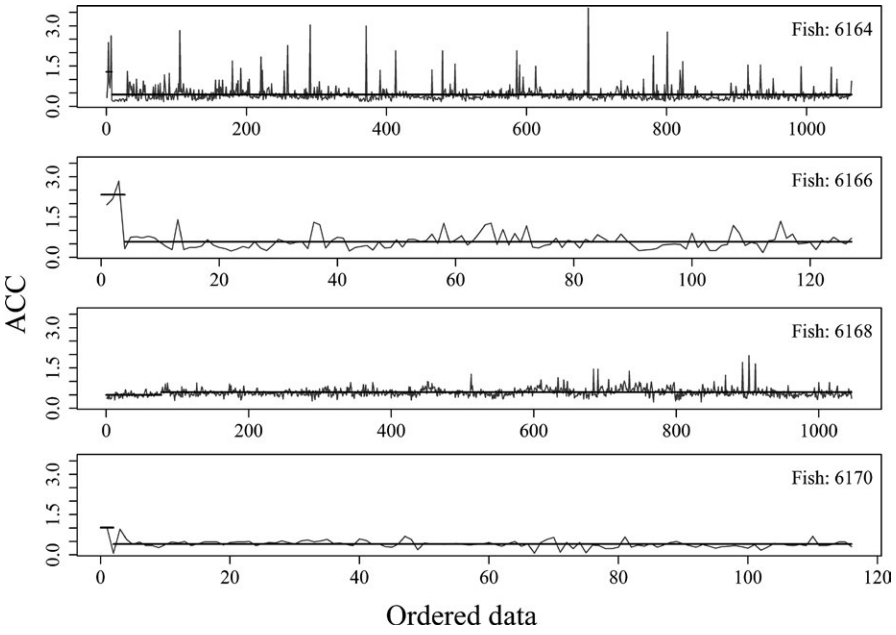

FIGURE 1 Time series of accelerometer measurements (ACC, m/s^2) for each green sturgeon, *Acipenser medirostris*, (black line) and mean values before and after the break point (blue line) given in chronological order (i.e., ordered data). Data were not collected continuously, nor from the same site and do not include data collected while fish were in the live car. Top panels = fish with internal tag placement (6164 and 6166); bottom two panels = fish with externally-mounted tags (6168 and 6170). Panels are from largest fish (6164) at the top to the smallest fish (6170) at the bottom

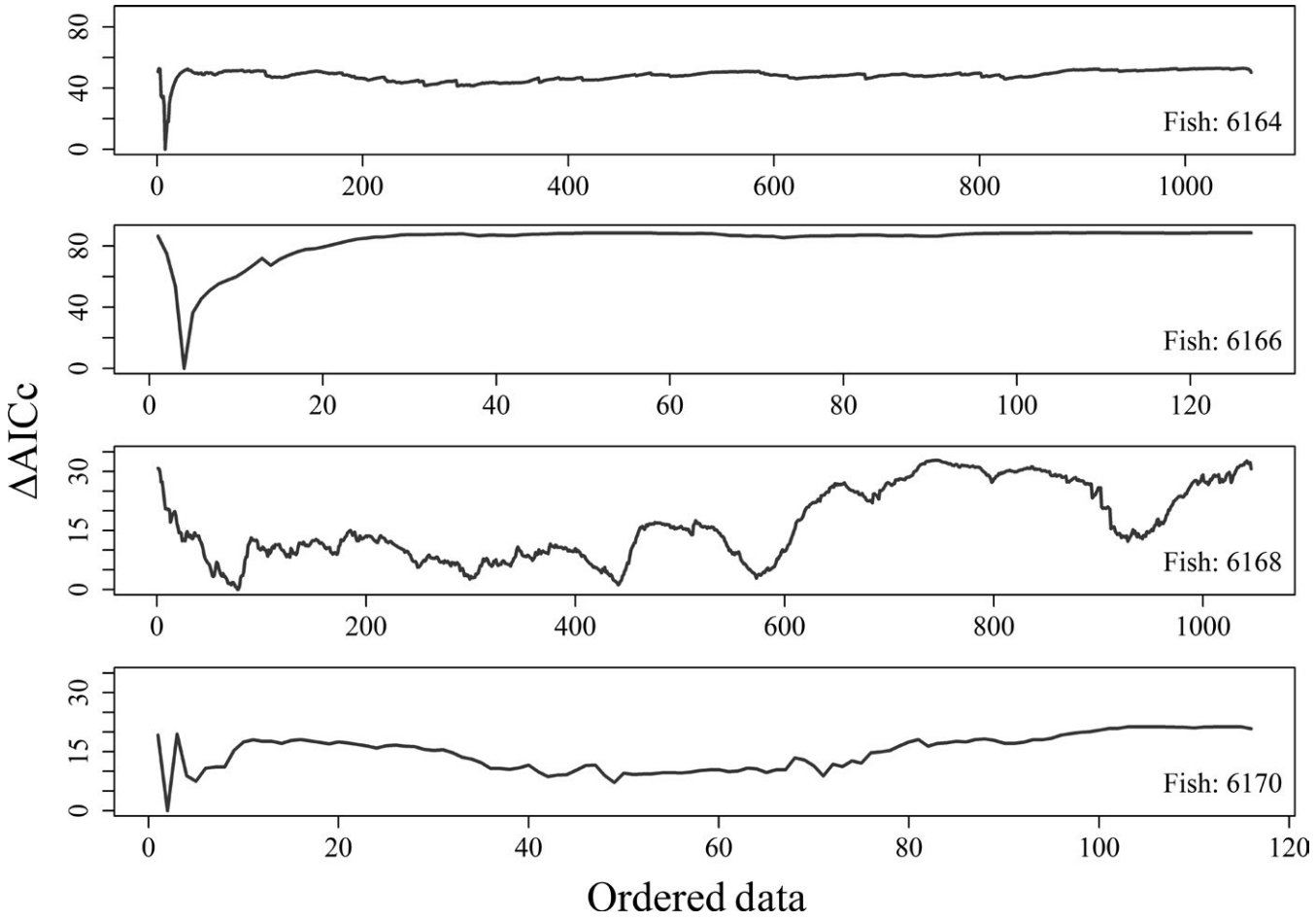

FIGURE 2 Difference between Akaike's information criterion corrected for small sample size (AICc) computed for each potential break point in each green sturgeon's (*Acipenser medirostris)* time series of accelerometer measurements and the minimum AICc. The break point occurs when this difference (ΔAICc) equals zero. Data are presented in chronological order and do not include data collected while fish were in the live car. Minima of each time series represents the location of the most parsimonious break point in that time series. Corresponding time from release is given in Table 2. Top panels = fish with internal tag placement (6164 and 6166); bottom two panels = fish with externally-mounted tags (6168 and 6170). Panels are from largest fish (6164) at top to smallest fish (6170) at bottom

green sturgeon behavior. Controlled experiments that compare the effects of gear type (e.g., trawl vs gillnet), soak time, and length of time fish were in air could help to identify the aspects of capture and release most stressful to these fish. Recent at-sea studies to document green sturgeon mortality after capture in the California halibut (*Paralichthys californicus)* trawl fishery have used pop-off satellite transmitters (unpublished data, P. Doukakis, National Marine Fisheries Service). Teaming this technology with accelerometer records would provide a more detailed portrayal of sub-lethal effects of capture and could provide estimated time to recovery for individual fish (Broell et al., 2016).

In summary, accelerometer tags provided a time series of activity data that could be used to identify discrete changes in sturgeon behavior after handling. This methodology represents a valuable tool for identification of both lethal and sublethal bycatch effects. However, the reporting interval accelerometer must be short enough (at most 70 s) and receivers must be dense enough to permit adequate numbers of accelerometer detections, particularly during the first days after fish handling. Such an evaluation of bycatch effects could inform development of management guidelines to protect listed species (e.g., seasonal closures, gear types, soak times, etc.).

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