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Survey-based assessment of recapture data for Atlantic sturgeon (*Acipenser oxyrinchus*) in Lithuanian fisheries

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Against the background of ongoing European activities since the mid-1990s to restore stocks of the extinct Atlantic sturgeon in the Baltic Sea region, from 2011–2018, a total of 6366 sturgeon have been tagged in Lithuania. Despite an information campaign, there has been a drastic decline of reported recaptures within this national, non-reward tagging study. Similar trends have been observed across the whole Atlantic sturgeon distribution area in the Baltic Sea. As commercial fisheries account for most recaptured tagged sturgeon, a survey of Lithuanian fisheries and analysis of fish landings during the 2014–2018 period was performed to evaluate conventional tagging study results. The survey data revealed that reporting rates of tagged sturgeon in Lithuanian territorial waters were 13.3% of the true numbers recaptured in the Curonian Lagoon and 19.3% in coastal Baltic waters. The results showed a marked difference between fishing gear types as the sturgeon bycatch in gill nets was up to eight times higher than in fyke nets. This study emphasized the vulnerability of stocked sturgeon to commercial fishing. The increasing use of fyke nets in conjunction with its lower bycatch of sturgeons could be a strong argument to limit gill net usage in order to reduce fishery-related mortality of sturgeon to safe limits.

Introduction

The Atlantic sturgeon (*Acipenser oxyrinchus*) was relatively common in the Baltic Sea basin until the 19th century. However, this species has completely disappeared from the Baltic Sea by the middle of the 20th century. Evaluative and preparatory work for sturgeon restoration in former historical region of their range started in 1996, though experimental releases in Germany and Poland started only in 2005. Since 2010, Lithuania, Latvia and Estonia joined efforts to restore sturgeon stocks (HELCOM 2019). In total, more than three million Atlantic sturgeon of various sizes — mainly fry and fingerlings and a significantly smaller amount of sub-adults, have been released in the Baltic Sea basin and its tributaries since the beginning of a re-introduction scheme (HELCOM 2019). Initial releases were usually performed in conjunction with various tagging studies to identify migration patterns, survival, causes of mortality, preferred habitat and, most importantly, to assess population recovery (Gessner *et al*. 2011; Kolman *et al.* 2011). Radio or acoustic telemetry were applied to small numbers of individuals to moni-

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tor short term post stocking migration, survival and habitat utilization in rivers (Fredrich *et al.* 2008; Kapusta *et al.* 2011; Kapusta *et al.* 2016). Simultaneous and subsequent conventional tagging of thousands of stocked sturgeons was carried out to assess long term survival and migration patterns and habitat use in the lagoons and sea environment based on information provided about recaptured tagged sturgeon (Kolman *et al.* 2011; Stakėnas and Pilinkovskij 2019). In Lithuania, 6366 tagged fish have been released since the start of sturgeon restoration in 2011 into the Nemunas River basin (south east Baltic Sea basin) and, to date, only 94 tagged sturgeon recaptures have been reported. However, reporting of tagged fish has declined drastically every year (Stakėnas and Pilinkovskij 2019). Similar situations have been observed in other countries (Gessner J., Arndt G-M., Kapusta A., Medne R., Tambets M., pers. comm. during the Second Meeting of the Expert Group on Sturgeon Remediation under HELCOM State & Conservation, January 23–25, 2020). The large declines in recapture rates are of great concern to scientists as this could indicate crucial flaws within ongoing multinational Atlantic sturgeon restoration programmes or just simply highlights the increasing under-reporting rates of caught tagged sturgeon. However, both reasons for the decline in reported recaptures could result in significant risk to the expensive restoration programmes, as under-reporting undermines efforts to evaluate population trends, causes of mortality and the efficiency of re-introduction, therefore making timely implementation of proper management actions, recovery strategies and protection measures considerably more difficult, especially for fish with long life span and late maturity (Haxton and Friday 2018; HELCOM 2019). Ultimately, it could jeopardise restoration efforts as only constant assessment of management and restoration measures and their subsequent improvement will ensure Atlantic sturgeon population recovery across the Baltic region (Flowers and Hightower 2015; Stakėnas and Pilinkovskij 2019). Good survival rates of stocked Atlantic sturgeon in various radio and acoustic telemetry projects in numerous rivers in the southern and eastern Baltic Sea basin (Gessner *et al.* 2011; Kolman *et al.* 2011; Kapusta *et al.* 2016) indicate success in the first phase of the post stocking sturgeon life cycle, when juveniles migrate predominantly downstream. However, little is known about the mid- and long-term survival of *A. oxyrinchus* in lagoons and in the Baltic Sea as the trend of under-reporting clearly prevents accurate assessment (Stakėnas and Pilinkovskij 2019). Numbers of returning spawners could also provide information to assess restoration measures, but due to long life span, late maturity and 2–5 years intervals between reproduction occasions of sturgeon (HELCOM 2019), information about the status of population could be already outdated and partial. CPUE is another widely used method for population monitoring, but to get reliable CPUE due to sturgeon rarity in vast waters could be an extremely difficult and expensive task.

Despite declines in reporting across the Baltic Sea basin, result of tagging studies revealed that overfishing must be considered as major threat to ongoing sturgeon restoration measures in the Baltic Sea (Gessner *et al.* 2011; Stakėnas and Pilinkovskij 2019). Generally, all studies revealed that sturgeon bycatch occurs mainly in commercial fisheries using predominantly fyke and gillnets (Stein *et al*. 2004; Gessner and Arndt 2006; Stakėnas and Pilinkovskij 2019). Inevitably, these findings raise a series of questions about possible additional fishing regulations and limitations. Consequently, commercial fishermen may be increasingly more concerned about possible actions that could impair their source of living. Therefore, even close contacts and trust-building between scientists and fishermen cannot always guarantee realistic reporting rates due to the reluctance of fishermen to cooperate in what could indirectly induce additional restrictions on fisheries. Recent evidence from New Zealand indicates that even nations with advanced environmental protection, sophisticated fisheries control and considerable penalties cannot prevent illegal under-reporting as fishermen failed to report bycatch of yellow-eyed penguins (*Megadyptes antipodes*) and other endangered species for many years. Only after worldwide outrage did "cameras on boats" become mandatory for every fishing vessel (Crawford *et al.* 2017; Fisheries (Electronic Monitoring on Vessels) Regulations 2017, 2020).

Under-reporting of "non-reward" tags is clearly an issue in fisheries and, most likely, the only solution that could significantly improve recapture reports, other than tougher control, is substantial financial reward (Meyer *et al.* 2012). In general, even informatively well prepared, the "non-reward" tagging strategy leads to a significant loss of valuable information, especially from sea fisheries (Taylor *et al.* 2006; Sackett and Catalano 2017). However, even tagging with very high reward tags cannot guarantee 100% reporting rates due to fraud, poor awareness and the presence of other tags with no or small reward (Pollock *et al.* 2001, 2002; Taylor *et al.* 2006).

The vast majority (96.8%) of sturgeon recaptures from the Curonian Lagoon and Baltic Sea have come from commercial fishermen, highlighting the high level of dependency on commercial fisheries in lagoons and the sea coastal zone for conventional sturgeon tagging studies (Stakėnas and Pilinkovskij 2019). Most ongoing multinational sturgeon tagging studies across the Baltic Sea basin are based on voluntary reporting with no reward and all have witnessed substantial falls in reported recaptures (Stakėnas and Pilinkovskij 2019, Gessner J., Kapusta A., pers. comm. during the Second Meeting of the Expert Group on Sturgeon Remediation under HELCOM State & Conservation, January 23–25, 2020), thus possibly risking that long-term tagging studies of sturgeon become meaningless. Therefore, we decided to assess real sturgeon recapture to compare it with official recapture reports by conducting a commercial fisheries survey. Recent studies in the Mediterranean based on fisheries interviews have already proved to be a good method to assess turtle bycatch and evaluate mortality (Domènech *et al.* 2015; Lucchetti *et al.* 2017). Based on the survey results, we then re-evaluate our most recent sturgeon tagging study (Stakėnas and Pilinkovskij 2019) and discuss means how to improve tagging studies to provide more reliable results.

Material and methods

All Atlantic sturgeon restoration efforts in Lithuania are focused solely on the Nemunas River basin because all sturgeon populations historically existed only in the biggest rivers of this basin. The Nemunas River drains 71.3% of Lithuanian territory and flows into the largest Baltic Sea lagoon — the Curonian Lagoon (1584 km^2), a quarter of which belongs to Lithuania and remaining part to the Russian Federation. The Curonian Lagoon enters the Baltic Sea approximately 50 km north from Nemunas River delta through the narrow (~0.4 km) Klaipėda Strait where the main national seaport is located.

Since the beginning of Atlantic sturgeon restoration in Lithuania, a total of 6296 Atlantic sturgeons of 9–10 months of age (84.3% of all stocked subadults) have been tagged with Floy® T-Bar Anchor Tags (mean TL 475 mm, mean weight 475 g) and 30 with radio tags (mean TL 501 mm, mean weight 524 g) (Table 1). Additionally, 40 specimens of 4-month-old sturgeons (mean TL 188 mm, mean weight 22.2 g) were tagged with radio tags. Information about the tagged sturgeons was highlighted in the mass media, provided to all regional environmental protection agencies and sent to all commercial fishermen using the fisheries authorities database. Providing updated contact and activity information to the fisheries authorities database is obligatory for all commercial fishermen to claim various state and EU subsidies. We assume therefore that information about the tagged sturgeons reached 100% of commercial fishermen and most anglers. Lithuanian angling rules oblige everyone to report all tagged fish caught (Environmental ministry 2020a), though a similar obligation is not clearly stated in commercial fishing rules as "fishermen must comply with other legislation regarding the exploitation and protection of fish stocks" (Environmental ministry 2020b). Every tagged fish caught must be reported (via phone, e-mail) to the regional Environmental Protection agency and/or to the Fisheries Service under the Ministry of Agriculture of Lithuania (thereafter Fisheries Service). Environmental Protection Offices usually transfer all data to the Fisheries Service, which runs the tagged fish database that is available for internal use and must be provided for other national state and scientific institutions free of charge on request.

All fishing companies and fishermen (hereafter fisheries) that operated in Lithuanian waters

Table 1. Atlantic sturgeon stocking and tagging in the Nemunas River basin during the 2011–2018 period and total, gill and fyke nets fish landings in the Curonian Lagoon and the Baltic Sea coastal zone with the proportion of catch for fyke nets in Lithuania territorial waters during the 2014–2018 period.

Year	2011	2012	2013	2014	2015	2016	2017	2018
Stocked numbers of Atlantic sturgeon fry	4640	6950	7825	19440	34330	30400	8200	43750
Stocked numbers of Atlantic sturgeon subadults	30	391	420	1227	2448	500	0	1000
Sturgeon subadults tagged with Floy Anchor tags	30	391	420	1207	2048	500	0	250
Total fish landings in lagoon (tons)	NDA	NDA	NDA	1061	1098	1052	963	756
Gill nets fish landings in lagoon (tons)	NDA	NDA	NDA	895	892	750	645	467
Gill nets fish landings in lagoon (tons)	NDA	NDA	NDA	166	206	302	318	289
Fyke nets fish landing proportion in lagoon (%)	NDA	NDA	NDA	15.6	18.8	28.7	33.3	38.2
Total fish landings in coastal sea (tons)	NDA	NDA	NDA	425	402	674	502	597
Gill nets fish landings in coastal sea (tons)	NDA	NDA	NDA	369	330	270	165	177
Fyke nets fish landings in coastal sea (tons)	NDA	NDA	NDA	56	72	404	337	420
Fyke nets fish landing proportion in coastal sea (%).	NDA	NDA	NDA	13.2	17.9	59.9	67.2	70.4

NDA = no data available

in the Curonian Lagoon and/or Baltic Sea coastal zone (up to 20 meters depth, hereafter the Baltic Sea) and performed commercial fishing operations during the 2014–2018 period were selected from the fisheries database. A relatively short questionnaire consisting of 18 questions was drafted to avoid long interviews that could possibly hinder the survey (see Table S1 in Supplementary Information). The whole survey was conducted via phone, as phone surveys are better than face-to-face interviewing in collecting data of sensitive nature, while other means of surveys (e-mail or web) give much lower response rates (McGivern 2003). Questions related to tag reporting were eliminated in order to enhance the better perception of informality among respondents. Attempts to contact every single fishery up to five times (if calls unanswered) were carried out during two periods in winter and spring 2019. Out of 94 registered fisheries that performed commercial fishing activity between 2014 and 2018, 86 were still operational during the surveying period. Contact was established with 78 of them while 60 respondents agreed to be questioned. The questioned fisheries represented 78.0% of the total fish landings in the Curonian Lagoon and 91.3% in the Baltic Sea during the 2014–2018 period. The margin of error (MOE — maximum amount by which the sample results may differ from the full population) for survey results was calculated at 95% confidence level (therefore z = 1.96) using a sample size (n) of 60 (the number of fisheries questioned), a population size (N) of 86 (the total number of fisheries available during the survey) and a population proportion (p) using a formula for finite population (Cochran 1963):

$$\mathrm{MOE} = \frac{z \times \sqrt{p \times (1-p)}}{\sqrt{(N-1) \times n / (N-n)}}. \qquad (1)$$

The population proportion (response distribution) was calculated for every response using the number of respondents (fisheries) or the percentage of total fish landings among those fisheries. The calculated MOE was provided for survey results as confidence intervals (±). Survey results from the Curonian Lagoon and the Baltic Sea were separated. Fisheries that operated in both water bodies were asked to provide separate information for each water body. All survey data were processed in accordance with personal data protection legislation. Survey results were adjusted to represent 100% of total fish landings for better data comparison, thus correction coefficients 1.282 and 1.095 for the related results from the Curonian Lagoon and Baltic Sea respectively were applied. It has to be noted that we analysed only official fish landings — the real catch was considerably larger, because only a 10% bycatch is allowed to be landed with gill nets and none with fyke nets, therefore fisheries are obliged to discard almost all undersized and prohibited species, which in some cases could be as high as 50% of the total catch according to some fisheries' statements. However, almost all bycatch from fyke nets and a considerable proportion from gillnets are released alive (Stakėnas and Pilinkovskij 2019). Numbers were rounded to the nearest whole number when appropriate. The sturgeon bycatch was calculated as the amount of fish landings (kg) per one caught sturgeon specimen (1/fish landings), thus indicating lower sturgeon bycatch if fish landings were higher. For more precise assessment of the variation of sturgeon bycatch in different types of fishing gear, only survey data from the last two years (20172018) of the study period were included (presented as a separate question in survey) to reduce data bias due to likely difficulties for respondents to remember facts from a long time earlier. Fisheries in Lithuania use a wide range of different fishing gear and are obliged to register "fishing effort" only when removing fishing gear from the water and/or landing fish catch. Therefore, "fishing effort" for gill nets could be up to 3–4 days during the cold season, while for fyke nets it could be up to a week. This makes it impossible to even approximately calculate any CPUE, therefore fish landings can be used to relate fisheries activity with sturgeon bycatch. Registration of fish landings by gill and fyke nets in Lithuania are separated, consequently it was possible to calculate the sturgeon bycatch for the only fishing gear types used in the Curonian Lagoon and Baltic Sea. Fish landings for different gear (Table 1) and designated areas where fisheries are allowed to fish were obtained from the Fisheries Service for the Baltic Sea and from the Environmental Protection Department under the Ministry of the Environment for the Curonian Lagoon. All fisheries are obliged to provide fish catch monthly, separately for the Curonian Lagoon and the Baltic Sea. However, regulations do not require separate catches to be specified for every designated fishing area, therefore spatial analysis was performed only on a large scale. Real reporting rates were calculated as the proportion of officially declared recaptures in comparison with survey estimated recaptures.

Results

The Curonian Lagoon

A total of at least 578 sturgeons (90 tagged and 488 untagged) were caught in the Curonian Lagoon during the 2014–2018 period according to the survey of fishermen. Only 2.3 ± 2.1% fisheries representing just 0.8 ± 1.2% of the total fish landings in the Curonian Lagoon did not catch a sturgeon during the 2014–2018 period, notably those indicating only using fyke nets as fishing gear. Most fisheries (68.2 ± 6.5%) caught their first sturgeons during the 2011–2013 period just after sturgeon restocking started and before the targeted period of the survey (Table 1). The overall sturgeon bycatch was 1/8576 kg during the 2014–2018 period among the surveyed fisheries. However, the sturgeon bycatch close to the Nemunas River mouth and/or in the central part of the Curonian Lagoon was 1/6834 kg, compared to 1/11597 kg in the northern part of the lagoon. All fisheries that never caught a sturgeon operated only in the northern part of the Curonian Lagoon. The mean reported depth where sturgeons were caught was 3.2 m and sandy or sandy-stony substrates were indicated as most common substrate for sturgeon bycatches in all gears. In 2018, at least 107 sturgeons were caught, while the year before yielded a slightly lower catch of 92 sturgeons, though total fish landings were much higher in 2017 (Table 1). 158 sturgeons were caught with gill nets and 41 with fyke nets. Despite a constant increase in the proportion of fyke nets in fish landings (Table 1), 30.8 ± 6.5 % of fisheries declared that they never caught sturgeon with fyke nets. The sturgeon bycatch in fyke nets over the 2017–2018 period (1/15769 kg) was more than half of gill nets (1/8039 kg), with the overall sturgeon bycatch for the lagoon being 1/10405 kg and 1/8040 kg in 2017 and 2018 respectively.

Only 26.6 ± 6.2% of fisheries expressed an opinion that the sturgeon bycatch is decreasing, while the majority were certain that sturgeon numbers were increasing (37.2 ± 6.8%) or staying the same (35.4 ± 6.7%). Autumn appeared to be the best season in the Curonian Lagoon to catch sturgeon (expressed by 90.8 ± 4.0% of fisheries, with none mentioning the winter season). In the Curonian Lagoon, most sturgeons caught weighed from 0.5 kg up to 1.0 kg, with the two biggest specimens recorded being ~2.5 kg. Sturgeon bycatch was highest in gill nets with a mesh size of 45–70 mm for 73.4 ± 6.2% of fisheries, with a relatively small proportion of fisheries (13.3%) struggling to define the most dangerous fishing gear for sturgeon.

A merely 4.4 ± 2.8% of fisheries representing 3.4 ± 2.5% of the total fish landings did not catch a tagged sturgeon in the Curonian Lagoon. The first tagged specimens being caught in 2012 — the same year that considerable numbers of sturgeons were tagged (Table 1). The survey revealed that at least 90 tagged specimens were caught during the 2014–2018 period, but only three in 2018. According to the fisheries, all but two tags were of Lithuanian origin — one tag description corresponded with those used to tag sturgeon in Poland or Germany and one (an aluminium plate with Cyrillic symbols) was likely used for marking sturgeons held in captivity in the Kaliningrad region, Russia. Therefore, a total of 88 sturgeon recaptures were of Lithuanian origin, but only 12 were officially reported during the 2014–2018 period, compared with 13 in year 2012 alone.

The Baltic Sea

A total of at least 415 sturgeon (57 tagged and 358 untagged) were caught in the Baltic Sea during the 2014–2018 period according to the fishermen survey. Only 7.0 ± 3.6% fisheries representing just 0.9 ± 1.3% of fish landings in the Baltic Sea did not catch a sturgeon during

2014–2018 period. Like in the Curonian Lagoon, the majority of fisheries (63.3 ± 6.7%) caught their first sturgeons in the Baltic Sea during the 2011–2013 period just after sturgeon restocking started and before the targeted survey period (Table 1). However, some fisheries (12.7 ± 4.7%) caught their first sturgeons even before the Atlantic sturgeon restoration programme started in Lithuania. The overall sturgeon bycatch was 1/5197 kg during the 2014–2018 period. However, the sturgeon bycatch in fishing areas just north of Klaipėda Strait was 1/4938 kg compared with 1/9305 kg in fishing areas south of Klaipėda Strait. All fisheries that never caught a sturgeon operated in fishing areas south of Klaipėda Strait. The mean reported depth where sturgeons were caught in the Baltic Sea was 6.9 m with only one fisherman stating that he caught sturgeon at 15–20 meters depth. Similar to the Curonian Lagoon, a sandy-stony substrate was indicated as most preferable for sturgeons in the Baltic Sea by all fishermen.

In 2018, a total of at least 58 sturgeons were caught, while the year before yielded a higher catch of 71 sturgeons, though total fish landings were much higher in 2018. Between them, 103 sturgeons were caught with gill nets and 26 with fyke nets. The proportion of fish landings with fyke nets was 70.4 ± 6.4% in 2018, though still 32.0 ± 6.5% of fisheries declared that they never caught sturgeon with fyke nets (Table 1). The sturgeon bycatch for fyke nets over the 2017–2018 period (1/28807 kg) was less than eighth of gill nets (1/3314 kg). The overall sturgeon bycatch for coastal sea was 1/7069 kg and 1/10289 kg in 2017 and 2018 respectively.

The survey revealed that fisheries expressed a differing opinion about the sturgeon bycatch trend in Baltic Sea than that in the Curonian Lagoon, as only 9.4 ± 4.1% of fisheries were certain that sturgeon bycatch was increasing, while the majority stated the same sturgeon numbers (64.0 ± 6.7%) or a decreasing bycatch (23.7 ± 6.0%). Autumn was the best season in the Baltic Sea to catch sturgeon for 72.3 ± 6.3% fisheries with only one fishery indicating wintertime. In the Baltic Sea, most caught sturgeons weighed from 1.0–2.0 kg with the biggest specimen recorded being ~12 kg. Sturgeon bycatch was highest in gill nets with a mesh size of 50–70 mm for 68.5 ± 6.5% of fisheries. However, a substantial proportion of fisheries (22.4 ± 5.8%) could not indicate the most dangerous gear for sturgeon.

Only 11.6 ± 4.5% of fisheries representing just 1.8 ± 1.9% of the total fish landings did not catch a tagged sturgeon in the Baltic Sea and the first tagged specimen was caught in 2012 — the same year that considerable numbers of sturgeons were tagged (Table 1). The survey revealed that at least 57 tagged specimens were caught during the 2014–2018 period, but only four tagged specimens were caught in 2018. According to the fisheries, seven tags were of foreign origin — six tags were exactly identical to tag sturgeon in Poland or Germany, and one was likely an external data storage tag or radio tag with an internal antenna of unknown origin. Therefore, a total of 50 sturgeon recaptures were of Lithuanian origin, but only 11 were officially reported during the 2014–2018 period. To date, the last official sturgeon recapture from Lithuanian territorial Baltic Sea waters was reported in 2016.

Discussion

In year 2012 alone, Lithuanian fisheries reported 15 recaptured sturgeons in Baltic Sea and Curonian Lagoon out of 421 tagged sturgeon released in Nemunas River basin (Table 1). During the 2014–2018 period, only 23 tagged sturgeons were officially reported by fisheries from the Lithuanian territorial waters in the Curonian Lagoon (12) and the Baltic Sea (11), though more sturgeons were tagged (Table 1). However, survey data suggest that at least 90 tagged sturgeons were caught in the Curonian Lagoon and 57 in the Baltic Sea. Thus, the reporting rates from Lithuanian fisheries were just 13.3% of the survey estimated number recaptured in the lagoon and 19.3% in the seacoast zone. Foreign fisheries provided 55% (22 out of 40) of all recapture reports of tagged sturgeon during first two years (2011–2012) of tagging, before almost complete cessation later (Stakėnas and Pilinkovskij 2019). Consequently, we can assume that the total number of recaptured tagged sturgeons of Lithuanian origin in the whole distribution area could be twice higher than in Lithuanian territorial waters alone, despite absence of reports from foreign fisheries during 2014–2018 period. Accordingly, the reporting rates of tagged sturgeons of Lithuanian origin in the whole sturgeon distribution area could be ~10% in the sea and even less in the lagoon fisheries. Moreover, widespread illegal, unreported and unregulated fishing (IUU) in the region, although declining, further impairs reporting rates (Zeller *et al*. 2011; ICES, 2017).

Our survey data strongly support estimates that reporting rates for long term conventional tagging studies without reward is less than 20% (Sackett and Catalano 2017; Stakėnas and Pilinkovskij 2019). Notably, in the first two years (2012–2013) of the sturgeon tagging study (Stakėnas and Pilinkovskij 2019), it was estimated that reporting rates were much higher (~50%), thus being in line with other results from short term tagging studies (Meyer *et al*. 2012). Total sturgeon catches by fisheries do not indicate any substantial drop in numbers, except 2017 in the Curonian Lagoon and 2018 in the Baltic Sea, but this was more likely related to far lower numbers of released sturgeon in the Nemunas River basin in 2017 (Table 1). Notably, total numbers of caught sturgeon increased again in the Curonian Lagoon following a large release of sturgeon in 2018, therefore eliminating the possibility of a decline in recaptures associated with unusual animal migration from the area.

Under-reporting of tagged fish recaptures causes serious challenges as, without proper adjustment, could easily lead to misleading findings even in the most sophisticated models (Xiao 2000; Haxton and Friday 2018). Even models designed to eliminate non-reporting require this to be at least constant over the entire tagging period (Pollock *et al.* 2001; McGarvey and Feenstra 2002). Scientists have implemented various methods to assess under-reporting rates using various tag reward schemes, lotteries, supervised fisheries, telemetry or even applying under-reporting coefficients based on personal experience (Robichaud and Rose 2001; Pollock *et al*. 2002; Pine *et al*. 2003). Still, almost every single high reward tags study acknowledges that a 100% reporting rate is likely to be incorrect even with applied corrections to compensate for under-reporting due to fraud, overlooked tags (especially in big scale commercial fishing), tags overgrown by algae/*Mollusca*, tag shedding during capture or simply due to tagged fish having a different probability of capture compared to untagged ones (Thorsteinsson 2002; Cowen *et al*. 2009; Brenden *et al*. 2010). Sometimes even high reward tag reports from specific fishing gear can be surprisingly low (Kleiven *et al*. 2016).

Most high reward studies were conducted within national borders and/or in limited areas, thus ensuring good communication with fishermen, maintaining simple procedures for reporting and providing swift reward payments. However even within national borders, the under-reporting of high reward tags can be substantially lower among foreign tourists than compared to locals (Kleiven *et al*. 2016). For projects with target fish that migrate over the large multinational areas, report management becomes much more complicated simply due to language barriers and legislation differences, therefore even high reward studies cannot provide the desired results unless it is a well-coordinated high cost multinational project (AOTTP Coordination Team 2019). The conducted fisheries survey already provided up to 7.5 times higher numbers of tagged sturgeon recaptures in lagoon and 5.2 times in the sea, than officially reported. However, when respondents were not sure of the "correct" number of caught specimens, they were asked to provide a minimum figure (see Table S1 in Supplementary Information), therefore actual numbers could be even higher. Comparison of different surveys, wider audience, sophistication of methodology is needed to get better precision. Still, the fisheries survey could be a very useful tool to help in estimating reporting rates or at least justifying some assumptions, especially if the target fish are rare enough to be noticed within the whole catch and are captured mostly by commercial fisheries, thus providing a limited number of potential respondents. Coordinated surveys across the entire distribution region could be a cost effective measure to ensure better data precision and to verify some assumptions, but this obviously will not provide the precision needed to estimate population and mortality (Pollock *et al*. 2001; Pollock *et al*. 2002; McGarvey and Feenstra 2002).

At least one tagged sturgeon was an escapee from an aquaculture and three fisheries noted significant appearance differences of some of the caught sturgeon with their descriptions mostly corresponding to Siberian sturgeon (*Acipenser baerii*). Although the survey suggested a relatively negligible number of non-native sturgeon, the real extent of escapees is unknown and needs proper assessment as non-native sturgeons pose a potential danger to the successful reintroduction of Atlantic sturgeon, because of interspecific competition, risk of hybridization and disease transfer (Gessner *et al*. 1999; HELCOM 2019). At least five fisheries noted that floy tags were lost while handling caught sturgeons, therefore double tagging of some or even all sturgeons is needed to assess tag loss (Björnsson *et al*. 2011; Sackett and Catalano 2017).

A previous sturgeon tagging study in Lithuania estimated that 55% of all tag reports of Lithuanian origin were from foreign fisheries, while the remaining 45% were received from national fisheries (Stakėnas and Pilinkovskij 2019). The survey estimated 138 sturgeon recaptures of Lithuanian origin from national fisheries, thus providing us with the likely number of possible recaptures being 307 specimens in the whole sturgeon distribution area. Together with the 52 registered tags from the 2011–2013 period, this gives us the total number of recaptures being 359 over the 2011–2018 period and a total number of 4846 tagged specimens during the same period (Table 1). This provides a recapture rate of 7.4%, being almost perfectly in line with the average recapture rate (7.1%) from published sturgeon projects reported by Haxton and Friday (2018). The survey results once more emphasized the vulnerability of stocked sturgeons to commercial fishing, though significantly less dramatically than estimated previously, as estimated sturgeon recapture rate in fisheries (7.4%) were less than predicted by Stakėnas and Pilinkovskij (2019). However, fisheries in Lithuania have recently undergone serious changes in terms of switching fishing gear from gill nets to fyke nets. Predation by seals (Hansson *et al*. 2018) and significant bycatch of fish illegal to land in gill nets together with EU subsidies available for fish friendly

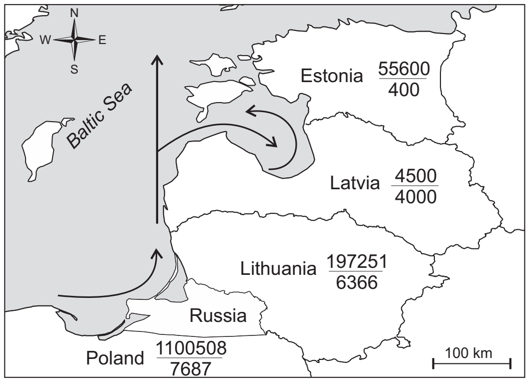

Fig 1. Atlantic sturgeon restoration data from 2006 to 2019 in the eastern Baltic Sea. Upper numbers are sturgeons stocked and lower numbers are sturgeons tagged per country. Arrows indicate dominant currents in the eastern part of the Baltic Sea (redrawn from Leppäranta and Myrberg 2009).

selective gear (fyke nets) have all stimulated increase in the proportion of fish landings with fyke nets, especially in the sea coastal zone (Table 1). Many fisheries reported that they are still in the process of changing fishing gear from gill nets to fyke nets. Our survey estimated the sturgeon bycatch for fyke nets was one eighth compared to gill nets in coastal sea. Similarly, a previous tagging study (Stakėnas and Pilinkovskij 2019) clearly indicated significant differences in fish gear selectivity on sturgeons. Most fisheries confirm that sturgeons are most vulnerable to gill nets with a mesh size from 45 mm up to 70 mm, while reports from a significant proportion of fisheries indicate a complete absence of sturgeon in fyke nets catch. In addition, sturgeon mortality in fyke nets appears to be negligible compared to the estimated up to 83.3% in gill nets (Stakėnas and Pilinkovskij 2019). Only two sturgeons were reported dead in fyke nets over the whole measurement period in the Curonian Lagoon and none in the Baltic Sea coastal area. All these fundamental changes in fisheries technique could be pivotal to push annual sturgeon mortality below the required safe 5% limit (Beamesderfer and Farr 1997; Friedrich *et al*. 2018).

The survey confirmed that sturgeon long-term migration patterns follow the dominant currents in the Curonian Lagoon and in the Baltic Sea (Fig. 1) reported by Stakėnas and

Pilinkovskij (2019). Only three tagged sturgeon (two of them of foreign origin) were caught south of Klaipėda out of a total of 57 tagged sturgeon caught in the coastal sea and all seven tagged sturgeons of foreign origin were from Germany or Poland and none from Latvia and Estonia, indicating migration of sturgeon northwards only. Three fisheries declared the capture of sturgeons before sturgeon stocking started in Lithuania, thus also indicating either northward migration from Germany or Poland or a substantial presence of escapees from aquaculture in the wild. Dominant current-related migration patterns were also observed in the 1960s when juveniles of Siberian sturgeon and Russian sturgeon (*Acipenser gueldenstaedtii*) were deliberately stocked in the Gulf of Riga and the Gulf of Finland (Kairov and Kostrichkina 1970). Similar results from North America with *A. oxyrinchus* and green sturgeon (*Acipenser medirostris*) (Huff *et al.* 2012; Kelly and Klimley 2012; Savoy and Pacileo 2003) provide evidence of various sturgeon species utilising ocean currents for long migrations. A rising negative opinion of anglers and a growing awareness within society about the detrimental effect of gill nets on sturgeon and other protected fish species could lead to a more rapid transformation of the whole sector towards increased use of fyke nets. Further possible relief for sturgeon could take place soon as a total ban on gill nets in the Curonian Lagoon is included in the political program of the elected government in Lithuania in 2020. Together with reduced fishing activities in the eastern Baltic Sea due to an EU ban on fishing cod, it could be a lifeline for successful sturgeon restoration in the whole area.

Concluding remarks

Overall, only a well-coordinated and informatively excellent multinational study with reward tags could determine much-needed data precision to assess some aspects of the sturgeon restoration programme, but it will unavoidably bring challenging management difficulties and high financial costs. As an alternative, even small-scale short term tagging projects can provide some important information on the status of a fish stock (distribution, movement patterns, preferable habitat, fishing gears selectivity) more cost effectively and efficiently than other more resource-intensive methods of assessing stock size, distribution and composition (Hall 2014). A fisheries survey thus could be a relatively cheap and cost-effective method to improve such small-scale studies or even verify key assumptions in high budget projects especially if conducted annually to eliminate "memory error" (Sudman and Bradburn 1973) and executed internationally on a large scale to provide higher precision (Cochran 1977). The present study findings confirm that a fisheries survey may be an effective method to estimate tag reporting and bycatch rates of various types of fishing gear. Additionally, fisheries survey results can help decide how, where and when to focus efforts for further research and could help to identify the need for urgent management measures.

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