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RESEARCH ARTICLE

Reintroduction of sturgeon, *Acipenser oxyrinchus*, in the Gulf of Riga, East-Central Baltic Sea

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Abstract. Atlantic sturgeon, *Acipenser oxyrinchus* Mitchill, inhabited and spawned in the territorial waters of Latvia from the early Neolithic. The *A. oxyrinchus* population in this area started to decline from the end of seventeenth century. By the twentieth century, just several sturgeon catches were documented. In 2012, Latvia joined the initiative to reintroduce native *A. oxyrinchus*. From 2013 to 2015, the Institute of Food Safety, Animal Health, and Environment (BIOR) released 4,500 *A. oxyrinchus* juveniles aged 1+ and 2+. The majority of sturgeon juveniles released inhabit the Gulf of Riga and Pärnu Bay and marine areas among the Estonian islands. Nearly all of the sturgeon released exhibit remarkable growth. The absence of visible pathologies suggests that the *A. oxyrinchus* individuals are in excellent condition. Increases in size and the absence of visible pathologies also suggest that *A. oxyrinchus* has a sufficient food base. Additionally, results indicate that there is free space in the food web for native Atlantic sturgeon. Sturgeon is caught primarily in salmon traps and other commercial fishing nets deployed at depths of 4-10 m or by anglers. While we do not have complete information about the fates (dead or alive) of all sturgeons caught, approximately half of them that were reported by fishers were released back into the sea alive and healthy.

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Introduction

Archeological material confirms that sturgeon was an important component of fish populations in Latvia from the Neolithic until the Bronze Age and the Medieval period. The broadest archeological data comes from the Daugava River basin dating from the oldest Iron to the early Middle Ages (800-1400). The percent of sturgeon remains found in ancient human settlements on the banks of the Daugava River ranges from 2 to 95% of total fish remains, which suggests that in some human settlements sturgeon was fished much more commonly than was salmon (Sloka 1979, Caune 1992).

Acipenser oxyrinchus Mitchill was the dominant sturgeon species in the Baltic Sea basin for at least 2,000 years (Popović et al. 2014). The alveolar sculpturing of the scutes found in Latvia corresponds to the sculpturing of *A. oxyrinchus* (Ludwig and Gessner 2007). This permits us to conclude that *A. oxyrinchus* spawned in Latvia. The *A. oxyrinchus* population in Western Europe (Netherlands, Germany, Poland) declined at the end of nineteenth and beginning of the twentieth centuries (Kolman 1996, Lenders 2017). In Latvia, the decline in *A. oxyrinchus* populations apparently began much earlier at the end of the seventeenth century. About *A. oxyrinchus* stock declining time we suggest because already in the eighteen century sturgeon was not recorded in Latvian commercial fish catches, but was documented only as single incidents that are mentioned in public records only as separate and extraordinary fish caught cases (Fischer 1791, Kawall 1858). The main reasons for the decline of the *A. oxyrinchus* population in Latvia were not anthropogenic factors, like pollution or ecosystem changes caused by the development of manufacturing or agriculture, as was noted in Western Europe. In Latvia industrial revolution that resulted in negative impacts on the environment begin on second half of the eighteenth and the beginning of the nineteenth centuries, when *A. oxyrinchus* have already been declined. Therefore, there is another main reason for the disappearance of sturgeon in Latvia. It is more likely that slight ecosystem changes were brought about by climate change caused by the so-called "Little Ice Age" when the European climate cooled considerably from 1550 to 1850 (Niedźwiedź et al. 2015). For instance, in Latvia from 1740 to 1880, the ice break-up time observed in the port of Riga was often late in the season, and, consequently, this period is thought to have experienced severe winters (Jevrejeva 2001). The slight cooling trend continued into the nineteenth century (Omstedt et al. 2004).

In nature, migrations of *A. oxyrinchus* are caused by temperature. Spawning occurs in waters with temperatures ranging from 13 to 26°C (Greene et al. 2009), and optimal *A. oxyrinchus* growth and food consumption rates occur at 20°C (Niklitschek and Secor 2009). Currently, optimal temperatures for sturgeon spawn in Latvian rivers would be two to three months because of the unusually high frequency of cyclonic circulation, positive temperature trends, and westerly winds (Omstedt et al. 2004). A few centuries ago this period was shorter. Unfortunately, we do not have precise or comparable historical information on air or water temperatures from the seventeenth or eighteenth centuries, but presumably colder and longer winters meant that summers were short and cool, so the optimal spawning, hatching, and juvenile development time was also shortened. This could have impacted the spawning outcomes of *A. oxyrinchus*. Apparently, during the end of seventeenth and beginning of eighteenth centuries, the northern border of sturgeon distribution shifted south and the Gulf of Riga become the northernmost border of the sturgeon area of occurrence in the Baltic Sea at that time. Since 1964, not a single *A. oxyrinchus* specimen has been caught in the Gulf of Riga.

First artificial acclimatization and introduction of non-native sturgeon species on a large scale in the Gulf of Riga and the eastern Baltic Sea was initiated by the Acclimatization Council of the Soviet Union in the mid twentieth century. The Baltic Fisheries Research Institute (BNIIRH) coordinated the program. The main purpose of the program was to increase catches of economically valuable fish. To acclimatize sturgeon from the former Soviet Union territories, fish were selected from the relatively large wild sturgeon populations in rivers flowing into the Black, Azov, and Caspian seas and in Siberian rivers (Tanasiychuk et al. 1961, Kairov and Kostrichkina 1969). Nevertheless, the periodic, temporary releases of non-native sturgeon did not produce long-term effects, and no population was established by any of the non-native sturgeon species that were exposed to acclimatization.

The preparatory work for restoring the native Baltic Sea sturgeon, *A. oxyrinchus*, in Europe started in Polish waters in 1996. Fertilized eggs was brought from Canada to Germany and Poland. Starting in 2004, *A. oxyrinchus* fry from the population in the St. John River in Canada were brought to Poland annually (Kolman et al. 2008). Since 2006, pilot stocking has been conducted in the Oder River basin. In 2006, the Drwęca and Wisłoka rivers were the first to be stocked with sturgeon fry reared in Poland (Kapusta et al. 2011), and in 2012 the Neman River in Lithuania was stocked (Kolman et al. 2011, Gushchin et al. 2013). Simultaneously with the first stocking activities, *A. oxyrinchus* broodstocks were established in Poland and Germany. In Latvia, the first native *A. oxyrinchus* juveniles were released into the

Daugava River in 2013. The initial data described in this article provide us with the first impressions on the spread and growth of *A. oxyrinchus* in the Gulf of Riga and the open Baltic Sea. This paper also includes information on the impact releasing the sturgeon has had on fishers.

Material and methods

Rearing *A. oxyrinchus*

From 2012 to 2014, the Tome fish farm (BIOR) obtained several weeks-old *A. oxyrinchus* fry reared from egg to fry from the Inland Fisheries Institute of Olsztyn (Poland) hatchery. These *A. oxyrinchus* fry originated from the St. John River in Canada. The fry had completely shifted to exogenous feeding. Commercially produced sturgeon feed with age-appropriate granule size was used to feed them applying the appropriate ration size. The fish were reared in flow-through-rearing tanks using Daugava River water drawn from the Kegums Reservoir. The water temperature regime fluctuated from 22°C in July to 10°C in October. When the temperature dropped below 10°C, the fish were transferred to breeding tanks in a recirculating aquaculture system that was supplied with water from the Sprinčupe River. The water temperature throughout the winter ranged from 8 to 10°C. In spring, when the Daugava River water warmed up to 10°C, the sturgeon juveniles were transferred back to the flow-through rearing system. This temperature regime was applied in the wintering period during the first year. In the second winter, the juveniles were reared in a natural temperature regime, which periodically dropped to 0.3°C in winter.

Juvenile release

From 2012 to 2015, a total of 4,500 *A. oxyrinchus* juveniles aged 1+ and 2+ were reared and released. Juveniles were released annually in September 2013-2015 into the Daugava River, approximately one km from the river inflow into the Gulf of Riga. The average weight of sturgeon aged 1+ was 160 ± 43 g at a length of 36 ± 3 cm, while juveniles aged 2+ weighed 605 ± 113 g and measured 52 ± 3 cm in length. All the sturgeon released were healthy without any signs of pathology or illness. Before release, 4,000 sturgeon individuals were marked with green T-bar anchor tags (Hallprint) containing individual numbers and identification details of the institute.

Site characterization

The Gulf of Riga is a relatively autonomous sub-sytem of the Baltic Sea where salinity is low (2-7 ‰), the average depth is 26 m and the maximum depth is 60 m. There is no permanent halocline, but strong temperature stratification occurs in summer. The annual freshwater inflow is 7.3% of the volume of the gulf. Of the total river input, 85% comes from the three main rivers located to the south of the gulf, and the contribution of the Daugava River is 65% (Andrushaitis et al. 1995).

Results

Recaptures

Shortly after release, fishers and anglers started to report the first catches of marked sturgeon, and reported the weight, length, place of catch, tag number, catch date, and fate (dead, alive, released) of the specimen. When the sturgeon were found alive and healthy in the fishing gear, they were released into the water. By the end of 2016, we received information about the fate of 132 fish, which was nearly 3% of the number of all the sturgeon released. The area in which the sturgeon were caught and the number os them was recorded in nearly all these reports. Fish weight, length, and fishing gear type was recorded in approximately 40% of these reports. The fate of fish (dead, alive, released) was recorded in 80% of the reports. Initially, the fishers mistakenly removed the tags and released live fish into the water and sent the

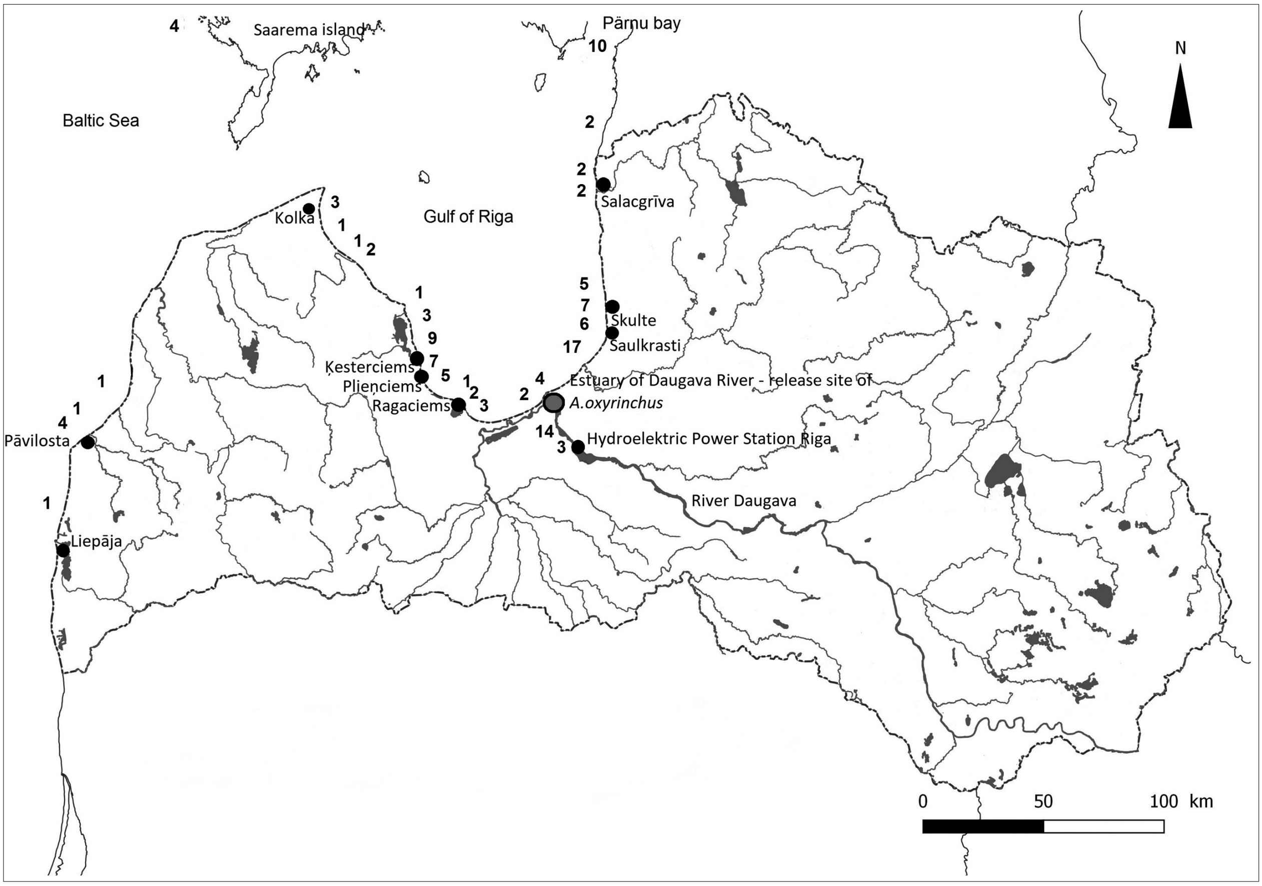

Figure 1. *A. oxyrinchus* catch sites on the Latvian and Estonian coasts.

tags to the institute. This error was reduced after supplementary discussions were held with fishers and the correct procedure was explained. The sturgeon catch sites along the Latvian coastline are illustrated in Fig. 1.

Spread of *A. oxyrinchus* in the Gulf of Riga and the Baltic Sea

During the first weeks after release, the sturgeon juveniles remained in the Daugava River, and most of them remained at the release site. Some of the released fish moved in the opposite direction to that of the main current of the Daugava River until they reached the dam of the Hydroelectric Power Station Riga. Several specimens entered the Gulf of Riga. Two juveniles were caught after two days in the Gulf of Riga at Saulkrasti approximately 30 km from the release site (Fig. 1). From November to February, we did not receive any information on fish catches from either the Daugava or the Baltic Sea, because of seasonal curtailments in fishing intensity, but starting from March all of the T-tag information we received came only from the Baltic. Obviously, during winter all juveniles left fresh waters and entered the brackish Gulf of Riga. Initial T-tag information from March to April started to come from the eastern coastline of the Gulf of Riga, and fish catches were registered from Saulkrasti to Salacgrīva. Thus, we concluded that the fish initially followed the counterclockwise direction of the dominant currents from the Daugava River estuary along the eastern coastline toward the north. At the beginning of March, one specimen reached Pärnu Bay in Estonia. In May and June they spread throughout the Gulf of Riga, and catches were registered along both the western and eastern shallow coastlines of the gulf. In summer 2014, one

Table 1
A. oxyrinchus body weight and total length during release and after 1, 2, and 3 years in the wild (mean± SD)

	Release		Recaptures		
Parameters	1+	2+	2+	3+	4+
Total length (m)	0.36 ± 0.03	0.52 ± 0.03	0.54 ± 0.04	0.72 ± 0.08	0.85 ± 0.10
Body weight (kg)	0.16 ± 0.04	0.60 ± 0.11	0.67 ± 0.15	2.07 ± 0.58	3.23 ± 0.97

sturgeon was caught at Kolka, which is the furthest most point of the western coastline. Seven specimens were caught in the northern area of the gulf near the Estonian island of Saaremaa.

The first sturgeon catches in the open Baltic Sea were recorded in October and November 2014 at Liepāja and Pāviosta (Fig. 1). After this, sturgeon were caught in the open Baltic Sea along the Kurzeme coastline and near Estonian islands. After ten months of living in the wild, one specimen was caught more than 500 km from the release site in the Gulf of Finland by Finnish fishers.

Data indicates that in the first year after release most of the sturgeon (95.8%) released remained in the Gulf of Riga, and only a small number of them (4.2%) left the Gulf of Riga and entered the open Baltic sea. This is confirmed by the catch of the largest specimen weighing 4.2 kg after three years of living in the wild in the Skulte region of the Gulf of Riga, which is close to the release site.

Data analysis suggests that most of the sturgeon that are several years old do not choose purposeful long-distance migration. They move from one local feeding area to another as was indicated by several repeat catches of one specimen in one feeding area. For instance, one specimen was first caught at Ragaciems on May 31, the second catch of the same fish occurred on June 9 in the same area, and the third catch of this same fish was on June 22 in Plieņciems, which is located 16 km from Ragaciems. Another specimen was caught two times within a 12-day interval in Pärnu Bay. A third individual was caught first in Ķesterciems and then eight days later in Plieňciems (at a distance of 7 km).

Growth

Every sturgeon differs in size and weight, depending on its initial size, individual feeding activities, season, and other factors; therefore, the growth of individual specimens varies within a wide range. After one year in sea, at age 2+, the sturgeon reached a length of 0.54 ± 0.04 m and a weight of 0.67 ± 0.15 kg. In the second year, the fish measured 0.72 ± 0.08 m and weighed 2.07 ± 0.58 kg, while in the third year they measured 0.85 ± 0.10 m and weighed 3.23 ± 0.97 kg (Table 1). After three years in the sea, one specimen weighed 4.2 kg and measured 0.95 m, which was a seventeen-fold weight increase. Fishers recorded the details of the fishing gear used to catch *A. oxyrinchus* in 40% of the reports, while in 53% of them the type of fishing gear was not mentioned. Sturgeon were mainly caught in fishing nets and fish pots along the length of the Gulf of Riga and Baltic Sea coastlines. Six specimens entered salmon pots in the Daugava River within two months after release. One was trapped in an eelpout pot at a depth of 17 m, and one was caught in a trawl. One sturgeon was caught in cod nets at a depth of 10 m, and it was released alive back into the sea, but on the next day it was caught again and again released. The catch depth of sturgeon in fishing gears ranged from 4 m to 17 m. Several sturgeon were caught by anglers. In total, we received 87 reports of the condition (alive or dead) the fish were in when they were caught, and 32% (44 reports) reported that the sturgeon were alive, and they were released back into the water, while 31% (43 reports) of the fish reported were dead or injured, so they were retained by the fishers. The fate of the remaining 35% of the fish is unknown.

Discussion

The spread of *A. oxyrinchus* in the Gulf of Riga and the eastern Baltic Sea today is similar to that of the Russian and Siberian sturgeon following the acclimatization program that was conducted from 1962 to 1966. During this period, a total of 40,000 sterlet, *Acipenser ruthenus* L., fry from the Oba River, 16,000 Russian sturgeon, *Acipenser gueldenstaedtii* Brandt & Ratzeburg, 8,200 Siberian sturgeon, *Acipenser baerii* Brandt, from Baikal Lake, and 900 Siberian sturgeon, *A. baerii*, from the Oba River were released into the lower reaches of the Daugava and Gauja rivers. Smaller numbers of Siberian and Russian sturgeon were released into the Gulf of Finland from 1964 to 1966 (Kairov and Kostrichkina 1969). Similarly to today, until 1970 more than 100 catches of Russian and Siberian sturgeon were reported in different regions of the Gulf of Riga and in the Väinamere region in the vicinity of the islands of Saaremaa, Hiiumaa, and Muhu as well as in the littoral zone of the northeastern part of the Baltic Sea.

Like today, fifty years ago, the major part of the sturgeon released remained in the Gulf of Riga and the Väinameri area, but some migrated to the northern coastlines of the gulf. Small numbers of sturgeon passed through the Irbe Strait and entered the Baltic Sea. Similarly, a small number of the Russian and Siberian sturgeon released in the Gulf of Finland from 1964 to 1966 in the Narva-Luga region in Estonia migrated with the main currents in a counter-clockwise direction along the eastern coastline of the Gulf of Finland and moved gradually to the northwest. Two years after release, they were in the southern part of the Bothnia Gulf in the vicinity of Åland Island. Several Russian and Siberian sturgeon were even caught in the Gulf of Bothnia, in the coastal waters of Sweden, and in the vicinity of the islands of Öland and Åland. Apparently, the fish released in the Narva-Luga region reached the Swedish coast by passing through the shallow waters near the island of Åland (Kairov and Kostrichkina 1970).

Preliminary observations suggest that the *A. oxyrinchus* released have excellent habitat conditions. Within the first year after release, the juveniles increased in weight approximately four times. By the fourth year, the sturgeon reached an average weight of 3.23 ± 0.97 kg and an average length of 0.85 ± 0.10 m. One specimen was even recorded as weighing 4.2 kg. After several years in the wild, the *A. oxyrinchus* were healthy and exhibited no external signs of any pathology. The remarkable seventeen-fold increase in size within three years suggests that habitat conditions are favorable and that the food base is sufficient in these natural waters. This also indicates that *A. oxyrinchus* juveniles adapted well to local conditions.

Significant increases in size were also observed in the Russian and Siberian sturgeon in the Gulf of Riga and the open Baltic Sea in 1970. The fastest length growth was recorded during the first three years after release after which the growth rate decreased, but weight continued to increase. In the first year after release, the average length was 26 cm and the average weight was 30 to 80 g (age 1+), in the second year fish length reached 45 cm and weight was 300 g (age 2+), in the third year it was 60 cm, but over six years it was nearly 80 cm (6+) (Kairov and Kostrichkina 1970).

Sturgeon growth suggests that there is free space in the food web for benthic feeding sturgeon, especially since the Gulf of Riga is inhabited by several benthic fish species. The native benthic feeders in the Gulf of Riga are flounder, eelpout, cod, and the new invasive competitor the round goby, which is expanding rapidly. Of these fish species, the only valuable benthic feeding fish are cod and flounder. Of course, to assess the real impact this new species has on other fish species and the whole ecosystem, new research is necessary.

A. oxyrinchus consume small, soft-bodied prey. Juveniles feed mainly on oligochetes, polychetes, crustaceans, and insect fry (Bogacka-Kapusta et al. 2011). Since the number and biomass of benthic organisms has increased recently in the Gulf of Riga and adjacent territories, an excess of them is available in these regions. Gaumiga and Lagzdins (1995) report that the biomass and abundance of zoobenthos have increased considerably in the Gulf of Riga over the course of the last 30 years and that the same pattern occurred in Pärnu Bay, where total macrozoobenthos biomass increased from 1.5 to 8 times (Kotta and Kotta 1997). Recently the biomass of macrozoobenthos in the Gulf of Riga and the adjacent Väinameri Sea reached more than 100 g m^{-2} and the abundance of individuals has reached more than 10,000 ind m^{-2} (Kotta et al. 1998). From an ecological point of view, the likely self-sustaining *A. oxyrinchus* population will replenish an ecological niche and promote benthic production and nutrient circulation in the Gulf of Riga and adjacent marine territories.

The spawning of Siberian or Russian sturgeon probably did not occur because local habitat conditions did not meet the requirements of these species. Nevertheless, from 1950 to 1953 three catches of 12-15 cm sterlet (*A. ruthenus*) juveniles (0+) were reported by anglers fishing in the Daugava River and the Gulf of Riga. Since the fish caught were smaller than those released in 1948 (more than 3,000 *A. ruthenus* L. individuals aged 4+ to 5+), we believe that the sterlet spawned successfully in Latvia. However, a population of sterlet was not established (Tanasiychuk et al. 1961, 1969). Periodic, temporal releases of non-native sturgeon species did not result in long-term effects, and no populations were established by any of the non-native sturgeon species exposed to acclimatization.

It is too early to predict the future spawning success of *A. oxyrinchus* because there are too many factors that can influence it. Today we can only conclude that *A. oxyrinchus* juveniles are developing properly under the current circumstances. The absence of visible pathologies prompts us to conclude that *A. oxyrinchus* has excellent habitat conditions in the Gulf of Riga and the open Baltic Sea. The growth recorded and the absence of visible pathologies suggest that *A. oxyrinchus* has a sufficient food base. Further, the results indicate that there is free space in the food web for native Atlantic sturgeon since the Gulf of Riga is inhabited only by several benthic fish species.

We should also consider that the climate warming in the twenty-first century is in contrast to the cooling that occurred some centuries ago. Climate change influences trends of increased air temperature, rising sea levels, and decreased ice cover in the Baltic Sea (HELCOM 2007). From our point of view, today *A. oxyrinchus* will have warmer climate conditions during spawning in Latvian waters, where temperatures will range from 18 to 20°C in June, which is the optimal range for eggs to hatch. Overwintering temperatures for fry will also be higher, which will influence spawning outcomes positively.

Establishing local sturgeon populations requires a longer period of time and fish stocking on larger scales as well as governmental support, such as public stocking contracts, rules, and protection measures. These are just the first steps in assessing ways to reestablish *A. oxyrinchus* populations in the Baltic Sea that will be possible to implement after mistakes from the past have been eliminated and after uniting the efforts of neighboring countries into one consistent, coordinated project.

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