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First Insights into the Migration Route and Spatial Distribution of the Endangered Chinese Sturgeon (*Acipenser sinensis*) in the Yangtze River Estuary

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Abstract: Chinese sturgeon (*Acipenser sinensis*) is an endangered species, and the Yangtze River Estuary is an important migration channel for this species. With the scale of Chinese sturgeon restocking along the Yangtze River gradually increasing, an increasing number of artificially bred Chinese sturgeon will come to the estuary. It is urgent to make the first insights about the distribution characteristics and migration strategy of the endangered Chinese sturgeon in the Yangtze River Estuary available. So, to balance the need for information about this endangered species and its conservation, a total of 14 Chinese sturgeons were released in the waters near Chongming Island on 9 April 2021 and 20 October 2022, and 50% of them have been successfully recovered. The data demonstrated that Chinese sturgeon had a good migration ability in the Yangtze River Estuary and its adjacent waters. One sturgeon returned to the freshwater area of the estuary after spending approximately 46 days in the sea at a maximum depth of 54.5 m, and two sturgeons returned to the Yangtze River mainstream within 3.5 days after release. We propose that the Northern Channel of the estuary may be the main passway for Chinese sturgeon to undertake the river–sea migration. The bycatch data of Chinese sturgeon showed that this species may prefer the southern area of the estuary. We hypothesize that the food resources and salinity regime are the main factors that promote Chinese sturgeon to enter the shoals around the coast of Chongming Island. The ocean currents, river runoff, salinity, and food resource may affect the distribution of Chinese sturgeon along the Chinese coast. Future work on the conservation of Chinese sturgeon should focus on the marine life history and continuously enrich the research data to improve conservation strategies.

Keywords: Chinese sturgeon; Yangtze River Estuary; pop–up satellite archival tag; distribution; marine life history

Key Contribution: The Yangtze River Estuary is a very important habitat for Chinese sturgeon in its life history, but limited data are available on the exact distribution of this species in this area. This study provides detailed data for the migration and distribution of Chinese sturgeon and an insight into the impact of the environment on its spatial distribution in the Yangtze River Estuary.

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1. Introduction

Chinese sturgeon (*Acipenser sinensis*) is a critically endangered species ion the IUCN Red List in 2010 (https://www.iucnredlist.org/species/236/219152605, accessed on 12 October 2023), and it used to be widely distributed in coastal areas of China from the Yalu River in the Korean Peninsula to the Pearl River in Guangdong Province of China. Exorheic rivers such as the Yellow River, the Yangtze River, the Qiantang River, the Oujiang River, and the Minjiang River (in Fujian Province) used to be inhabited by Chinese sturgeon [1,2]. Due to negative factors such as overfishing and habitat degradation, the populations of Chinese sturgeon have been severely depleted in the past thirty years, with a sharp reduction in distribution areas. At present, the Chinese sturgeon only appears in the Yangtze River, with the only known spawning ground located within 4 km downstream of the Gezhouba Dam; no traces of the Chinese sturgeon have been found in other rivers of its natural distribution [2,3]. As a typical diadromous species, mature sturgeons at the third stage of gonadal development usually start swimming upstream from the estuary to the only spawning ground every July and August. They remain in the spawning ground to overwinter until their gonads develop to the fourth stage and can participate in reproduction. From mid–October to the end of December, mature sturgeons generally lay eggs [4–7]. The postpartum individuals and newly hatched juveniles quickly leave the spawning ground and descend the river to the sea for fattening [3,8,9]. The Yangtze River Estuary (YRE) serves as a crucial pathway for the migration of the Chinese sturgeon, allowing it to complete its life history through migrations [10], and the unique terrain in the YRE offers an appropriate habitat for both adult and juvenile Chinese sturgeon for salinity adaptation and feeding [11]. Research on Chinese sturgeon in the YRE has basically clarified the issues of juvenile resources [12–15] and its food resources [11,16]. A principal impediment to sustaining and expanding the natural Chinese sturgeon populations is the lack of scientific understanding of the distribution, migration attributes, and habitat selection [9]. This dilemma is particularly pronounced in the YRE, as there are four channels with access to the sea, such as the North Branch (NB), the North Channel in the South Branch (NC), the North Passage in the South Channel (NP), and the South Passage in the South Channel (SP) in this area, and more choices create more uncertainty. Up to now, only Wu et al. had speculated that the NC was the main channel for sturgeon entering the sea, based on the difference in the number of bycatch (7 sturgeons in the NC, 2 sturgeons in the Chongming Shoal, and 1 sturgeon in the SP) [10]. Other studies have not reported detailed migration trajectories [17,18]. Obviously, the answer to the question of what channels Chinese sturgeon use will help formulate and improve conservation policy to increase the effectiveness of conservation efforts.

Bottom trawling, fyke nets, marine bycatch, and mark–recapture have been the main methods used to locate Chinese sturgeon around the YRE and its adjacent areas [9,10,15,18,19]. Due to the lower probability of tag recapture [9,18,20] and the expensive cost of electronic tags, there are limited data available on the exact distribution of Chinese sturgeon in this area. eDNA technology has recently been utilized to analyze the spatial distribution in various environments in the YRE [21,22], but is still in the technology validation phase. For aquatic organisms that do not surface for long periods of time, the pop–up satellite tag (PAT) has become an effective tool for tracking large–scale migrations due to its low behavioral disturbance, wide monitoring range, and ability to be located underwater [23]. The use of the PAT to study the movement and habitat selection of species like bigeye thresher shark [24], whale shark [25], and the broadnose sevengill shark [26] has been increasing. Acipenseriformes are typically bottom dwellers and are relatively rare, usually found at great depths, and swimming too rapidly to be tracked, especially in low–light or turbid conditions [27]. This situation makes it more difficult to effectively monitor sturgeon behavior, whereas the PAT provides an excellent tool for monitoring. Studies on the marine habitat use of Shortnose sturgeon [28] and the oceanic migration trajectories of Atlantic sturgeon [27] had used the PAT as an effective research tool. A total of eight green surgeons caught in the Columbia and Rogue Estuaries also allowed obtaining information about offshore distribution using PATs [29]. Another advantage of the PAT is the longer working life for tracking sturgeon movement in different periods. A one–year–long continuous monitoring study on Gulf sturgeon migration was successfully implemented in northwestern Florida [30], and the migration pattern was similar to the Atlantic sturgeon [31]. Given the widespread distribution of Chinese sturgeon along the coastal continental shelf, the PAT appears to be an ideal research tool [1,17,18,23].

With the scale of the Chinese sturgeon restocking program along the Yangtze River gradually increasing, an increasing number of artificially bred Chinese sturgeon will be released into the natural environment [32], and more and more sturgeons will appear in the YRE. It was essential to identify how the Chinese sturgeon distributes upon arriving at the YRE, which could help to clarify exactly the habitat selection and utilization of this species in the sea. The objective of this research was to investigate the migration and spatial distribution characteristics of Chinese sturgeon in the YRE and to obtain the first insights into the influence of the environment on their spatial distribution.

2. Materials and Methods

2.1. Study Area

The Yangtze River is the third longest river in the world, and the YRE is located at the midpoint of China's coastal line (where the East China Sea meets the Yellow Sea). The YRE has a maximum width of about 90 km, and its unique estuary topography is formed by the islands of Chongming, Changxing, Hengsha, and several shoals, creating a land–sea complex with large runoff and strong tidal currents. In April 2021, eight Chinese sturgeons were released in the nearshore waters of Chongming Island (31.457373° N, 121.775723° E) and six sturgeons were released in the nearshore waters on the northwest side of Hengsha Island (31.37495° N, 121.9148° E) in October 2022 (Figure 1b). The water temperature was about 14.88 °C in April and 21.48 °C in October, while the salinity was about 1.76 in April and 8.13 in October.

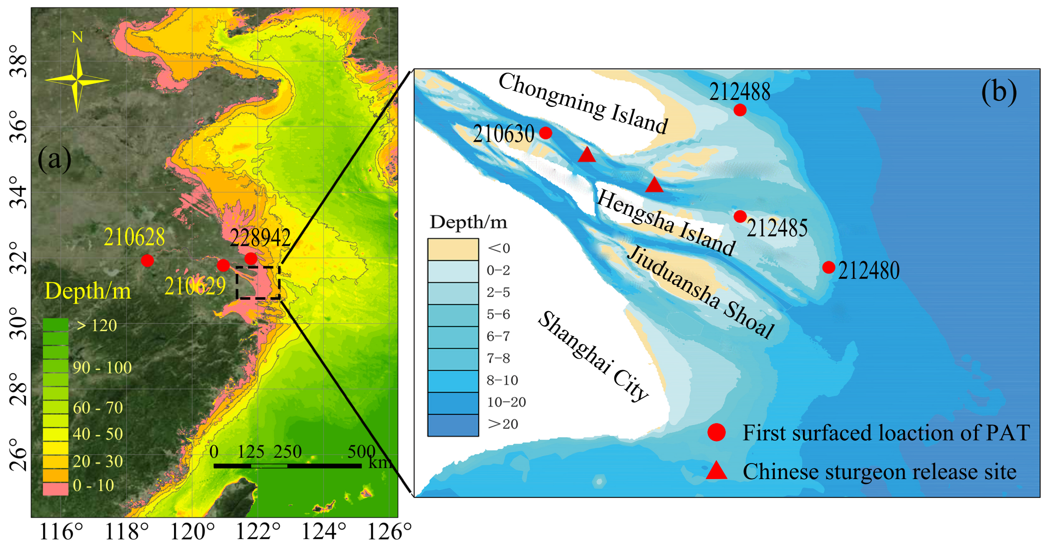

Figure 1. A total of 14 Chinese sturgeons were released in the North Channel of the Yangtze River Estuary (2021, 31.457373° N, 121.775723° E; 2022, 31.37495° N, 121.9148° E) (**b**). Chinese sturgeons were distributed between Hengsha Island and the Chongming Island (212480, 212485, and 212488), the mainstream of the Yangtze River (210628 and 210629), the North Channel of the Yangtze River Estuary (210630), and the offshore shoals (228942) (**a**,**b**).

2.2. Tagging and Releasing

The eight sturgeons in 2021 and six sturgeons in 2022 had a total length range of 200–210 cm ($\bar{x} = 205$ cm) and 165–175 cm ($\bar{x} = 168.75$ cm) and a body weight range of 55.0–64.5 kg ($\bar{x} = 59.5$ kg) and 28.0–34.5 kg ($\bar{x} = 31.38$ kg), respectively (Table 1).

Table 1. Basic information on Chinese sturgeon released in 2021 and 2022.

PAT ID	Age (a)	Gender	Total Length (cm)	Body Weight (kg)	PAT Type	Sturgeon Release Date	First Surfaced Coordinate
210628	10	Male	175	32.5	mini-PAT	9 April 2021	32.1675° N, 119.5188° E
210629	10	Male	165	28.0	mini–PAT	9 April 2021	31.7299° N, 121.1042° E
210630	12	Male	200	60.0	mini–PAT	9 April 2021	31.4897° N, 121.6867° E
212480	10	Male	165	30.5	mr–PAT	9 April 2021	31.235° N, 122.355° E
212482	12	Male	210	64.5	mr–PAT	9 April 2021	——
212485	12	Male	200	58.5	mr–PAT	9 April 2021	31.336° N, 122.095° E
212486	12	Male	210	55.0	mr–PAT	9 April 2021	——
212488	10	Male	170	34.5	mr–PAT	9 April 2021	31.579° N, 122.084° E
228935	9	Female	180.0	31.5	mini–PAT	20 October 2022	——
228936	9	Male	167.0	27.5	mini–PAT	20 October 2022	——
228937	9	Male	155.0	21.0	mini–PAT	20 October 2022	——
228938	9	Female	155.0	16.5	mini–PAT	20 October 2022	——
228941	9	Male	155.0	21.0	mini–PAT	20 October 2022	——
228942	9	Male	140	14.5	mini–PAT	20 October 2022	32.0002° N, 121.7209° E

Each sturgeon was tagged with a PAT (mini–PAT and mr–PAT from Wildlife Computers Inc., Washington, DC, USA, https://wildlifecomputers.com/; mini–PAT size of 124 mm × 38 mm, 60 g in air, maximum deployment length of 2 years; mr–PAT size of 127 mm × 28 mm, 40 g in air, maximum deployment length of 730 days). The mini–PAT is a microprocessor–controlled data–logging tag that records parameters such as dive depth (via pressure), water temperature, wet/dry readings, and light levels over time. Estimates of location can be determined from light intensity. When the preset time arrives, the mini-PAT automatically pops up and floats to the surface, then transmits data through the ARGOS.The mr–PAT only provides the locations after surfacing. The mini–PAT release program was based on the 'Activate premature release–tag detachment/mortality' function, which is, if a tag has been floating on the surface or remaining at a constant depth for an extended period, the animal would be deemed do be in danger of mortality and premature release would be initiated. The mr-PAT deployed in 2021 only reported a series of locations after the PAT surfaced. It also has the 'Activate Premature Release-Tag Detachment' function, automatically triggering if the PAT's status is more than 5% dry for 2 consecutive hours.

The wet/dry sensor of the PAT gives a range of readings depending on the conductivity of the water, for example fresher water causes high readings (>100), while salt water causes lower readings. This indicator becomes the decisive factor in determining the status of the PAT, that is when the readings are > 100, the PAT would default to being on the surface of the seawater, even if the PAT is suspended in fresh water, which will initiate the premature release procedure. The mini–PATs deployed in 2021 were set to 'Start' mode, which allows a tag to begin its deployment immediately, and PATs deployed in 2022 were set to 'Auto–Start' mode, which allows the tag to start once submerged in the seawater.

One dorsal bone plate, selected from the 3rd to 5th bone plates of the sturgeon, was drilled with a 2 mm diameter hole. A stainless rope ring was then bound through the hole to fix the PAT (Figure 2d). All operations were performed under anesthesia (MS–222, Tricaine Methane Sulfonate, which was used to make the sturgeons calm enough; the concentration was 80–90 mg/L), and the anesthesia took less than 5 min. When the sturgeon was unconscious, indicators such as body weight and total length were measured. Each fish transport vehicle has 5 water tanks with a size of 2.5 m × 1 m × 1 m and two tanks of 50 L of liquid oxygen for oxygen supply and temperature control (Figure 2a). Each vehicle carries four sturgeons and reserves a water tank to hold aquaculture water for replenishment along the way. After transferring the Chinese sturgeon to temporary tanks (3 m × 2 m × 0.8 m) on the deck of the workboat, the vessel immediately departed for the release site (Figure 2b).

Figure 2. The Chinese sturgeon was transferred from the transport vehicle (**a**) to the release workboats (**b**). Before release, a health check was carried out (**c**), and pop–up satellite tags were attached to their dorsal plates (**d**).

2.3. Data Analyses

The monitoring data, such as dive depth, water temperature, wet/dry reading, light intensity, and geolocation data, were obtained from the recovered PATs (https://my.wildlifecomputers.com/) and processed using WC–DAP and the IGOR PRO 6.37 software. The hydrological data of the Southern Branch of the YRE, such as salinity, water temperature, and depth at the monitoring stations, were obtained from the Shanghai Estuarine Coastal Science Research Center. Seabed topography data for China's offshore areas were obtained from the National Marine Data Center, National Science & Technology Resource Sharing Service Platform of China (http://mds.nmdis.org.cn/). Marine bycatch information for 58 Chinese sturgeons from 2015 to 2023 was obtained from networks, including TikTok and WeChat. The East China Sea Fisheries Research Institute, Chinese Academy of Fisheries Sciences, China, provided the bycatch information of 150 Chinese sturgeons in Hangzhou Bay in 2022.

SPSS 21.0 and Origin 2021 were used for statistical analysis and plotting. ArcGIS Pro 3.0. was used for mapping.

3. Results

3.1. Marine Bycatch Information

The limited marine tracking data on Chinese sturgeon indicate that this species can be found in deep waters (water depths > 20 m, and up to 100 m) away from the coast [17,18], in contrast with marine bycatch, which is mainly distributed near the coast (water depths do appear to exceed 50 m) (Figure 3a). Meanwhile, the analysis of marine bycatch data from 2015 to 2023 showed that Chinese sturgeon have a higher probability of occurrence (68%) in the southern part of the YRE, such as Hangzhou Bay, the Zhoushan Island area, and the Taizhou and Wenzhou area on the southeast coast of Zhejiang Province (Figure 3a,b). In particular, a total of 183 Chinese sturgeons (weighing 1–4 kg, less than 2 years old) were bycatched in Hangzhou Bay from 2022 to 2023, which is much higher than the marine bycatch in the above-mentioned areas. This suggests that although the Chinese sturgeon is reportedly widespread along the Chinese coast, there are still areas of concentration.

Chinese sturgeon are only found in the southern part of the YRE from January to July, with concentrations of sturgeon bycatch occurring in March (29.41%) and April (29.41%) (Figure 3b), coinciding with the East China Sea fishing season (http://www.yyj.moa.gov.cn/gzdt/202102/t20210225_6362228.htm, accessed on 12 October 2023). Meanwhile sturgeon is found in Hangzhou Bay almost year round (except for June and July, which are closed seasons, the bycatch data not being available, https://www.gov.cn/zhengce/zhengceku/2019-10/15/content_5439903.htm, accessed on 15 December 2023). In addition, April (22.95%) and September (31.15%) are the months with the highest proportion of Chinese sturgeon in Hangzhou Bay (Figure 3c). Changes in bycatch number could provide an initial indication that there is a cyclical migration of Chinese sturgeon in their coastal habitat.

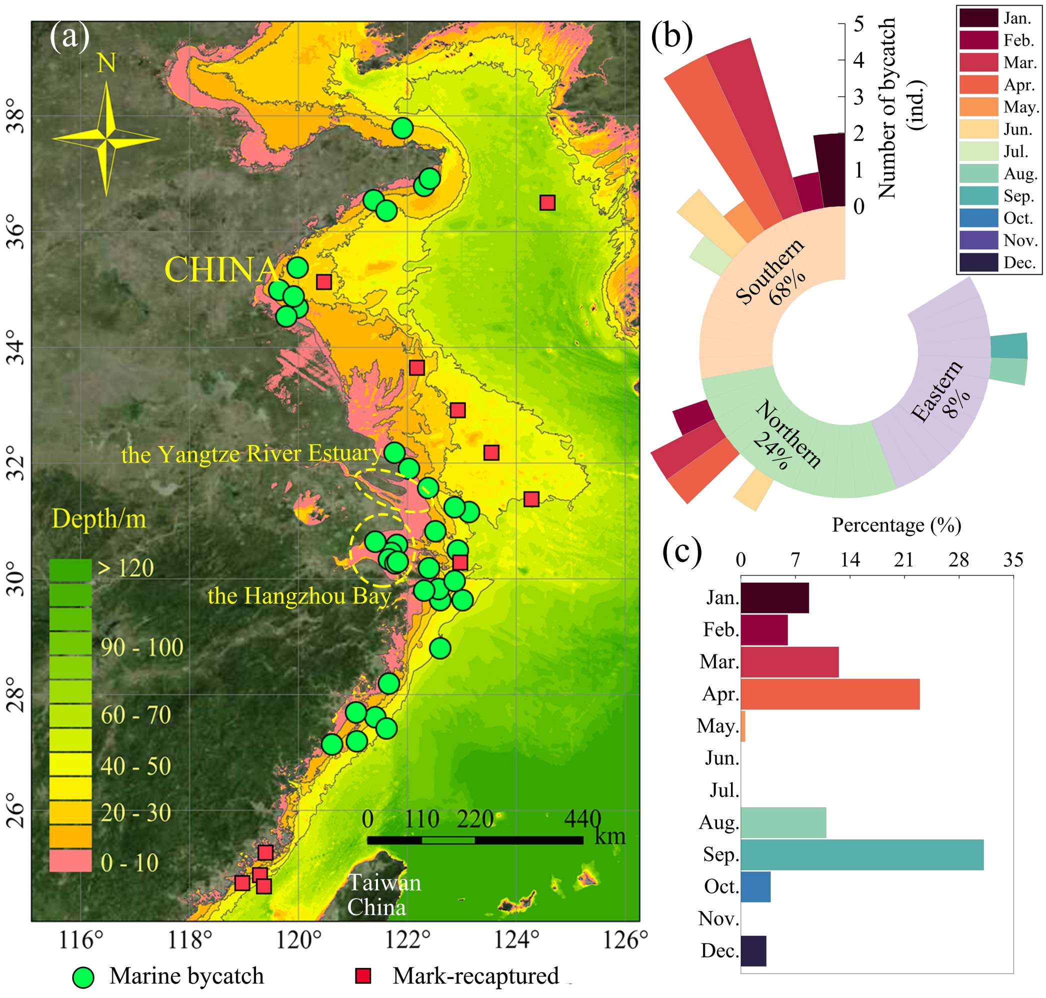

Figure 3. According to marine bycatch from 2015 to 2023 and mark–recapture from 2006 to 2012 [17,18], Chinese sturgeon was mainly distributed along the Chinese coast (**a**). The number of bycatched animals in the southern part of the Yangtze River Estuary is higher than the northern and eastern parts, with a concentration in March (29.41%) and April (29.41%) (**b**). April (22.95%) and September (31.15%) are the months with the highest bycatch proportion of Chinese sturgeon in Hangzhou Bay (**c**).

3.2. Tag Deployment

Fourteen PATs were deployed, and 50% of them provided a set of post–surfacing coordinates that did not characterize the underwater movement. There were 60% of the mr–PATs (212480, 212485, and 212488) that were successfully recovered, which were prematurely released within 1 day after deployment, and located in Hengsha Shoal and the northern Chongming Shoal, and 50% of the mini–PATs (210629, 210629, 210630, and 228942) were recovered and spread along the Yangtze River and the offshore shoals (Table 2 and Figure 1).

According to the time difference between tag release and first transmission, these mr–PATs should successfully start the release program by moving into the saline water, and they remained in the marine water until returning to the freshwater 2 h before release (according to the premature release program of the mr–PAT). The first coordinate of 210628 was located in the Zhenjiang River section (approximately 260 km upstream from the release site) 37.2 days after release. The time difference between tag deployment and release was 3.5 days, indicating that this sturgeon took no more than 3.5 days to migrate upstream to Zhenjiang after tag release. The coordinate of 210629 exhibited the same migration characteristics, which took no more than 3.52 days to move back to the Taicang River section (approximately 60 km upstream from the release site). The completion rates of the preset time for 210630 and 228942 were much higher than the others. It was interesting that 228942 appeared offshore in Lvsi, north of the YRE (Table 2 and Figure 1).

Table 2. Information on seven recovered PATs that were attached to Chinese sturgeon.

PAT Type	PAT ID	Deploy Time	Tag Release Time	Actual Working Time/Preset Time (d)	First Transmission Time	Time Difference between Tag Release and First Transmission (d)
mini–PAT	210628	2021–4–9 13:53	2021–4–13 1:00	3.5/30	2021–5–14 19:37:28	31.78
mini–PAT	210629	2021–4–9 14:09	2021–4–13 4:00	3.52/100	2021–5–7 8:36:39	24.19
mini–PAT	210630	2021–4–9 13:49	2021–6–6 10:00	56.85/60	2021–6–16 4:33:25	9.77
mini–PAT	228942	2022–10–20 12:01	2023–4–19 4:00	179.67/180	2023–4–19 5:05:40	0.05
mr–PAT	212480	2021–4–9 13:42	2021–4–10 14:00	1.01/60	2021–4–11 18:24:35	1.18
mr–PAT	212485	2021–4–9 13:44	2021–4–9 19:00	0.22/100	2021–4–15 3:34:18	5.37
mr–PAT	212488	2021–4–9 13:39	2021–4–10 3:00	0.56/100	2021–4–11 7:09:06	1.17

3.3. Distribution Characteristics

Due to the varying monitoring durations of the recovered data, the entire monitoring period of the PATs (210629, 210630, and 228942) was divided into phases of varying durations based on changes in dive depth for post–data analysis. The monitoring duration of 210629 could be divided into three phases (Figure 4a). The depth and temperature were significantly lower in phase 1 (within 21 h after release) than in phase 2 (22–37 h after release) and phase 3 (38–88 h after release) ($p < 0.01$). It should be noted that the depth (9.38–16.63 m, $\bar{x}$ = 13.15 m) had a significant positive correlation with the temperature (15.61–15.9 °C, $\bar{x}$ = 15.8 °C) ($p < 0.05$) during phase 2 (22–37 h after release), which may be related to the high-temperature water tongue at the bottom of the YRE, which will gradually strengthen as the flood season approaches [33].

The change in depth of 210630 appears to be more complex and can be divided into four phases (Figure 4b). In phase 1, this PAT remained in shallow waters (1.46–15.38 m, $\bar{x}$ = 7.5 m; 12.8–15.6 °C, $\bar{x}$ = 14.26 °C) for the initial 52 h after release, with no significant correlation between depth and temperature ($p > 0.05$). This PAT rapidly came to deeper waters (19.88–54.5 m, $\bar{x}$ = 31.77 m; 11.47–17 °C, $\bar{x}$ = 12.98 °C) and remained for approximately 403 h (from 11 April to 5 May) in phase 2. From 5 May, this PAT gradually came to a shallower area ($\bar{x}$ = 15.25 m in phase 3 and $\bar{x}$ = 6.27 m in phase 4). A significant negative correlation was found between depth and temperature in phase 2, phase 3, and phase 4 ($p < 0.05$).

The classification of 228942 was relatively straightforward, although it had the longest recorded data from 24 October to 19 April of the following year (Figure 4c). Phase 2 had a significantly lower depth (0.5–12.0 m, $\bar{x}$ = 2.46 m) and temperature (−1.4–21.0 °C, $\bar{x}$ = 8.63 °C) than those in phase 1 (2.0–23.5 m, $\bar{x}$ = 11.91 m; 18.9–19.4 °C, $\bar{x}$ = 19.24 °C) ($p < 0.01$). It should be noted that the temperature dropped below 0 °C and reached a minimum of −1.4 °C on 31 January with the depth remaining at 1.5–2.5 m, and the water temperature on 31 January and 10 March was highly consistent with the changing rhythm of the air temperature in Rudong City, Jiangsu Province, where the PAT popped up (Figure 1a). This abnormal water temperature and depth data indicated that the PAT had probably been entangled by something since phase 2, and the sturgeon's situation could not be determined.

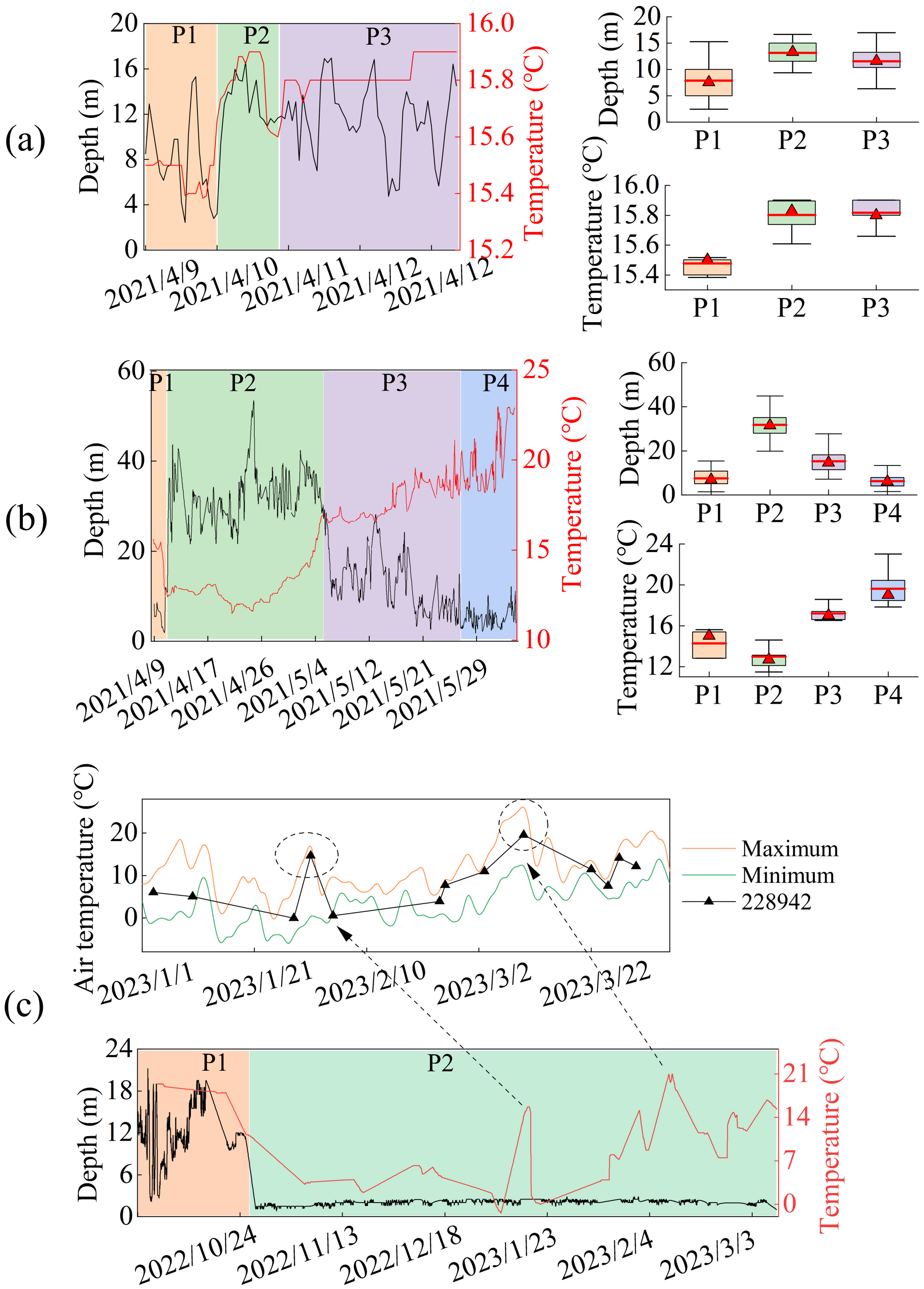

Figure 4. Changes in depth and temperature of 210629 (**a**), 210630 (**b**), and 228942 (**c**) during different phases. 'P' in the diagram means 'phase'.

3.4. Projection of Migration Trajectories

The depth of 210630 in phase 2 (30.45 ± 7.12 m) was significantly deeper than that of the monitoring stations along the South Branch ($p < 0.01$), which indicated that this sturgeon must be present in deep water (>20 m) off the YRE in this period (Figure 5a). Although the dive depth of 210630 was close to the water depth of the monitoring stations during phase 1 and phase 4, there was no similarity to the characteristics of the hourly water depth variations in these two phases (Figure 5b), indicating that this sturgeon may not pass through the range of the monitoring stations (basically covering the lower reaches of the South Branch waterway) during its departure and return from the YRE.

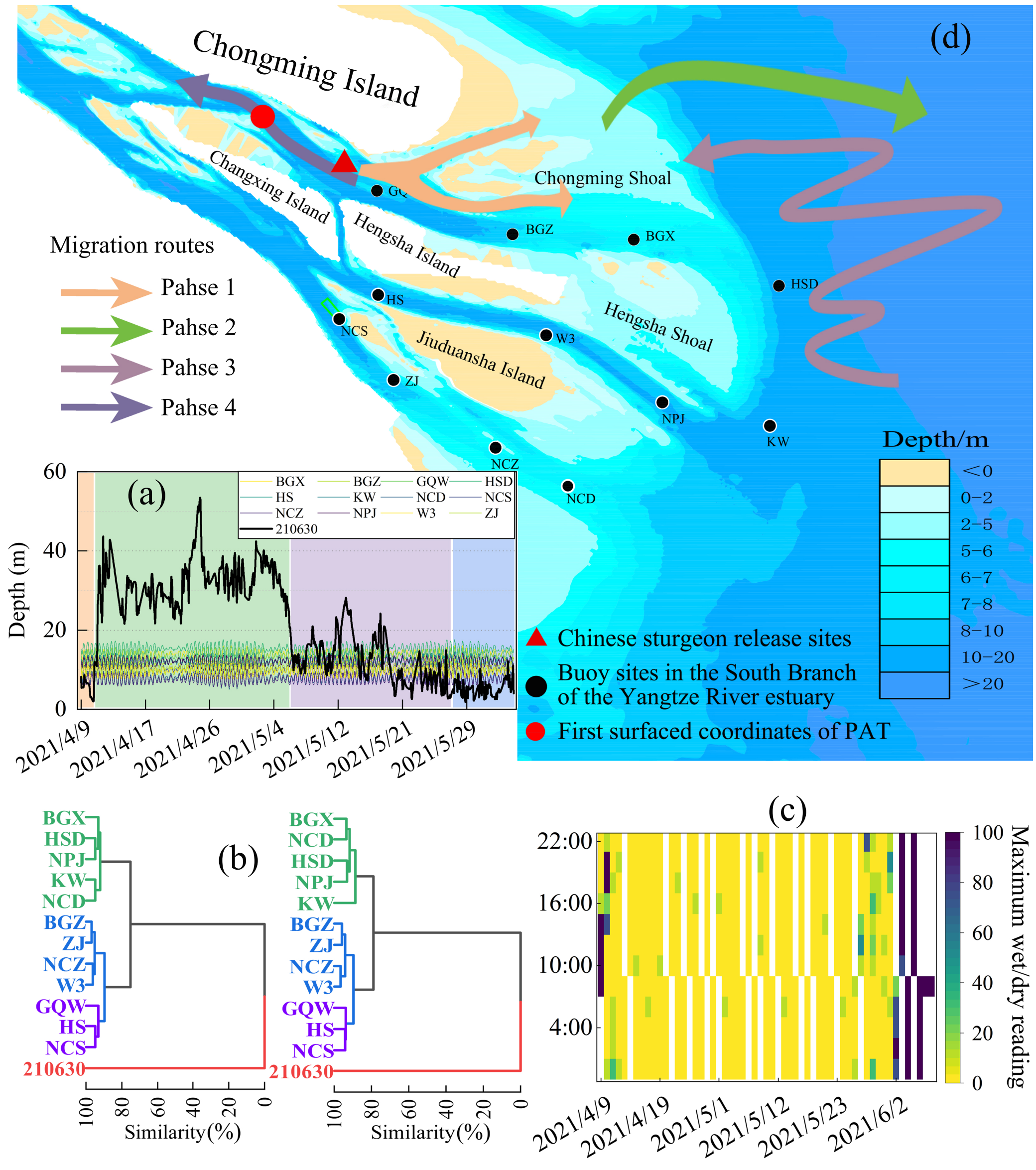

Figure 5. The dive depth of 210630 was different from the twelve monitoring stations along the Southern Branch of the Yangtze River Estuary (**a**), and there was no similarity between 210630 and those monitoring stations (**b**). The maximum wet/dry reading of 210630 showed that this sturgeon could move in both salt and fresh water (**c**). Based on this evidence, it has been suggested that Chinese sturgeon migrate freely between deeper waters and shallower shoals and that the North Channel in the Yangtze River Estuary may be the main passage for sturgeon to enter and exit (**d**). The arrows only indicate the potential migration direction of the Chinese sturgeon and do not represent the actual migration route.

The maximum wet/dry reading of 210630 varied from 0 to 75 between 9 April and 3 June and remained at 100 from 3 June to 6 June. This indicated that this sturgeon had stayed in the seawater for tens of days and, finally, returned to the freshwater of the Yangtze River after 3 June. Interestingly, the maximum wet/dry reading changed from 100 to 0 to 100 within 28 h from 9 to 10 April and from 2 and 4 June (Figure 5c), suggesting that this sturgeon may have moved from freshwater to saltwater, then back to freshwater, and finally, back to saltwater during these periods.

It was shown that, 24 h before this sturgeon entered the deep zone, its average depth was 3 m with a maximum change of 8 m (phase 1); considering that it remained in the saltwater and freshwater interface zone, it was estimated that this sturgeon could be distributed in Chongming Shoal in phase 1 before it formally entering the deep sea; specifically, it could choose to pass through the northern waters of several monitoring stations (GQW–BGZ–BGX) in the NC towards the sea (Figure 5d). The average depth of this sturgeon showed no difference between different periods in phase 4 (before 2 June, 6.3 ± 2.71 m; from 2 to 4 June, 5.88 ± 2.57 m; after 4 June, 7.2 ± 2.89 m), indicating that the distribution area in phase 4 was a salt and freshwater interface zone with a depth of less than 20 m, which could be met by the Chongming/Hengsha Shoals in the YRE. Based on the first surfaced coordinate (Table 1) and the time difference between tag deployment and release (Table 2), it can be confirmed that this sturgeon had entered the mainstream of the Yangtze River before 6 June (Figure 5d).

4. Discussion

4.1. Why Does the Sturgeon Choose the North Channel Seawards?

Wu et al. highlighted that the NC was the main place for Chinese sturgeon to stay and the main channel for Chinese sturgeon to enter the sea, based on the data showing that 7 of 12 recaptured sturgeons were found in the NC, while only 2 were found in Chongming Shoal and 1 in the SP [20]. In this study, more detailed data revealed that one sturgeon (210630) seemed to enter and exit the YRE through the NC waterway, further corroborating the speculation that the NC could be the Chinese sturgeon's main seaward and anadromous passage. Further evidence can be found in research carried out by Wang et al., who discovered seven large Chinese sturgeons from the Nantong waters in the southern part of the Yellow Sea to Xiangshan Port in Zhejiang Province in 2006, with three individuals found in the NC [19]. Also, the bycatch information of this species in the YRE confirmed this observation [6,19,34,35]. Moreover, several juvenile Chinese sturgeons were recently captured in the NC (about 10 km upstream of the 2021 release site) 2 months after release (unpublished data), which presented additional supporting evidence.

Why did Chinese sturgeon choose the NC to pass through rather than others? Food resource may play a key role. Areas with abundant dietary resources, referred to as biological 'hotspots', have attracted green sturgeon migrating northward to the Bering Sea for overwintering [29]. The YRE might be such a well–known hotspot for Chinese sturgeon. The diet of Chinese sturgeon in the YRE mainly consisted of small, soft–bodied suprabottom or intrabottom organisms, such as goby, oligochaetes, crustaceans, and polychaetes [11]. With the growth of the Chinese sturgeon, its predatory ability is gradually strengthening [34]. The phytoplankton biomass in the NC is higher than other areas in the YRE [19], which might increase fish species richness and total fish catch per unit effort (CPUE) significantly [36]. Shallow areas such as Chongming Shoal, Hengsha Shoal, and Beisha Shallow are abundant in potential appropriate food resources, and they might also attract a concentration of Chinese sturgeon [11,37,38]. Meanwhile, influenced by high sedimentation rates, the scouring effect of the Yangtze River outflow, and disturbances from anthropogenic channel dredging and ship anchoring, the benthic environment of the South Channel is highly unstable and difficult for most benthic fauna to acclimate to, reducing benthic composition and abundance [39,40]. These factors would further exacerbate the distribution of fish to the NC. The Chinese Sturgeon Nature Reserve and the Shanghai Chongming Dongtan National Nature Reserve, which are located downstream of the NC, have been fully protected for an extended period [41]. This protective measure minimized human interference and guaranteed safe passage for the Chinese sturgeon.

The physiological structural (osmotic pressure) tolerance may also be a major factor influencing Chinese sturgeon's choice of passage through the NC. Research on the isosmotic point of Chinese sturgeon suggested that sturgeon that had been reared for a long time in a freshwater environment would show a phenomenon of avoiding or accelerating their passage when released into saltwater [42–44]. The diversion ratio of the NC is comparable to that of the South Channel, almost half of the Yangtze River runoff, while the diversion ratio of the NB does not exceed 5% [45]. The significant diversion ratio between the NC and the NB results in the water in the NC having a relatively low salinity level before passing through the entrance of the NC, and the freshwater mainly affects the surface and subsurface water bodies, with less impact on the middle and bottom water bodies [45,46]. Chinese sturgeon, which had recently arrived at the YRE, were more likely to disperse in shallow waters of the NC (Figure 4), as the flow pattern and low salinity level in these areas are close to the mainstream of the Yangtze River. Sturgeons were released into lower salinity–level water (1.76 salinity at release site) in 2021, and different activities were shown, e.g., three sturgeons (212480, 212485, 212488) stayed in the saline water for one day and returned to the freshwater, one sturgeon (210629) returned to the freshwater immediately, while one sturgeon (210630) entered the saline water and stayed for dozens of days. These differentiated behaviors may be the result of adaptation to salinity.

4.2. How Does the Sturgeon Distribute along the Chinese Coast?

The YRE is well known as a natural habitat for the Chinese sturgeon, with the most concentrated populations and the longest staying period throughout its whole lifetime [9,10,17]. Several Chinese sturgeons released in this study were mainly distributed in the nearshore area in the YRE, such as the eastern Jiuduansha Shoal, southern Hengsha Island, and northeastern Chongming Island (Figure 1b). The vast area of mudflats in the YRE and the large number of nutrients brought by the confluence of salty and fresh water make this area the estuary with the richest fish biodiversity and the highest potential for fishery production in China [37,47]. This might be the major reason why this area was able to attract sturgeon stock. If Chinese sturgeon were to leave the YRE, what factors would attract their arrival? Evidence shows that Chinese sturgeon can be found in the waters of the Yellow Sea, the East China Sea, the Korean Peninsula, Goshima Island, the Zhoushan-Xiangshan Islands, and the Xiamen area [6,9,17,19]. These locations with time of these sturgeons being present seemed to align with the East Asian ocean currents. From May to August, the northward Taiwan warm current and the Yangtze River runoff formed a complex current environment in the shallow stretch between the YRE and the Zhoushan Islands, creating the Hangzhou Bay Circulation and other whirlpools [48,49]. The large amount of nutrients brought by the current made these regions rich in food resources, which attracted the sturgeons to concentrate [18] (Figure 3a). During autumn and winter, the southward littoral current was strengthened [48], and the nutrients of the YRE–Zhoushan Islands moved with the current southward [50], with 29.17% of tagged sturgeons recaptured at the south of the YRE [10]. At the same time, the low–salt water mass began to follow the course of the seafloor topography outward the YRE and then turned sharply to the northeast around 122° E, pointing directly at Jeju Island [45]. The nutrients moved with the current and attracted some of the Chinese sturgeon to appear in the vicinity of Goshima Island [17]. Meanwhile, with the retreat of the northeast monsoon in the spring and the rise in water temperature in the autumn, the current along the Fujian and Zhejiang coasts continued to weaken, while the Kuroshio and the South China Sea warm currents strengthened, creating a situation of nutrient enrichment and the growth of fishery resources in the Xiamen region (south of Chongming Island, the linear distance was 850 km) and its near–shore bay waters [51], resulting in the Chinese sturgeon released in Xiamen in autumn mainly concentrating in the Xiamen waters [18].

Abundant food resources can be another direct and important factor in attracting sturgeon to a particular area. Changes in flow from the Yangtze River to the sea could cause changes in the temperature of estuarine and offshore waters [43], which in turn affect the distribution of macrobenthos and fishes [52–54]. The unique trend of hydrological variability in the YRE had resulted in an abundance of benthic organisms in this area, which contributed to the normal feeding and concentrated residence of both released and wild individuals in these areas [11,16,18,34,55]. Several other known distribution areas of Chinese sturgeon, such as the Zhoushan Islands area, Zhejiang coastal area, etc., were areas of high fish abundance [56,57]. In the northern coastal area of Zhejiang, high–quality food resources for large Chinese sturgeon such as *Chaeturichthys hexanema*, *Larimichthys polyactis*, and *Collichthys lucidus* had become a component of the 16 dominant species in the Zhoushan Fishing Ground [34,56]. The marine bycatch information showed that the proportion occurring in the southern area of the YRE was much higher than in the other areas (Figure 3a). A reasonable explanation could be that the northwards warm currents and freshwater from the Yangtze River meet at the Zhejiang coast, significantly increasing turbidity and nutrients in the coastal waters [58]. With the increase in phytoplankton and fish resources, this coastal area had gradually become a concentrated distribution area preferred by the Chinese sturgeon.

The salinity levels in the YRE may be a potential limiting factor affecting the distribution and migration of Chinese sturgeon in the sea. In 2021, the salinity along the YRE increased from 0.1 to 24.7 along its seaward course, as the salinity at GQW was only 1.76, but 4 at BGZ, 9.3 at BGX, and 24.7 at HSD. During low water levels with high tides, the salinity can reach up to 34 at HSD [46]. The gradually increasing salinity level may force released Chinese sturgeon to stay in areas with low salinity, or even return to the mainstream of the Yangtze River. There was clear evidence to prove that 5 of 6 tagged sturgeons with recovered PATs (210628, 210629, 212280, 212485, and 212485) in 2021 moved back to the freshwater within three days. The bycatched Chinese sturgeons were mainly distributed within 15 km of coastal areas [18] (Figure 1a), where the salinity may not exceed 31 [43,59]. Li et al. pointed out that the Chinese sturgeon had normal activity at salinities of 25, but mortality occurred above 35 [42]. This can be explained as the sturgeon having to engage in some resistance behavior to reduce the physiological stress caused by the excessive salinity and to ensure the organism's normal energy intake and survival. In addition, the high salinity brought by the Taiwan warm current was a barrier to the distribution of macrobenthos, and the 32 isobath restricted their further development outward to the open ocean [52,60]. As a quality food resource for Chinese sturgeon, the distribution of macrobenthos may somewhat determine the sturgeon's distribution (most locations of Chinese sturgeons were within a 50 m depth of the continental shelf [18]).

5. Conclusions

As the scale of the Chinese sturgeon restocking along the Yangtze River gradually increases, it has become necessary to clarify how sturgeon migrate and disperse in the Yangtze River Estuary to gain insights into their marine habitat utilization. This study provides relatively detailed evidence that the released Chinese sturgeons can adapt to the estuarine environment and can autonomously choose the North Channel as their migrate passage. This study makes a positive contribution to the advancement of the marine conservation of Chinese sturgeon. Given the limited research data, more marine studies need to be conducted to help formulate and improve conservation policies.

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