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The original submitted manuscript has been translated into English. The translation was done using artificial intelligence. A subsequent revision was performed by the author(s) to further refine the work and to ensure that the translation is appropriate concerning content and scientific correctness. It may, however, read stylistically different from a conventional translation.

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Preface

Chinese sturgeon is considered "living fossil" with significant scientific research value. Like other sturgeons, the wild population of Chinese sturgeon is at serious risk of extinction. In 2010, it was listed as a critically endangered (CR) species by the International Union for Conservation of Nature (IUCN). Currently, Chinese sturgeon is only distributed in the Yangtze River and its adjacent sea waters. As a flagship species in the Yangtze River, the wild population of Chinese sturgeon reflect the health of the Yangtze River ecosystem, with immeasurable ecological and social values.

Chinese sturgeon is a typical anadromous species, spawning in the middle and upper reaches of the Yangtze River and growing in the sea. The Yangtze River estuary (YRE) is the only nursery ground for Chinese sturgeon, where young fish complete physiological and ecological adaptations before entering the sea, playing a vital role throughout their life history. The authors and their research team have focused on growth, development, environmental adaptation, and regulation of the young Chinese sturgeon for over 20 years, including field investigation and experimental researches. These works accumulated a wealth of first-hand research data and scientific achievements and have enriched knowledge of the Chinese sturgeon's life history. It also provides a scientific basis for the conservation management of Chinese sturgeon.

The *Environmental Biology of Young Chinese Sturgeon* is compiled based on our findings mentioned above and consists of a total of 8 chapters written by esteemed researchers. This book opens with an overview of the Chinese sturgeon and its research history in Chap. 1. The morphological characteristics and ecological adaptation are discussed in Chap. 2. The early development and ontogenetic behavior are discussed in Chap. 3. The growth, feeding, and environmental regulation are discussed in Chaps. 4 and 5. The salinity adaptation and osmoregulation are introduced in Chap. 6. The toxicological effects of heavy metals are discussed in Chap. 7. This book concludes with Chap. 8, which introduces migration and population dynamics of Chinese sturgeon. We are grateful to all our colleagues who contributed to this book.

We hope to achieve both academic and practical value, aiming to provide reference for scientific researchers, decision-making support for government departments, and popular science knowledge for a wide range of readers.

Shanghai, China Feng Zhao
Shanghai, China Ping Zhuang
Shanghai, China Tao Zhang
October, 2023

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Feng Zhao

Contents

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Abbreviations

$^1O_2$	Singlet oxygen
973 Program	The National Key Basic Research and Development Program
A. baerii	*Acipenser baerii*
A. brevirostrum	*Acipenser brevirostrum*
A. fulvescens	*Acipenser fulvescens*
A. longirostris	*Acanthomysis longirostris*
A. medirostris	*Acipenser medirostris*
A. naccarii	*Acipenser naccarii*
A. ommaturus	*Acanthogobius ommaturus*
A. oxyrinchus desotoi	*Acipenser oxyrinchus desotoi*
A. oxyrinchus	*Acipenser oxyrinchus desotoi*
A. ruthenus	*Acipenser ruthenus*
A. schrenckii	*Acipenser schrenckii*
A. sinensis	*Acipenser sinensis*
A. sturio	*Acipenser sturio*
AAS	Amino acid score
AChE	Acetylcholinesterase
AE	Anterior edge of the eye
Ala	Alanine
ALB	Albumin
ALP	Alkaline phosphatase
ALT	Alanine aminotransferase
AM	Anterior edge of the mouth
AMOVA	Analysis of molecular variance
Arg	Arginine
AS	Rostrum tip
Asp	Aspartic acid
AST	Aspartate aminotransferase
B. rerio	*Brachydanio rerio*

BCFs	Bioconcentration factors
C. carpio	*Cyprinus carpio*
C. crocodilus	*Cociella crocodilus*
C. ectenes	*Coilia ectenes*
C. fluminea	*Corbicula fluminea*
C. gracilis	*Cynoglossus gracilis*
C. guichenoti	*Coreius guichenoti*
C. heterodon	*Coreius heterodon*
C. joyneri	*Cynoglossus joyneri*
C. mystus	*Coilia mystus*
C. nasus	*Coilia nasus*
C. stigmatias	*Chaeturichthys stigmatias*
Ca	Calcium
cAMP	Cyclic adenosine monophosphate
CAT	Catalase
CI	Confidence interval
CK	Creatine kinase
Cl	Chlorine
CPUE	Catch per unit effort
Cr	Cadmium
CR	Critically endangered
CREA	Creatinine
CS	Chemical score
CWT	Coded wire tags
Cys	Cystine
DDT	Dichlorodiphenyltrichloroethane
DHA	Docosahexaenoic acid
D_{hold}	Adhesive ability
D_{swim}	The net swimming ability
E. annandalei	*Exopalaemon annandalei*
E. carinicauda	*Exopalaemon carinicauda*
E. leptognathus	*Eriocheir leptognathus*
E. morsei	*Euprymna morsei*
E. muticus	*Eupleurogrammus muticus*
EAA	Essential amino acids
EAAI	Essential amino acid index
EDCs	Endocrine-disrupting chemicals
ELHF	The early life history of fish
EPA	Eicosapentaenoic acid
F^-	Fluoride ions
F_{c}	Feeding quantity
Fe	Iron
F_{i}	Feeding intensity
F_{r}	Feeding rate

FT_3	Free triiodothyronine
FT_4	Free tetraiodothyronine
G. punctata	*Girella punctata*
G. spp.	*Gammarus* spp.
GH	Growth hormone
GLB	Globulin
GLU	Blood glucose
Glu	Glutamic acid
Gly	Glycine
GSH	Glutathione
GSH-PX	Glutathione peroxidase
H	Heterozygosity
H. huso linnaeus	*Huso huso linnaeus*
H. nehereus	*Harpadon nehereus*
H_2O_2	Hydrogen peroxide
HDLC	High-density lipoprotein cholesterol
HEAA	Semi-essential amino acids
His	Histidine
HSI	Habitat suitability index
IGF	Insulin-like growth factors
Ile	Isoleucine
ISS6	The 6th International Symposium on Sturgeon
IUCN	The International Union for Conservation of Nature
K	Potassium
L. ocellicauda	*Lophiogobius ocellicauda*
L. haematocheila	*Liza haematocheila*
L. hoffmeisteri	*Limnodrilus hoffmeisteri*
L. longirostris	*Leiocassis longirostris*
L. maculatus	*Lateolabrax maculatus*
L. ocellicauda	*Lophiogobius ocellicauda*
LC_{50}	Lethal concentration 50%
LDH	Lactate dehydrogenase
LDH-L	Lactate dehydrogenase
Leu	Leucine
LP	Lipid peroxidation
Lys	Lysine
MDA	Malondialdehyde
Met	Methionine
Mg	Magnesium
MRA	Multivariate regression analysis
mtDNA	Mitochondrial DNA
MTs	Metallothioneins
MUFAs	Monounsaturated fatty acids
N. polybranchia	*Nephtys polybranchia*

N. variciferus	*Nassarius variciferus*
Na	Sodium
NACA	National Advisory Committee for Aeronautics
NEAA	Nonessential amino acids
NKA	Na^+/K^+-ATPase
O. fasciatus	*Oplegnathus fasciatus*
O. oratoria	*Oratosquilla oratoria*
O_2^-	Superoxide anion
OC	Dorsal origin point of the caudal fin
OD	Origin of the dorsal fin
-OH	Hydroxyl radical
OP	Origin of the pectoral fin
P	Phosphorus
P. grufulvidraco	*Pelteobagrus fulvidraco*
P. spathula	*Polyodon spathula*
P. vannamei	*Penaeus vannamei*
PAHs	Polycyclic aromatic hydrocarbons
PAT	Pop-up archival transmitting
Pb	Lead
PbC	Control group
PbH	High concentration group
PbL	Low concentration group
PbM	Medium concentration group
PC	The posterior end of the caudal fin
PCBs	Polychlorinated biphenyls
PE	Posterior edge of the eye
Phe	Phenylalanine
PLS	Partial least squares regression
PP	Polypropylene
PRL	Prolactin
Pro	Proline
PUFAs	Polyunsaturated fatty acids
R. giurinu	*Rhinogobius giurinu*
R. olidus	*Repomucenus olidus*
RAPD	Random amplified polymorphic DNA
ROS	Reactive oxygen species
RW	Relative warp
S. constricta	*Sinonovacula constricta*
S. costatum	*Skeletonema costatum*
S. crassicornis	*Solenocera crassicornis*
S. laevidorsalis	*Synidotea laevidorsalis*
S. sinensis	*Siriella sinensis*
S. spp.	*Sinocalanus* spp.
S. taty	*Setipinna taty*

Se	Selenium
Ser	Serine
SFAs	Saturated fatty acids
SOD	Superoxide dismutase
SSR	Microsatellites
T	Temperature
T_4	Thyroxine
T. vermiculus	*Tortanus vermiculus*
T. tubifex	*Tubifex tubifex*
TBARS	Thiobarbituric acid reactive substances
T-BIL	Total bilirubin
TC	Total cholesterol
TG	Triglyceride(s)
TH	Thyroxin hormone
Thr	Threonine
TP	Total protein
Trp	Tryptophan
TT_3	Total triiodothyronine
TT_4	Total tetraiodothyronine
Tyr	Tyrosine
U_{crit}	The critical swimming speed
UREA	Concentration of urea
Val	Valine
W_{EAA}	Total essential amino acids
W_{HEAA}	Total semi-essential amino acids
W_{NEAA}	Total nonessential amino acids
W_{TAA}	Total amino acids
YRE	The Yangtze River Estuary
Zn	Zinc

Chapter 1
Overview of Chinese Sturgeon and Brief Research History

Feng Zhao

Abstract This chapter provides a brief introduction to the origin, classification, and distribution of sturgeons, as well as an overview of the biological characteristics, research, and conservation history of the Chinese sturgeon.

1.1 Taxonomic Status and Morphological Characteristics

1.1.1 Taxonomic Status

Chinese sturgeon (*Acipenser sinensis* Gray, 1834), also known as “La Zi” in Chinese, belongs to the Chordata, Vertebrata, Osteichthyes, Actinopterygii, Chondrostei, Acipenseriformes, Acipenseroidei, Acipenseridae, and *Acipenser*.

1.1.2 Major Morphological Characteristics

The Chinese sturgeon (Fig. 1.1) has an elongated, spindle-shaped body. The body surface of juveniles is smooth, while that of adults is rough. It is covered with five longitudinal rows of scutes, with the lateral plates being taller than wide. The rostrum region has sensory organs called rostral pit organs. The mouth is horizontally cleft. There are two pairs of barbels below the rostrum, near the mouth, and they are cylindrical. The gill membranes are not connected, and the gill rakers are short and club-shaped. The number of dorsal fin rays ranges from 49 to 59. Like other members of the Acipenseriformes, the skeleton of the Chinese sturgeon is mostly

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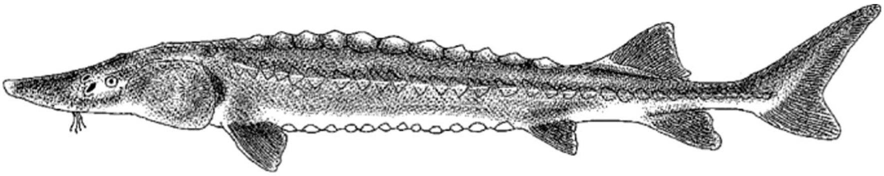

Fig. 1.1 Chinese sturgeon (Zhuang et al. 2017)

cartilaginous, except for the cranial bones and scutes. The notochord persists into adulthood, and the jaw structure is primitive. The digestive tract possesses spiral valves, and the tail has a heterocercal shape. These characteristics represent more primitive traits within the Acipenseriformes.

1.2 Life History and Stock Dynamics

1.2.1 Geographic Distribution

Historically, the Chinese sturgeon had a wide geographic distribution, ranging from the northern Yellow Sea's offshore islands to the Pearl River and the coastal waters near Wanning County in Hainan Province. The species was most abundant in the YRE fishing grounds and Zhoushan fishing grounds in the East China Sea. There are also records of its distribution in rivers such as the Yellow River, Min River, and Qiantang River (Wu et al. 1963; Zhu et al. 1963; The Yangtze Aquatic Resources Investigation Group of Sichuan Province 1988). There are records of Chinese sturgeon migratory distribution in the southwestern part of the Korean Peninsula and the waters off western Kyushu, Japan. Currently, the Chinese sturgeon is no longer found in the Yellow River, Min River, Qiantang River, and Pearl River. Its spawning grounds are only found in the Yangtze River.

1.2.2 Life History

The Chinese sturgeon is a typical anadromous fish. It inhabits and feeds in coastal areas and becomes fertile after reaching sexual maturity. It migrates upstream to the upper reaches of the Yangtze River for spawning during the autumn. The Chinese sturgeon is an omnivorous fish with a diet primarily consisting of animal-based prey. The young fish in the upper and middle reaches of the Yangtze River mainly feed on aquatic insects and plant debris, while those in the YRE feed on shrimps, crabs, and small fishes. In the offshore continental shelf area, their diet primarily consists of predatory crustaceans, such as shrimps and crabs, and mid-to-bottom dwelling fish.

The Chinese sturgeon has a fast growth rate and can reach a large size, with maximum lengths of up to 400 cm and weights of up to 560 kg. It has a long life cycle, with a maximum lifespan of 40 years. It reaches sexual maturity relatively late, with females maturing between 14 and 26 years of age and males between 8 and 18 years. It is a once-spawning species, and the spawning season in the Yangtze River occurs from October to November, with a minimum interval of 2 years between spawning events.

Prior to the construction of the Gezhouba Dam on the Yangtze River, mature Chinese sturgeon individuals would migrate upstream for reproductive purposes from July to August each year. During this period, they would stop feeding and rely on their internal fat reserves to provide energy for migration and to support the maturation of their gonads. The following year, the spawning population would migrate to the spawning grounds in the Jinsha River section of the upper Yangtze River, approximately 3000 km away from the YRE. The resulting larvae would drift downstream with the river's current and arrive at the YRE in June of the second year. They would then remain in the estuary for several months to feed and grow before gradually migrating to the open sea. After spending over 10 years in the marine environment, they would return to the upper reaches of the Yangtze River for reproduction. Since the completion of the Gezhouba Dam in 1981, the reproductive migratory pathway of the Chinese sturgeon has been blocked, and mature individuals are unable to migrate to the Jinsha River spawning grounds for reproduction. In 1982, small-scale spawning activities of Chinese sturgeon were discovered in the downstream section of Gezhouba Dam. After years of investigation and research, it was confirmed that there is a small spawning ground for Chinese sturgeon downstream of Gezhouba Dam, located approximately 1700 km from the YRE. The reproductive migration distance of Chinese sturgeon in the Yangtze River has been reduced by over 1000 km, and the spawning time has been delayed. The arrival time of young fish at the YRE is now between April and May, about 1 month earlier than before (Fig. 1.2). Due to the cumulative impacts of cascade hydropower development in the upstream Yangtze River, the ecological environment of the Chinese sturgeon spawning ground downstream of Gezhouba Dam has undergone changes, resulting in serious impacts on the spawning and reproduction of Chinese sturgeon, including a decrease in spawning frequency and a delay in spawning period.

1.2.3 Stock Dynamics

In the past, the Chinese sturgeon stock was abundant and served as a significant target for fishing activities. Prior to the construction of the Gezhouba Dam on the Yangtze River, a large number of mature Chinese sturgeons migrated to the middle and upper reaches of the river for spawning. Due to their large population during the migration period, they constituted a substantial portion of the fishery in Sichuan and Hubei provinces, contributing to high yields and economic value. According to

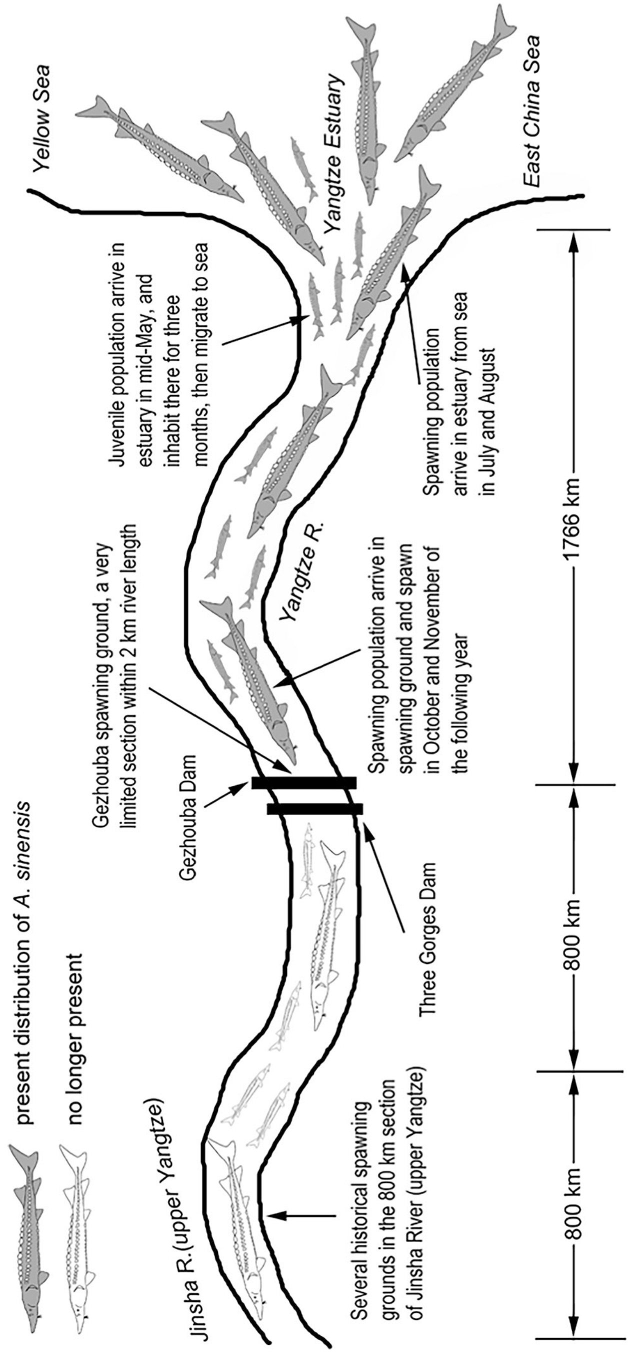

Fig. 1.2 Simplified diagram of Chinese sturgeon migration in the Yangtze River before and after the closure of Gezhouba Dam (Zhuang et al. 2016)

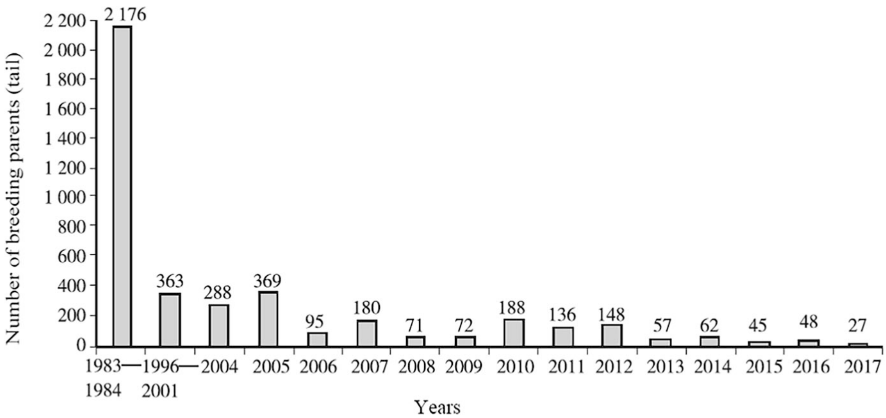

Fig. 1.3 Variations in the population size of Chinese sturgeon breeding groups in the spawning grounds below the Gezhouba Dam

statistics from 1972 to 1980, the annual catch of adult Chinese sturgeons in the entire Yangtze River basin ranged from 394 to 636 individuals, with an average of 517 individuals per year and a total yield of 60–75 tons, exhibiting relative stability. Initially, after the completion of the Gezhouba Dam, a large number of Chinese sturgeons congregated in the downstream section of the dam, resulting in a peak in the annual catch of Chinese sturgeons in the Yangtze River. Incomplete records indicate that during the autumn and winter of 1981, more than 800 Chinese sturgeons were caught in Hubei Province, representing approximately 5.5 times the average annual catch of 145 individuals before dam construction (Xiao 2012).

In 1983 and 1984, the number of reproductive individuals migrating to spawn below the Gezhouba Dam reached a historical peak of 2176 individuals. However, since then, the number of Chinese sturgeon reproductive individuals has been decreasing year by year. As shown in Fig. 1.3, from 1996 to 2001, the number of reproductive individuals below the Gezhouba Dam ranged from 292 to 473 individuals, with an average of approximately 363 individuals per year. Until before 2005, the number of Chinese sturgeon reproductive individuals remained around 300 individuals (Wu et al. 2015; Ministry of Environment Protection of the People's Republic of China 2017). In the past decade, the declining trend of Chinese sturgeon resources has become more severe. Except for the years 2007 and 2010–2012 when reproductive individuals of 130–190 Chinese sturgeons were detected at the spawning ground below the Gezhouba Dam, the numbers were less than 100 individuals in other years. Since 2015, the number has dropped to below 50 individuals (Ministry of Environment Protection of the People's Republic of China 2017). More alarmingly, during the 2013, 2015, and 2017 breeding seasons, no natural spawning activity of Chinese sturgeons was observed at the spawning ground below the Gezhouba Dam. Similarly, during the spring seasons of 2014, 2016, and 2018, no wild young Chinese sturgeon were monitored in the YRE. The natural population of

Chinese sturgeon has shifted from continuous spawning to intermittent reproduction, posing a worrisome situation for the population.

In the 1960s, young Chinese sturgeon were also an important fishery resource in the Chongming waters of the YRE, with significant catches. However, after the construction of the Gezhouba Dam, the young population experienced a drastic decline due to the blockage of the migratory pathways of adult spawners. Within 3 years, the stock declined by approximately 97%. Between 1981 and 1999, the stock of young Chinese sturgeon and parental replenishment populations decreased by about 80% and 90%, respectively. Studies have shown that the estimated number of young Chinese sturgeon stock from 1998 to 2001 ranged from 183,000 to 865,000 individuals. However, data from 2004 to 2008 indicated a drastic decrease in the number of young sturgeons in the YRE, ranging from 12,000 to 100,000 individuals, representing a reduction of one order of magnitude over 10 years (Zhuang et al. 2009).

Given the declining trend of natural resources for Chinese sturgeons, the Chinese government implemented a comprehensive ban on commercial fishing for Chinese sturgeons and imposed strict regulations on artificial propagation for scientific research purposes in 1983. In 1988, the Chinese sturgeon was listed as a Class I key protected wildlife species, prohibiting all commercial utilization. The status of the Chinese sturgeon shifted from valuable large-scale economic fishes to a critically endangered species under Class I key protection by the state. In 1996, the International Union for Conservation of Nature (IUCN) assessed the Chinese sturgeon based on factors such as total population, population decline rate, geographical distribution, and degree of population fragmentation. It was classified as endangered (EN) and included in the Red List. In the 2010 reassessment, the Chinese sturgeon was classified as critically endangered (CR).

1.3 Brief History of Chinese Sturgeon Research

In China, there are historical records of the name, morphology, behavior, fishing methods, and culinary value of sturgeon from the Western Zhou Dynasty to the end of the Qing Dynasty. Ancient scholars' understanding of sturgeon was primarily based on their external characteristics, behavior, geographical distribution, and economic value. Due to variations in naming conventions and the existence of different species, there were over 30 different names for the three sturgeon species found in the Yangtze River alone. Ancient works such as Compendium of Materia Medica contain numerous descriptions of sturgeons' habitat, distribution, and medicinal value (Zhuang et al. 2017).

The ancient descriptions of sturgeons were generally vague and classified under the *Acipenser*. Based on these records, It was impossible to study them at the species level. In the early years of the Republic of China, Xu Ke mentioned in his work "Qingbai Leichao: Animal Compendium" that "sturgeons, also known as zhans, inhabit rivers, seas, and deep waters. They lack scales and resemble sturgeons." This description documented the migratory behavior of sturgeons in rivers and seas and is perhaps the closest account to the living habits of the Chinese sturgeon in modern times (The Yangtze Aquatic Resources Investigation Group of Sichuan Province 1988).

In 1834, British zoologist John Edward Gray described and named a new species of sturgeon collected in China as *A. sinensis*. This taxonomic classification was published in Part 2, page 122, of the Proceedings of the Zoological Society of London. Despite subsequent scholarly investigations and discussions on the species name of the Chinese sturgeon, the scientific name *A. sinensis* (Gray, 1834) has been consistently used to this day.

Prior to the 1970s, research on the Chinese sturgeon was mainly limited to morphology and taxonomy, lacking a systematic approach. Subsequently, with the development of the Gezhouba Dam project on the Yangtze River, the investigation, research, and conservation of the Chinese sturgeon gradually gained significant attention. Until now, the process of Chinese sturgeon conservation research can be broadly divided into the following three stages:

1. **The first stage (before the 1980s)**: During this stage, specialized surveys of the Chinese sturgeon in the Yangtze River were conducted, providing insights into its morphology, ecology, spawning behavior, migration patterns, feeding habits, and reproduction. Initial explorations of artificial propagation and breeding techniques for the Chinese sturgeon were also carried out. Representative works or events include the following:

   In 1963, Wu Xianwen published Economic Animals of China: Freshwater fishes, which described the morphological characteristics and life history of the Chinese sturgeon, giving it a Chinese name.

   In 1964, the Changshou Lake Fisheries Research Institute in Chongqing conducted investigations and research on the Chinese sturgeon's spawning grounds in the lower reaches of the Jinsha River and explored its artificial propagation and breeding.

   In 1971, successful experimental artificial reproduction of wild Chinese sturgeon was achieved.

   In 1972, the Ministry of Agriculture and Forestry issued a research project called "Special Survey on Yangtze Sturgeons," which conducted systematic investigations on the morphology, ecology, spawning behavior, migration patterns, feeding habits, and reproduction of sturgeons in the Yangtze River.

   From 1972 to 1975, the Sichuan Fisheries Research Institute and Southwest Normal University formed the Sichuan Province Yangtze River Fisheries Resources Investigation Group, which conducted comprehensive surveys of the Chinese sturgeon reproductive population and its spawning grounds in the upper reaches of the Yangtze River. The group authored and published Research on the Biology and Artificial Propagation of Yangtze Sturgeons) in 1988.

2. **The second stage (1980–2009)**: During this stage, extensive research was conducted on various aspects of the Chinese sturgeon, including population structure and dynamics, natural reproductive ecology, artificial propagation and rearing, stock enhancement and evaluation, spawning grounds and feeding grounds surveys. The "Conservation Technology Research of Chinese Sturgeon" project received the National Science and Technology Progress Second Prize. Representative works or events include:

   In 1981, the Gezhouba Dam interrupted the reproductive migration pathway of the Chinese sturgeon.

   In 1982, a new spawning ground for the Chinese sturgeon was discovered downstream of the Gezhouba Dam, and natural spawning and reproduction were observed.

   In 1983, the "National Cooperative Group for Artificial Propagation of Chinese Sturgeon in the Gezhouba Dam Area" achieved the first successful artificial propagation of Chinese sturgeon in the Gezhouba Dam area, marking the beginning of artificial propagation and release efforts for Chinese Sturgeon.

   In 1985, the successful induction of Chinese sturgeon spawning using artificially synthesized hormones was accomplished.

   In 1993, the utilization of telemetry tracking technology commenced to study the distribution of Chinese sturgeon breeding populations and their natural reproductive ecology.

   In 1995, a breakthrough was made in the breeding technology of Chinese sturgeon fry, enabling the large-scale cultivation of young Chinese sturgeon with a length of 10 cm or more.

   In 2000, the Ministry of Science and Technology initiated the social welfare research project "Technological Research on the Conservation of Yangtze Sturgeon Species."

   In 2004, the Major Program of the National Natural Science Foundation of China, "Long-term Ecological Effects of Large-scale Water Conservancy Projects on Important Biological Resources in the Yangtze River Basin," was launched to conduct in-depth and systematic ecological response research on Chinese sturgeon and other significant biological groups underwater environment stress.

   In 2004, comprehensive work commenced on the ecological environment investigation and monitoring of the Chinese Sturgeon Natural Reserve in the YRE in Shanghai, as well as the biological research on the protection of Chinese sturgeon fry. After 5 years of continuous investigation and research, the publication "The Yangtze River Estuary Nature Reserve for Chinese Sturgeon: Scientific Studies and Management" was completed in 2009.

   In 2007, the achievements of the "Technological Research on the Conservation of Chinese Sturgeon" were honored with the National Science and Technology Progress Award (second-class).

   In 2009, the 6th International Symposium on Sturgeon (ISS6) was successfully held in Wuhan, Hubei Province, China.

In 2009, a major breakthrough was achieved in the complete artificial propagation technology of Chinese sturgeon, resulting in the successful acquisition of second-generation Chinese sturgeon offspring.

3. **The third stage (2010–present)**: During this phase, due to the intermittent natural reproduction of the Chinese sturgeon, investigations into natural breeding populations, spawning grounds, "land-sea-land" relay breeding studies, and research on its marine life history have become and will continue to be the main focus. Representative works or events include:

In 2010, the Chinese sturgeon was classified as CR by the IUCN.

In 2013, no natural reproductive activity of wild Chinese sturgeon was observed, indicating a disruption in natural reproduction.

In 2015, a large number of wild young Chinese sturgeon were discovered in the YRE, suggesting the presence of new spawning grounds. Research on natural reproduction and spawning grounds of the Chinese sturgeon received further attention.

In 2015, the National Key Basic Research and Development Program (973 Program) initiated the project "Key Biological Issues in Controllable Water Body Chinese Sturgeon Aquaculture."

In the same year, wild Chinese sturgeon experienced another interruption in natural reproduction.

In 2015, the Ministry of Agriculture issued the "Chinese Sturgeon Rescue Action Plan (2015–2030)."

In 2016, the "Land-Sea-Land" relay breeding research project for the Chinese sturgeon was launched.

In 2017, once again, no natural reproductive activity of wild Chinese sturgeon was observed.

To date, the focus of Chinese sturgeon conservation research has centered on the breeding populations, systematically studying the natural reproductive ecology of the Chinese sturgeon and its response to environmental changes. Breakthroughs have been made in complete artificial breeding techniques, and artificial propagation and release have been implemented, providing valuable data for the study of the species' life history and conservation. However, our understanding of the life history of the Chinese sturgeon, a species that has evolved over millions of years, remains limited. There are still many research gaps concerning abnormal phenomena in natural populations (such as the mystery of spawning grounds in 2014 and subsequent interruptions in spawning) and post-migration behaviors during its marine life stage.

In the face of the current critical state of the Chinese sturgeon facing extinction, it is imperative to further strengthen research on its conservation. The following five areas of research are urgently needed: (a) Conduct fundamental research on the entire life history cycle and behavior, with a focus on the early life stages of Chinese sturgeon and their post-migration behaviors during the marine life phase. (b) Conduct research on the habitat requirements and ecological restoration of key life history stages, with a specific focus on the spawning grounds and foraging habitat requirements of Chinese sturgeon and their ecological restoration. (c) Conduct research on the "land-sea-land" relay breeding of Chinese sturgeon, with an emphasis on seawater acclimation and breeding as a key area of future research. (d) Conduct research on the fundamental and applied technologies of artificial propagation and release, focusing on the factors influencing propagation and evaluating its effectiveness. (e) Conduct research on genetic resource conservation.

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Chapter 2
Morphological Characteristics and Ecological Adaptation

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Abstract This chapter provides an overview of the fundamental morphological characteristics, quantitative characteristics, and meristic characteristics of young Chinese sturgeon in the YRE, as well as the research progress on the morphological development and morph-ecology of young fish under different environmental conditions.

2.1 Morphological Characteristics

Fish populations, as well as different developmental stages within the same population, exhibit distinct morphological characteristics. During the young stage of the Chinese sturgeon, particularly during the period of increased feeding and rapid growth in the YRE and its adjacent waters, important life-history traits are observed. The young sturgeon exhibits unique morphological features that are specifically adapted to its habitat.

2.1.1 External Morphology

Young Chinese sturgeon in the YRE exhibit an elongated fusiform body shape with a slightly pointed anterior end. The cross-section of the body in the trunk region is

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Fig. 2.1 The young Chinese sturgeon in the YRE

pentagonal, gradually tapering towards the posterior end, while the ventral region appears relatively flat (Fig. 2.1).

The head of the Chinese sturgeon is triangular and slightly flattened, presenting a wedge shape in a lateral view. It features scutes on the dorsal side. The rostrum is pointed, and the ventral and lateral surfaces of the head possess numerous arranged small pores, known as ampullae, which are unique sensory organs in fish.

The gill openings are located on both sides of the head. A pair of crescent-shaped spiracles is found above the gill cover. There are remnants of gill filaments visible inside the spiracles, which are connected to the pharynx. The sturgeon has two pairs of barbels located on the ventral surface of the rostrum. The eyes, oval-shaped and lacking eyelids and nictitating membrane, are found in a pair. The mouth is transversely cleft, positioned ventrally. The upper and lower jaws have tubercles, and there are lip folds at the mouth angle and on both sides of the lower jaw. The operculum is located on both sides of the head.

The trunk of the Chinese sturgeon is composed of five rows of scutes. There is one row along the dorsal midline, one on each lateral side, and one on each ventral side. The tail region consists of four rows of scutes: one along the dorsal midline, one along the ventral midline, and one on each lateral side. Located on the ventral side of the anterior body, there is a pair of pectoral fins that are flattened and leaf-shaped, extending horizontally towards the posterior sides. Towards the posterior region, a pair of pelvic fins are smaller than the pectoral fins and slightly spread laterally. Two openings can be observed on the ventral midline behind the pelvic fins. The anterior one is the anus, and the posterior one is the urogenital opening. On the dorsal side of the tail, there is a single dorsal fin extending diagonally towards the urogenital opening on the ventral surface. The anal fin is situated on the ventral side of the tail, with its base located behind the urogenital opening and corresponding vertically to the dorsal fin. The anal fin is smaller and lighter in color compared to the dorsal fin. The caudal fin is heterocercal, with a larger upper lobe supported by closely arranged spiny rhomboid scales on both sides and a smaller lower lobe supported by fin rays.

The body coloration above the lateral scutes is typically bluish-gray, grayish-brown, or grayish-yellow, gradually transitioning from lighter gray to pale yellowish-white below the lateral scutes. The ventral region is milky-white in color. The fins are gray with lighter edges.

2.1.2 Meristic Characteristic

Meristic characteristics of the Chinese sturgeon primarily include the number of gill rakers, dorsal fin rays, pectoral fin rays, pelvic fin rays, anal fin rays, caudal fin rays, dorsal scutes, lateral scutes (left and right), and ventral scutes (left and right). In the young stage of the Chinese sturgeon found in the YRE, these meristic characteristics exhibit certain variations with increasing body length.

2.1.2.1 Number of Gill Rakers

The number of gill rakers ranges from 12 to 23, with the majority concentrated between 16 and 18. There are some differences observed between different length groups (Table 2.1). As the young sturgeon grows in body length, the number of gill rakers slightly increases. Compared to adults, young Chinese sturgeons have relatively fewer gill rakers. However, both adults and young sturgeons of the Chinese sturgeon tend to have a lower number of gill rakers, which is associated with their predominantly carnivorous feeding habits.

Table 2.1 Meristic characteristics of young Chinese sturgeon in the YRE

	Body length groups							
	0–10 cm ($N > 10$)		10–20 cm ($N > 10$)		20–30 cm ($N > 400$)		30–40 cm ($N > 50$)	
Character	Range	Mode	Range	Mode	Range	Mode	Range	Mode
Gill rakes	_	_	13–19	17	14–21	16	12–23	18
Dorsal scutes	10–15	13	10–16	14	10–16	13	11–15	13
Left scutes	29–44	32/36/38/39	27–34	36	27–42	36	30–40	37
Right scutes	28–41	31	28–45	36	28–43	36	30–42	33
Left ventral scutes	7–11	11	7–16	11	7–16	11	8–15	12
Right ventral scutes	6–13	11	8–15	11	6–15	11	8–15	11/12
Dorsal fin rays	61–69	65	46–71	58/63	46–71	58	47–70	60
Anal fin rays	33–45	33/37	23–49	36	23–49	38	23–49	40
Left pectoral fin rays	36–52	36	35–56	39	35–56	49	38–54	48
Right pectoral fin rays	36–50	47	34–59	43	34–59	40	38–54	40/47
Left pelvic fin rays	36–52	39	32–50	38	32–56	40	34–52	42
Right pelvic fin rays	32–45	39	30–56	38/40	30–57	40	33–57	40
Caudal fin rays	86–95	86/95	72–102	96	72–102	88/92	72–102	92/93

2.1.2.2 Number of Fin Rays

There are variations in the number of fin rays in different fins of the young Chinese sturgeon. The dorsal fin rays range from 46 to 71, pectoral fin rays range from 34 to 59, pelvic fin rays range from 30 to 57, anal fin rays range from 23 to 49, and caudal fin rays range from 72 to 102 (Table 2.1).

2.1.2.3 Number of Scutes

The Chinese sturgeon has 10–16 pieces of dorsal scutes in a single row. It has one row of lateral scutes on each side, with 27–44 pieces on the left and 28–45 on the right. Additionally, it has one row of ventral scutes on each side, with 7–16 pieces on the left side and 6–15 pieces on the right side (Table 2.1).

2.1.3 Quantitative Characteristic

The quantitative characteristics of young Chinese sturgeon in the YRE were measured following the methods described by The Yangtze Aquatic Resources Investigation Group of Sichuan Province (1988). The measurements included total length, body length, body width, body depth, and head length, among others. The measurements were recorded with an accuracy of 0.1 cm. Figures 2.2 and 2.3 illustrate the measurement indices and their corresponding standards.

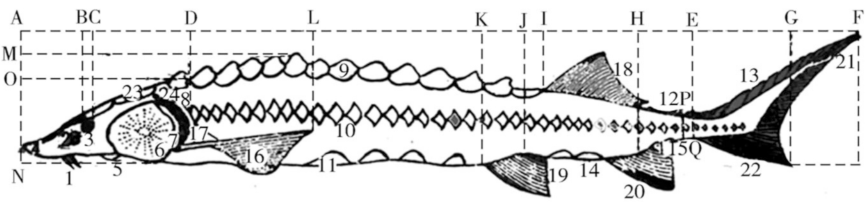

Fig. 2.2 The morphological landmarks for young Chinese sturgeon. (1) Barbels on the rostrum. (2) Anterior and posterior nostrils on the left side. (3) Eyes. (4) Rostrum. (5) Lips. (6) Lower gill cover. (7) Branchial membrane. (8) Exposed gill filament. (9) Dorsal scute. (10) Left scute. (11) Left ventral scute. (12) Anterior scutes of the dorsal fin. (13) Spiny scales on caudal fin. (14) Posterior scutes of the anal fin. (15) Anterior scutes of the anal fin. (16) Pectoral fin. (17) Hard spines of the pectoral fin. (18) Dorsal fin. (19) Pelvic fin. (20) Anal fin. (21) Upper lobe of the caudal fin. (22) Lower lobe of the caudal fin. (23) Top head scutes. (24) Spiracle. (**A**–**B**) Rostrum length. (**B**–**C**) Eye diameter. (**A**–**D**) Head length behind eyes. (**D**–**L**) Pectoral fin length. (**A**–**E**) Body length. (**A**–**F**) Total length. (**E**–**F**) Upper lobe length of caudal fin. (**H**–**L**) Dorsal fin base length. (**E**–**G**) Lower lobe length of caudal fin (slope at intersection). (**E**–**H**) Caudal peduncle length. (**J**–**K**) Pelvic fin base length. (**M**–**N**) Body depth. (**O**–**N**) Head depth. (**P**–**Q**) Caudal peduncle depth