Title
Population dynamics of sturgeon in the southern part of the Caspian Sea

Author
Taghavi Motlagh, Seyed Aminollah.

University of Wales Swansea. School of Biological Sciences.

Subjects
Sturgeons -- South Caspian Sea
Fish populations -- South Caspian Sea

Creation Date
1996

Language
English

Dissertation
Thesis (Ph.D.) - University of Wales Swansea, 1996.

Source
Library Catalogue (Swansea University)

Population Dynamics of Sturgeon in the Southern Part of the Caspian Sea

A thesis submitted to the University of Wales in partial fulfilment of the requirements for the degree of Doctor of Philosophy

By Seyed Aminollah Taghavi Motlagh
School of Biological Sciences University of Wales, of Swansea

August 1996

DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

Signed..S. A. Taghavi........(candidate)
Date......11.8.96..................

STATEMENT 1

This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by footnotes giving explicate references. A bibliography is appended.

Signed....S. A. Taghavi............(candidate)
Date........11.8.96.................

Signed...........................(supervisor)
Date..............................

STATEMENT 2

I hereby give consent for my thesis, if accepted, to be available for inter-library loan, and for the title and summary to be made available to outside organization.

Signed...S. A. Taghavi..............(candidate)
Date......11.8.96......................

In the name of Allah,
The Beneficent, the Merciful.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

I would like to convey my greatest thanks to my supervisor Professor John Stanley Ryland, for all his guidance, help, advice and encouragement during this study.

The financial support of the present study was provided by the Ministry of Jehad-e-Sazandegy of the Iranian government through the fishery company of the Shilat-e-Iran, and I am greatly indebted. I am grateful to Director-General of fisheries, Mr. Lahijanian, head of the Training and Research Institute of Shilat, Dr. Amini and the Deputy of Jehad Ministry Training Department, Mr. Rajabbaigi.

In the course of collecting the data I have been greatly helped by a number of people in one way or another, and to them I am deeply grateful: Dr. Rezvani, previous director of the fishery research centre in Mazandaran Province; Dr. Porgholam, the present director; Dr. Nezami, the director of the Gilan Province fishery research centre; the heads of the fish stock assessment in both provinces.

I am also grateful to all the staff of the School of Biological Sciences at Swansea especially Marine Biology Department for all their help and kindness during this study.

The administration for starting this study was made by the Ministry of Science and Higher Education of Iran and I am greatly thankful to all their staff.

Last and not least, I would like to thank my family who encouraged and supported me morally to go ahead with their huge patience during these years.

Summary

Five years' data of the Beluga, *Huso huso*, Stellate Sturgeon, *Acipenser stellatus*, Persian Sturgeon, *A. persicus* and Russian Sturgeon, *A. guldenstadti*, in the southern Caspian Sea were analysed for sex and age, and length and weight composition. The von Bertalanffy growth parameters, and total, natural and fishing mortalities were estimated. Yield-per-recruit curves were derived for each species, based on growth parameters and mortality rates, and the optimum fishing mortality in terms of yield-per-recruit was calculated as a basis for sturgeon fishery management in the Caspian Sea.

Age of the sturgeons was determined from the fin ray sections. In all five years, for all the species, there were more females than males in the catches. Catches of fish older than 20 years were a very low percentage.

Von Bertalanffy growth parameters for each species were estimated for sexes separately. For female Beluga, the values of L_∞ and K were estimated for three growth stanzas as 320 cm and 0.065 for juveniles, 450 cm and 0.029 for the middle stanza and 533 cm and 0.023 for older fish. For male Beluga and other species the values of L_∞ and K were estimated both from L_{max} and by using the Fishery Science Application System (FSAS) computer program. L_∞ and K for male Beluga were estimated as 270 cm and 0.086 using L_{max}, 302 cm and 0.072. For female Stellate Sturgeon L_∞ and K were 213 cm and 0.062 using L_{max}, 188 cm and 0.104; and for males 190 cm and 0.083 from L_{max}, 171 cm and 0.113. For female Persian Sturgeon L_∞ and K were 225 cm and 0.066 from L_{max}, 207 cm and 0.079; and for males 197 cm and 0.084, 186 cm and 0.105 respectively. For female Russian Sturgeon L_∞ and K were 201 cm and 0.073 from L_{max}, 192 cm and 0.082; and for males 189 cm and

0.077, 178 cm and 0.092 respectively.

The value of total mortality (Z) depended on method of estimation. For female Beluga Z was 0.21-0.67, for males 0.22-0.75; for female Stellate Sturgeon 0.52-1.1, males 0.62-1.1; for female Persian Sturgeon 0.24-0.57, males 0.40-1.1; and for female Russian Sturgeon 0.33-0.67, males 0.46-0.82.

Natural mortality (M) was estimated from the growth parameters L_∞ and K: for female and male Beluga 0.03 and 0.05; for female and male Stellate Sturgeon 0.07 and 0.08; for female and male Persian Sturgeon 0.04 and 0.06; and for female and male Russian Sturgeon 0.05 and 0.07.

Fishing mortalities (F) were estimated as 0.45 and 0.33 for female and male Beluga; 1.03 and 0.54 for female and male Stellate Sturgeon; 0.47 and 0.34 for female and male Persian Sturgeon; and 0.62 and 0.39 for female and male Russian Sturgeon. The optimum fishing mortalities (F_s) derived from yield-per-recruit calculations were 0.07 and 0.16 for female and male Beluga; 0.42 and 0.30 for female and male Stellate Sturgeon; 0.16 and 0.34 for female and male Persian Sturgeon; and 0.21 and 0.37 for female and male Russian Sturgeon respectively.

The population of the Beluga, probably because of higher quality of its caviar, is most depleted, and the number of spawners has become limited. To maintain the spawning stock, harvesting should be restricted for a period of several years.

The sturgeon populations of the Caspian Sea are in need of protection. Fishing effort needs to be reduced in all species to conserve stocks and, ultimately, to increase yields.

CHAPTER 1

GENERAL INTRODUCTION

1. 1. The Caspian Sea

The Caspian Sea is the largest enclosed body of water in the world, and is unique. It is located between the Islamic Republic of Iran, the Republic of Azerbaijan, the Russian Federation, the Republic of Khazakhstan and the Republic of Turkmanestan (Fig 1.1). The Caspian Sea borders the northern part of Iran and is surrounded by the Alborz Mountains and the provinces of Gilan and Mazandaran. In the past, as a consequence of the different tribes inhabiting the adjoining coasts, the Caspian Sea has been given different names, such as Varukesh, Tabarestan and Caspian. Sea of Mazandran is the local Iranian name for the Caspian Sea.

The Caspian Sea extends in a north-south direction and is about 1204 km long, by 204 to 566 km wide. It lies between 47° 13 ' and 36° 34' 35 " N latitude and between 46° 38' 39" and 54° 44' 19" E longitude. The area of the sea is 436,000 km^2. Its volume is about 77,000 km^3, with an average depth of 208 m.

On the basis of physico-geographical and relief characteristics, the sea is divided into three parts, the North, Middle and South Caspian (Kosarev and Yablonskaya 1994). The North Caspian covers about 25% of the total sea area, while the Middle and South parts are about equal in size. However the water volumes in the northern, middle and southern parts of the sea are very different, being 0.5, 33.9 and 65.6% of the total sea volume respectively (Caspian Sea: Hydrology and Hydrochemistry, 1986, quoted in Kosarev and Yablonskaya, 1994). The southern Caspian, which is the deepest part of the sea, has a maximum depth of about 1,000 m and an average depth of 325 m. The huge area, 3.7 million km^2, of the drainage basin annually receives about 355 km^3 of river water; of this the Volga (in the Russian Federation) supplies approximately 76.3%; the Kura (in the Azerbaijan), 4.9%; the Ural (in the Republic of Khazakhestan) 3.7%; the Terek also in Azerbaijan, 3.2%; Sefid-Rud in Iran, and other rivers, 11.9%. The total annual volume of water supplied to the Caspian, including rainfall, is about 451km^3.

The level of the Caspian Sea is not constant but depends on evaporation and river input (Kosarev and Yablonskaya 1994). In 1975, according to information from the Harbor Office of Bandar Anzaly, the level of the water of the Caspian Sea was 28.48 m. Since that year, the water level has been constantly increasing. By 1991, the total increase was approximately 1.70 m. Fluctuation in level caused by runoff accounts for 60 to 90% of the variations in volume (Skriptunov, 1970). Atmospheric precipitation over the Caspian is distributed very unevenly. There is about 200 mm of rainfall onto the open sea; on the western coast there is about 300-400 mm annually, and up to 1700 mm on the southwestern area. The driest areas are along the eastern coastline, where the annual rainfall does not exceed 100 mm (Kosarev and Yablonskaya 1994). Since the total precipitation over the sea area and the amount of subsequent evaporation are about 200 and 1000 mm respectively, the sea annually loses five times more moisture to the atmosphere than it gains. As the volume of precipitation over the sea area is much smaller than the volume of river runoff, its role in the water balance is also much smaller.

Temperature conditions in the Caspian Sea are very peculiar and are determined by a sharp difference in temperature between its southern and northern parts in winter and a more uniform temperature regime in summer. Only the northern Caspian has ice-cover every winter. The most important hydrochemical conditions of the northern Caspian differ greatly from those in the rest of this sea because of instability, strong seasonal fluctuations, and greater dependence - owing to its shallowness - on winds, and the chemical properties of its soil. The salinity of the Caspian Sea differs greatly from that of the open oceans both in the ratio of its compositions and in their sum. The average salinity is between 12.80 and 12.85 ‰. Salinity-stratification of its waters is much less pronounced than in the Black Sea; an oxygen supply, sufficient for penetration of individual numbers of its fauna to their limiting depths, is provided by water circulation. However, the density of the population is high only in the upper layers; below 100 m life is very much restricted owing to a shortage of oxygen. Salinity increases, at the boundary between the Northern and Central Caspian and is highest in the south. The northern Caspian mainly has a salinity of 8 to 9‰, dropping sharply in the estuaries of the rivers Volga and Ural (Zenkevitch 1963). Caspian Sea waters are poor in sodium and chlorine and rich in calcium and sulphates by comparison with the oceans; this difference in the salt ratio makes Caspian water more similar to river water than to that of the oceans (Zenkevitch 1963).

The Caspian Sea fauna, qualitatively very poor, is very varied in its origin; it is, in the main, descended from the Tertiary marine fauna, which underwent considerable evolution as a result of orogenesis and consequent changes in the geography and hydrological conditions of the Sea (Zenkevitch 1963, Mordukhai-

Boltovskoi, 1978). In the sea and deltas of the Caspian basin approximately 126 species and subspecies of fish occur, belonging to 17 families (Kazancheev, 1981). Most are from the families of carp (33%), gobies (28%) and shads (14%), which together make up about 3/4 of the species and subspecies inhabiting the Caspian Sea. A characteristic feature of the Caspian Sea ichthyofauna is the wide range of species which migrate between fresh and saline waters, with many varied forms of adaptation to different salinity - from fresh water to the relatively high salinity of eastern inlets of the Caspian Sea. Among the fish there is a distinct group of migratory fish which inhabit the sea but migrate up the rivers for spawning. Acipenseridae (except the sterlet (native river fish)"*A. ruthenus*"), *Stenodus leucichthys*, Salmonidae and some herrings undertake such migrations. A second group of semi-migratory fish includes, firstly, those which primarily keep to the less saline areas of the Sea and move up the rivers for spawning (pike perch (*Lucioperca lucioperca)*, golden shiner (*Notemigonus cryseleucas*), carp (*Cyprinus carpio*) and *Pelecus cultratus*), and, secondly, those which keep only to the much more diluted waters of the river mouths but also move upstream for spawning (*Abramis ballerus*, *Abramis sapa*, *Rutilus rutilus*, *Aspius aspius*, and others). A third group consists of the native river fish. They are either absent or rare even in the areas of the sea with reduced salinity (sterlet, tench (*Tinca tinca)*, *Carassius auratus*). Finally, the fourth group comprises fish which very rarely enter waters of lowered salinity (marine species such as pike perch (*Lucioperca lucioperca*), and some varieties of south Caspian herrings). The exceptional richness of migratory fish is a particularly interesting feature of the Caspian Sea. All the

Acipenseridae (except the sterlet), Salmonidae and Cyprinidae of the Caspian Sea enter a river for spawning and then return to the sea. The direction of the migration in the Caspian Sea is determined to a great extent by the constant influence of the cyclonic current. In the rivers, water flow serves as the main basis for the navigation (Holci'k 1959).

The fisheries are rich. Among the 40 commercially exploited fish species, the six species of the sturgeon are unique. For about half a century, yearly catches amounted to roughly 30 x 10^3 tonnes, and provided 90 percent of the world's caviar (Dumont 1995).

Among the teleost species, herrings (kilkas) , carp (*Cyprinus carpio*), kutum (*Rutilus frisii kutum*) and mullets (*Liza saliencs* and *Liza auratus*) are nowadays the most commercially important fish in the Caspian Sea. Total catches of these species between 1990 and 1993 from the Iranian waters were recorded as 70,000 tonnes for herring, 69,504 tonnes carp, 45,227 tonnes kutum, and 11,338 tonnes mullets (FAO, 1993). The common kilka (*Clupeonella delicatula caspia*), the big-eye (*Clupeonella grimmi*) and the anchovy kilka (*Clupeonella engrauliformis*) take first place among the Caspian fishes in sheer number and biomass (Caspian Sea, Ichthyofauna, 1989, quoted in Kosarev and Yablonskaya 1994). The main spawning population (80%) of anchovy (*Clupeonella engrauliformis*) reproduces in the eastern part of the South Caspian (Dementyeva and Prikhodko, 1975) and the main harvest (95%) is now caught in with the aid of fish pumps and electric light attraction techniques. The mullet (Mugilidae) are a new target for Caspian fisheries. The long-finned (*Liza* *auratus*) and the leaping grey (*Liza saliens*) mullet were introduced from the Black Sea during 1930 and 1934 as fingerling. The main fishing areas are located along the eastern shores of the Middle and South Caspian.

1. 2 General aspects of population dynamics

Population dynamics can be simply defined as the quantitative study of the four primary factors listed in Russell 's axiom (Pauly 1984). This axiom states that

$$B2 = B1 + (R + G) - (M + Y)$$

where B1 and B2 are the total weights of the exploited phase of a fish stock (or population) at the beginning and end, respectively, of a given time period, R denotes the recruitment (in weight) to the exploited phase, G the growth of individuals in the exploited phase, M the biomass of fish that died due to natural causes in the exploited phase, and Y the yield or catch (in weight) during the aforementioned time period.

In the last century fishery biologists started studying the biology of those species of fish and shellfish which were of commercial interest. The objective was primarily to gain knowledge of the life of these animals. They studied the areas of distribution, the migration patterns, spawning seasons, fecundity, development of eggs and larvae, food, feeding habits and behaviour. Fisheries science gradually became quantitative during the middle years of the 20th century, starting with the concepts developed by Baranov (1918), Russell (1931) and Graham (1935), culminating in the fish stock assessment models of Beverton and Holt (1956, 1957) and Schaefer (1954, 1957). The new techniques enabled fisheries biologists to describe the dynamics of fish stocks, to calculate in quantitative terms the interaction between the production of living resources in the sea and the fisheries which exploited these resources. Fishery biologists tried to predict what would happen to the stocks and to the yield under different assumptions of the future fishery. With these models the fishing industry and fisheries administrations now had techniques, which could estimate maximum sustainable yields for example, could be used as a basis fisheries management. Since the works of Beverton and Holt, and of Schaefer, theoretical studies of the dynamics of fish stocks and the practical problems of managing commercial fisheries have been closely linked.

The beginnings of fishery research as a distinct scientific activity, and the establishment of many of the major research institutes in Europe and North America around the turn of the century, as well as the setting up of the International Council for the Exploration of the Sea (ICES) in 1902, were largely due to the concern about falling catch rates of some of the prime fish stocks which were the first targets of industrial scale fishing, such as the plaice in the North Sea (Gulland 1988). Fisheries are based on wild stocks, living in their natural environment. These stocks cannot be controlled in the direct and positive way that the farmer controls his domestic animals. Nevertheless, the fish stocks are affected by man's activities to an increasing extent and the success of the fisheries depends critically on the state of the fish stock, which all those concerned with making policy decisions about fisheries must take into account. The decision makers therefore need scientific advice about the state of the fish stock (Gulland 1983). The basic purpose of fish stock assessment is to provide advice on the optimum exploitation of aquatic living resources. Living resources are renewable but limited, and fish stock assessment may be described as the search for the exploitation level which in the long run gives the maximum yield in weight from the fishery (Sparre *et al.* 1989).

1. 3 A brief history of Iranian fisheries

The Islamic Republic of Iran lies in western Asia between 44° 14' and 64° 20' N latitude and 25° and 36° 47' E longitude, boarded by Azerbaijan and Turkmenistan to the north, Turkey and Iraq to the west, the Persian Gulf and the Gulf of Oman to the south, and Pakistan to the east. Iran's geographic location, owing to its 1800 km coastline along the Persian Gulf and the Gulf of Oman, 990 km coastline along the Caspian Sea, and about 1.5 million hectares of inland waters, gives it great potential in fisheries. The fisheries sector has been divided into seven independent districts but the main divisions are Northern, Southern, and Inland Fisheries. Prior to the Islamic revolution in 1979, the Iranian fisheries were divided between two companies, the Northern and the Southern, relating to the Caspian Sea in the north and the Persian and Oman Gulfs in the south. In 1980, through the legislation passed by the Council of the Revolution, the southern and the northern companies were merged into a single organization which officially began its activities in 1982. Two years later, in accordance with the proposal offered by the heads of the three authoritative powers and the approval of late Imam Khomeini, Iranian fisheries organizations came under the sponsorship of the ministry of Jihad-e-Sazandegi. This organization is now managed by a vice-minister, acting as the general director and the head of the board of directors. The fisheries sector of the Islamic Republic of Iran has the privilege of planning and exploitating the commercial resources of the Caspian Sea in the north, the Persian Gulf and Gulf of Oman in the south, and all the inland waters of the country. More than 114 species in the Caspian Sea, of which the sturgeon are the world's most valuable, and 350 species of fin and shellfish in the Persian Gulf and Gulf of Oman, provide the good and sometimes unique fish resources of the country.

Up to the year 1835, fishing in the Iranian sturgeon fishing areas of the Caspian Sea was controlled by the local governors. From that year up to 1927, in a mutual agreement between the Iranian and Russian governments, permission for fishing in the Iranian part of the sea was given to different contractors, mainly Russians. In 1972, by a new agreement between both countries, a joint company named the Mixed Fishing Company of Iran and Russia was established for a 25 year period. At the beginning of February 1952, the Iranian fisheries were nationalized and named Shilat-e-Iran, translated as Iranian Fisheries. Table 1.1 shows the annual catches of sturgeons by Iran and the former Soviet Union from 1978 to 1991. As the data show, the annual catch of sturgeon started to decrease in 1983. The decrease in the first six years (1983-1988) was not large, but from 1989 the annual catches of sturgeon in the Caspian Sea declined sharply.

Table 1.1: Annual catches (thousands of tonnes) of sturgeon fish from Caspian Sea by Iran and the former Soviet Union from 1978 to 1991.

years	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
U.S.S.R	24	25	25	25	25	24	22	21	20	19	19	16	13.3	10,523
Iran	2.2	1.9	1.8	1.9	2	1.8	1.9	2	2.2	2	2.2	2.2	2.25	3,036
Total	26.2	26.9	26.8	26.9	27	25.8	23.9	23	22.2	21	21.2	18.2	15.55	13.559

The annual catches of sturgeon by both Iran and Russia from 1991 to 1993 have been reported as 13,559, 12,442, and 7274 tonnes respectively (FAO, 1993; Mr. Moghim head of the stock assessment section of the Mazandran fishery research centre, pers. com.). As an illustration of the decline, the sturgeon catches were 27,000 tonnes in 1982, but only 13,558 tonnes in 1991, which means that the catches of 1982 were more than twice those of 1991. According to Barannikova (1987) and Vlasenko (1992), the Caspian Sea provides the major part (90-92%) of the sturgeon catches of the world.

1. 4 Principal features of Acipenseridae

Sturgeons have been separated from the main line of teleost evolution for at least 200 million years (Sewertzoff, 1923). They are chondrostean fishes belonging to the family Acipenseridae. The sturgeon occur in fresh, brackish and marine waters in the northern hemisphere (Europe, eastern Asia and North America) (Binkowski and Doroshov 1985). However, anadromous sturgeons share with anadromous teleosts a similar life history strategy (McEnroe and Cech 1987). Approximately 25 species have survived to the present time. Sturgeon are an important group of commercial and recreational fish. The annual world sturgeon catch has ranged from 20,000 to 40,000 metric tonnes during the past fifty years and, as such, has been less significant than the catch of many other commercial fisheries (Doroshov 1985). However, because of the sturgeon's high value as a source of caviar and as a game fish, its fishery has far exceeded the importance and monetary returns of many others.

The high value of the fish has contributed to the rapid decline of sturgeon stocks. They attract enormous economic interest. Commercial fishing in the Caspian Sea is currently very intensive for four species: Stellate Sturgeon *(Acipenser stellatus)*, Russian Sturgeon *(A. guldenstadti)*, Persian Sturgeon (*A. persicus)* and Great Sturgeon or Beluga (*Huso huso)*. The same situation is reported for the Yellow or Lake sturgeon, *Acipenser fulvescens,* in Canada (Rochard *et al.* 1990). Commercial exploitation is mainly for caviar, made from the eggs (roe), but use is also made of the flesh, variously fresh, smoked or tinned. Angling for sport is becoming more popular, especially for *A. ruthenus* in Hungary, *A. transmontanus* in the U.S.A., and *A. fulvescens* in Canada.

All species of sturgeon reproduce in fresh water. Some spend all their lives there but others move to brackish water and some of these then migrate into the sea. Therefore, three types of life history can be distinguished. In the first, juveniles and adults remain in freshwater rivers and lakes. In the second, the adults migrate from fresh water into estuarine, brackish water after spawning and the juveniles follow more slowly. In the third, the adults migrate rapidly to the sea after spawning, where they remain until ready to spawn again; the young also leave fresh water quite early, as alevins (three to five weeks), and the juveniles then move between estuaries and the sea (Rochard *et al.* 1990).

Sturgeon are flexible and opportunistic predators which eat a variety of prey and switch as availability changes. These fish can also withstand long periods of starvation during periods of low food availability or spawning migration (Dadswell 1979, Mason and Clugston 1993). Sturgeon generally feed on invertebrates in the benthic food chain (Held 1969, Dadswell 1979, Carlson *et al.* 1985, Sandilands 1987, McCabe *et al.* 1993). Fish may also be an important diet component of some sturgeon species (Semakula and Larkin 1968).

One particular characteristic of the sturgeons' life histories makes them especially interesting in terms of population dynamics. They require a relatively long time to reach sexual maturity; the actual time varies greatly between populations but is about eight years for males and 14 years for females. After spawning for the first time, males reproduce every 1-2 years whereas females reproduce every 3 or more years. The spawning life of both sexes is often about 40 years (Russow 1957, Conte *et al.* 1988, Guenette *et al.* 1992, Keenlyne and Jenkins 1993, Rochard *et al.* 1990). A long life span (Pycha 1956, Wilson 1987, Rien and Beamesderfer 1994) allows fish numerous opportunities to spawn and reduces the need to spawn in years when conditions are not suitable.

Many sturgeon species depend on free-flowing rivers and seasonal floods to provide suitable spawning conditions. Adhesive eggs are typically broadcast over rocky substrates in turbulent, high-velocity areas during periods of high discharge in spring (Smith 1985, Hall *et al.* 1991). Recruitment has been widely correlated with spring and summer discharge (Stevens and Miller 1970, Votinov and Kas'yanov 1979, Kohlhorst *et al.* 1991, Veshchev 1991).

Twenty five species of sturgeons were recognized in the world (Romanycheva 1976). The greatest number inhabit the Caspian Sea and the Sea of Azov. Thirteen sturgeon species inhabit the waters of the former USSR, of which the Stellate Sturgeon (*Acipenser stellatus),* the Russian Sturgeon (*A. guldenstadti*), Beluga (*Huso huso*), and the Sterlet (*A. ruthenus*) are the main species caught for commercial purposes (Romanycheva 1976).

The history of sturgeon culture is over a century old, although its husbandry level is far behind that of trout, common carp and channel catfish. For example, no F_2 of any sturgeon species, with the exception of hybrids, have been established in hatcheries. Knowledge of sturgeon genetics is very limited, and of nutritional requirements and pathology practically absent. In Russia, alevins have been reared on a large scale since 1949 to maintain stocks of *A. stellatus*, *A. guldenstadti* and *Huso huso*. At present there are about 23 breeding farms for restocking sturgeons, 17 on the Caspian Sea (three of them established and run by Iran) and seven on the Azov Sea. Two of the Iranian units only, release 4-7 x 10^6 fingerlings a year (Dumont 1995). Adult fish are caught during the spawning migrations. Eggs are grown at fish culturing farms, where both egg incubation and the rearing of young fish take place.

The young are kept at the farms until their length reaches 6 cm and body weight 1.5 g and then they are transported to their marine areas of feeding and growing. About 100-140 million alevins are put into the sea each year (Barannikova 1987). According to Romanycheva (1976) almost all the sturgeon stocks of the Sea of Azov and the southern Caspian Sea are recruited on the basis of artificial reproduction of the fish species.

The sturgeon population in the southern seas declined as a result of increased riverine and, particularly, marine catches between the end of the last century and 1913 (Barannikova 1987). The magnitude of the marine catch decreased during the period of World War 1 and the Russian Civil War, and the sturgeon reserves gradually recovered. However, a further reduction of the sturgeon stocks in the Caspian and Azov seas occurred between 1930 and 1940 as a result of intensive marine fisheries using automatic hook-and-line gear and gill nets. For instance, sturgeon catches from the Caspian Sea were only 7,500 tonnes in 1949 as compared to 23,000 tonnes in 1910 (Barannikova 1987). Other reductions of sturgeon catches in the Caspian Sea have occurred since 1989, when the annual catches of sturgeon began to decrease. Later there was a sharp reduction in the catches after the break-up of the former Soviet Union. According to recent published data (FAO, 1992, and pers. comm. with Iranian fisheries research centres, Dr. Nezami and Dr Pourgholam), Caspian Sea sturgeons are in danger from both overfishing and unfavourable ecological conditions. Division of the former Soviet Union into new republics has greatly affected the sturgeon populations of the Caspian Sea, since each nation has a tendency to catch the sturgeon without any protection and regulation.

Dams and artificial embankments, which prevent migrating fishes from freely ascending or descending rivers, also prevent them from completing their life histories. For example, hydroelectric dams were built on the Rivers Don and Kuban (U.S.S.R), preventing migratory fish from ascending the rivers (Barannikova 1987).

The management of fishing for all the migratory fish is extremely complex, owing to their particular life histories. It is even more difficult when the fish are of great economic value, as in certain species of sturgeon. Some stocks are exploited by more than one or two countries (e.g. in the Caspian Sea) which leads to problems of legislation and control. These are difficult to resolve, bearing in mind a continuing tendency towards overfishing.

1. 5 Sturgeon fishing methods in the southern Caspian Sea

The marine catches of sturgeon began at the end of the last century; previously, the sturgeon were caught in rivers (Barannikova 1987). In the southern part of the Caspian Sea (Iranian side) most of the sturgeon catches are made in the sea, due to the lack of rivers. As a result of legislative restrictions on gear (for protecting the sturgeon) only gill nets have been used for catching the sturgeon.

The Iranian Fisheries Company is in charge of both managing and fishing sturgeon. Two provinces, Mazandaran and Gilan, are located in the southern part of the Caspian Sea, each with a general fisheries office and a research and training organization. Four fishing districts in both provinces were established in 1970 for managing and organizing the sturgeon fisheries, and each district has several fishing stations from which the sturgeon captured by fishermen are delivered for processing caviar. Districts 1 and 2 are located in Gilan province, and districts 3 and 4 in Mazandaran. Sturgeon are fished only by anchored gill nets, although sometimes a few may be caught by beach seine, when fishing for teleost fishes. The standard mesh sizes (knot to knot) and length and width of gill nets used for capturing different sturgeon in the south part of the Caspian Sea are given in Table 1. 2.

Table 1. 2: Standard mesh size, and length and width of gill nets used for fishing different species of the sturgeon in the south part of the Caspian Sea (Emadi 1989).

species	mesh size (mm)	meshes and length (m)	width (meshes)
Acipenser stellatus	100	164 (18 m)	21
Acipenser persicus	150	120 (18 m)	18
Acipenser guldenstadti	150	120 (18 m)	18
Huso huso	280	64 (18 m)	7

It should be noted that, for most of the time, the bigger species like Beluga are captured by gill net set for smaller fish like Stellate Sturgeon. This is a common problem in estimating the value of catch per unit effort (CPUE) for the sturgeon captured in the southern part of the Caspian Sea.

The number of nets used for capturing the sturgeon in the south Caspian depends on the fishing season and varies between the districts. Usually the number of nets used daily for each district varies between 100 and 200. The standard mesh size for Beluga until 1988 was 250 mm, but then mesh size was increased to 280 mm to prevent catches of young. It should be noted that, with regard to the fishery managing policy fishermen have to release the immature fish if caught. The gill nets have a length of 18 m, their lower edge rests on the sea bed during the fall fishing season (August to October) but the nets are raised a few metres in the spring season (February to June). The sea bed is sandy over almost the whole fishing area. The length of coastline comprising the catching area is almost 900 km. Sturgeon fishing takes place at depths of up to 70 m and within 15 km of the shoreline. Fishing for sturgeon beyond these limits is restricted. The fishing season in the south part of the Caspian Sea (Iranian fisheries) starts on July 27 and ends on June 21 of the next year and is known as the spring and fall fishing season. The season for and duration of fishing for different species of sturgeon varies between districts. The sturgeon fishing calendar for different districts is given in Table 1. 3.

Table 1. 3: Sturgeon fishing calender in different fishing districts in south part of the Caspian Sea (obtained from Iranian Fisheries Management).

season	district	species			
		A. stellatus	*A. persicus*	*A.guldenstadti*	*Huso huso*
spring	1	Feb. 8 to June 21	Feb. 8 to May 22	Feb. 8 to May 22	no fishing
"	2	Feb. 8 to June 21	Feb. 8 to May 22	Feb. 8 to May 22	no fishing
"	3	Feb. 8 to June 21	Feb. 8 to May 22	Feb. 8 to May 22	no fishing
"	4	Jan. 21 to May 31	Aug 12 to May 22	Aug 12 to May 22	Sept to Apr. 4
fall	1	no fishing	Aug. 2 to Oct. 12	Aug. 2 to Oct. 12	Aug. 23 to Oct 12
"	2	no fishing	Aug. 2 to Oct. 12	Aug. 2 to Oct. 12	no fishing
"	3	no fishing	Aug. 2 to Oct. 12	Aug. 2 to Oct. 12	no fishing
"	4	no fishing	Aug. 12 to May 22	Aug. 12 to May 22	Sept. 1 to Apr. 4

1. 6 Importance of caviar in Iranian fishing exploitation

The term caviar can be applied to prepared and salted roe of any female fish species. However, the most appreciated varieties are from sturgeon only. Usually caviar constitutes 10 to 15 percent of the total weight of the mature female sturgeon. The value of the caviar is at least ten times that of the flesh, and caviar production is probably the greatest contributor of profit in sturgeon investments.

Caviar production from the whole Caspian Sea decreased sharply from 13,300 tonnes in 1990 to 2,100 tonnes in 1994 (Dumont 1995). The annual yields of caviar in the southern Caspian from 1971 to 1989 (Iranian sides) varied between 191.5 tonnes to 304.5 tonnes (average 234.5 tonnes per year). For this period (1971-1988), Stellate caviar was 49.8-67.3% (minimum in 1972, maximum in 1987), Persian and Russian

Sturgeon caviar 26.4-45.4% (minimum in 1974, maximum in 1980) and Beluga 18.8-1.2% (minimum in 1986, maximum in 1972) of the total yield, (Rezvani 1989). The proportion of the Beluga caviar has decreased by 16 times from 1971 to 1988.

Among Iranian exports sturgeon caviar has a special place. The Beluga caviar is known as the best from the Caspian Sea and might even be the best in the world, but nowadays the yield is minimal. According to Vosogh (1989), the consumption of caviar in Iran shows an increasing trend from 10.6 tonnes in 1951 to 71 tonnes in 1988.

Smuggling of caviar to the rest of the world and illegal fishing of sturgeon, especially in the Caspian Sea (DeSalle and Birstein 1996), confirms the importance and high value of caviar. No official data are available on the percentage of Iranian income derived from caviar production, but certainly caviar is an important source of income for the country.

1. 7 The objective of this study

The commercial importance of the sturgeon in the Caspian region, the benefit to the countries fishing them on the one hand, and the decline in catches on the other, should be taken into consideration by the countries with fishing interests. After the division of the former Soviet Union and the establishment of new Republics, catches have decline and the species of sturgeon in the Caspian Sea are endangered (see Table 1.1, FAO 1993, Vlasenko 1992, Bemis and Findeis 1994, DeSalle and Birstein 1996).

The objectives are to study the growth, mortality and yield-per-recruit of sturgeon species in the southern Caspian Sea from the landing statistics and age data; and to use this information to provide the Iranian authorities with advice for the rational management of this valuable resource.

Fig. 1. 1 Map showing the Caspian Sea and adjacent countries, river systems and lakes that are historically important for sturgeon.

CHAPTER 2

MATERIALS AND METHODS

2.1 Materials

In the southern part of the Caspian Sea, adjacent to the northern part of Iran, the Iranian Fisheries Company established two research centres in the Mazandran and Gilan provinces to under take research projects in their respective areas. A most important assignment for these research centres was to investigate different aspects of the sturgeon population. From 1990 to 1994, sampling was conducted for *Acipenser stellatus* (Stellate Sturgeon), *A. guldenstadti* (Russian Sturgeon), *A. persicus* (Persian Sturgeon) and *Huso huso* (Beluga) in the southern Caspian. Four fishing districts, two in each province were established for managing and organizing the sturgeon fisheries and each district has several fishing stations from which the sturgeon captured by fishermen are delivered for processing caviar. Districts 1 and 2 are located in the Gilan province, districts 3 and 4 in Mazandaran. Figure 2.1 shows the location of each district, with the fishing stations where samples were obtained. The sampling periods coincided with the fishing periods for the sturgeon in each area (see Chapter 1). Samples were obtained every day of fishing, except when the weather was not suitable. The fishing methods, net type, and mesh size used for sturgeon fishing in the southern Caspian are given in Chapter 1. When the catch was high (e.g. during March and June for the Stellate Sturgeon), part of the catch was taken randomly as a subsample. When the fish are transferred by the fishermen from the sea to the processing station place, technicians record all the necessary data: total and fork lengths, weight, and weight of caviar, and the pectoral fin ray was removed for age determination. Females and males, sexed according to the gonads, were recorded separately. The ages of the fish were later calculated from sections of the pectoral fin (see Chapter 3). All sturgeon were routinely examined for spawning condition, mature individuals being distinguished by the degree of gonad development and differentiation of the gonads.

2. 2 Data Analyses

Sex, age, fork length and total weight data were supplied for each species. The SPSS (version 6.0 1993) computer program was used for the statistical analysis of the data. The analyses were conducted for each year separately and all combined, as well as for sexes separately. The relationships between weight and length, weight and age, and length and age were calculated for years and sexes separately using different curve fitting equations for estimating the best fit according to the correlation coefficient. The von Bertalanffy growth parameters (L_∞, K and t_0) were then calculated for each species (Chapter 9).

Total mortality (Z) of each species was estimated for each species using linearized catch curves based on age and length composition data, and Beverton and Holt's Z-equations (Beverton and Holt, 1956) based on length and age data (Chapter 10).

Natural mortality (M) was estimated for each species using Pauly's (1980b) empirical formula based on growth parameters and mean environmental temperature, and Rikhter and Efanov's formula (1976) (Chapter 10).

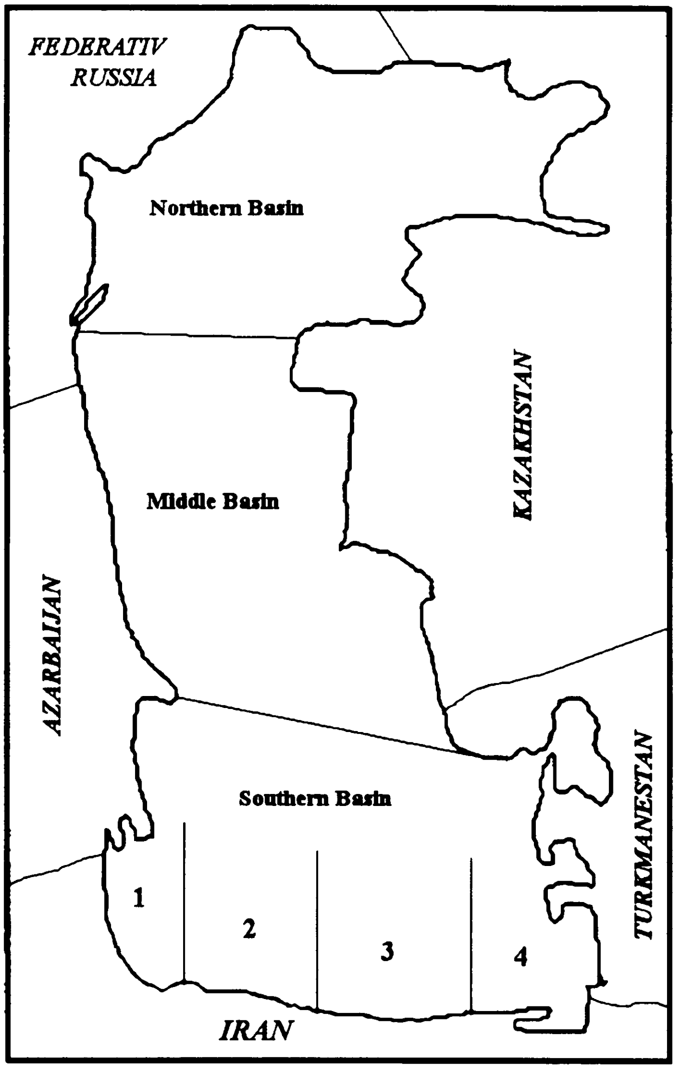
Fishing mortality (F) of all species under study was estimated from $F = Z - M$

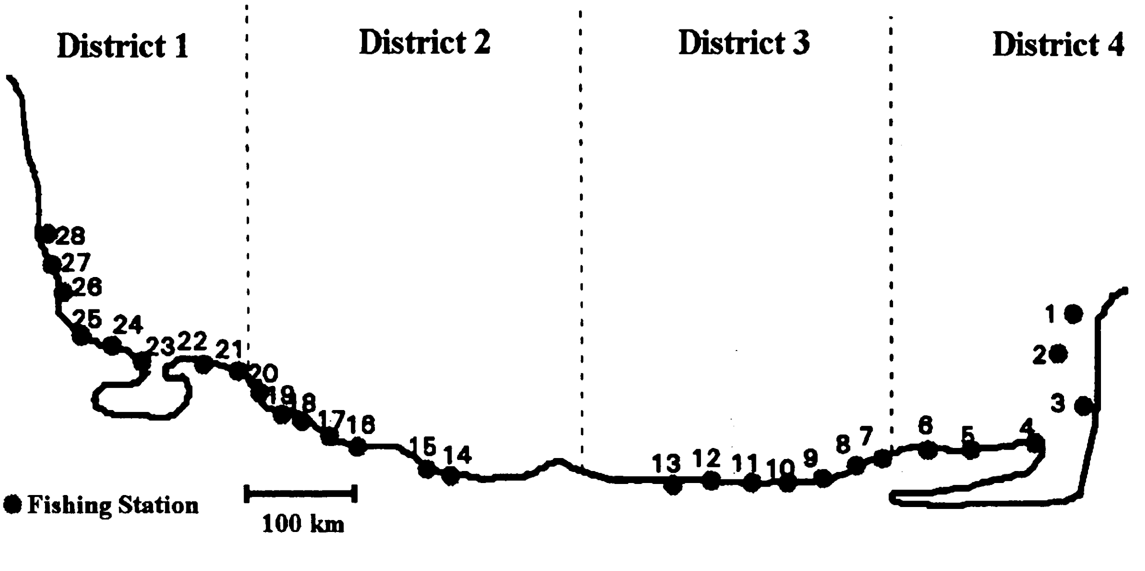
(Chapter 10).

Finally, the yield-per-recruit curve (Beverton and Holt 1957) was estimated for each species based on growth parameters and mortality rates, to provide advice for sturgeon fishery management in the Caspian Sea (Chapter 11).

More detailed information is given in the relevant chapters. Aging is discussed in the next chapter.

Fig. 2.1 - Map of the Caspain Sea
showing location of sturgeon fishery stations in the South





CHAPTER 3

Age determination of sturgeon species in the Caspian Sea

3. 1 Introduction

Age and growth studies constitute an extremely important field of commercial fisheries biology, knowledge of which is required for the solution of such problems as population dynamics, assessment of fishing grounds, yield, fishery management techniques, etc (Brennan and Cailliet 1989). In order to study the life history of a fish, including age at first maturity and subsequent spawning, life span, and the effects of environmental conditions, it is necessary to know its age and rate of growth (Chugunova 1963).

The most frequently used method of age determination is based on the number of growth zones or growth checks which appear on hard parts of fishes. Those that are considered to be formed annually are called year marks, annual marks, annual rings or annuli. These are formed during alternating periods of faster and slower growth (or no growth at all), and reflect various environmental or internal influences. In temperate regions the period of little or no growth usually occurs between the beginning of winter and early summer. In general the greater the seasonal temperature differences, the clearer are annual marks (Bagenal 1978). The most frequently used bones are the opercula, vertebrae, cleithra, fin spines or spiny rays, and soft rays. In chondrosteans the most useful method for estimating the age of fish is to use cross sections of the pectoral fin ray which, unlike otoliths and vertebrae, can be removed without killing the fish (Cuerrier 1951; Chugunova 1963; Kohlhorst *et al.* 1980; Jearald 1983; Smith *et al.* 1984; Threader and Brousseau 1986; Rien and Beamesderfer, 1992). According to Chugunova, sections (or polished cuts) of the bony rays of the pectoral fin (marginal) of sturgeons were first used for aging by a Russian investigator, Kler, in 1916. Later the method was perfected by Chugunova (1925, 1926) and extensively applied to sturgeons of the Sea of Azov. The utilization of the bony rays of sturgeons stimulated work on the age determination of these fish, because the collection of the rays does not spoil the commercially valuable exterior of the fish. Later, these methods were also applied for catfish and smaller fish (Chugunova, 1963). As far as could be found from the literature, most of the sturgeon examined were from fresh-waters. Estimating the age of the sturgeons living in the Caspian Sea was a key feature of this project.

3. 2 Material and Methods

For this part of the project and other field work I travelled to Iran (North of Iran, southern Caspian) from the middle of August to the middle of October 1993. The age determination of species was done partly (most of the catches of 1993 and 1994) by me and the rest by research teams back in both provinces in Iran. Ages of Caspian Sea sturgeon were estimated by counting annuli on cross-sections of the anterior pectoral fin rays. All fish were captured by gill nets during the fishing seasons (see Chapter 1). When the boats arrived at the landing station, a part or sometimes the entire pectoral fin ray was taken from the fish by making a cut with a knife or coping saw, close to the body. It is simplest to cut the fin ray approximately 25 mm away from the body. If the fin ray is cut too far from the body, there might be a loss of the first year rings. In this instance, to dry the fin ray samples, a small hole was drilled in one side of the ray and, after recording all the necessary data (total and fork length, weight, fishing place, etc...) on an identification card, the labelled fin was hung up in the sun to dry (depending on the sunshine, normally two days) before further processing.

A minimum of three sections, ranging from 0.3 to 0.6 mm in thickness, were taken from each sample to ensure that at least one would be readable. The fin rays was first placed in a vice, the marginal ray uppermost. Transverse cuts were made with a specially constructed fret saw having two parallel metal cutting blades. The completed sections were polished with a very fine file, after which they were ready for study. Sections were mounted on glass microscope slides with clear fingernail polish, and the annuli were counted under a binocular microscope at x40 magnification. Both transmitted and reflected light were used according to the characteristics and legibility of the growth rings. Sections must not be too thin because high transparency transmits too much light, which causes difficulty in observing the growth lines. The annual layers were observed most clearly in sections prepared with the saw blades fixed 0.5 mm apart. When the sections were obtained less than 0.2 mm in thickness, part of the bone was destroyed during sawing. Sometimes the sections were polished with carborundum, but this operation was found unnecessary for routine examination. Some obscure sections were cleared with ethyl alcohol or glycerol. The glycerol was used to exaggerate the differentiation between the rings, but if the sections are too thin, the penetration of the glycerol becomes uniform and makes them entirely transparent. In order to be more accurate an additional reader, with 2 to 3 years experience aging sturgeons, examined the annuli at the same time.

3. 3 Interpretation

Fin-ray sections were found to vary between different species of sturgeon. The ray sections of the Stellate Sturgeon have rounded margins, and the lateral lobes are usually extended very little, while in Beluga the lateral lobes are widely extended. Quite often the annual layers of the first years are destroyed, especially in Beluga and Russian Sturgeon. The broad opaque zones correspond to the more rapid summer growth and fade into narrow transparent winter bands which usually end abruptly with the start of the next summer zone (Chilton and Beamish 1982). The annual layers of sturgeons were easily counted on the lateral lobes of a section (Fig. 3.1). For counting the lines, a laboratory needle was used to trace the complete annual layer. It was assumed that one pair of translucent and opaque rings was formed annually. This has been the basic assumption of all sturgeon ageing studies (Brennan 1988). Under transmitted light, the opaque zone appeared dark, was usually wider than the translucent ring (especially in the earlier years), and was assumed to have formed during the summer months, a period of faster growth. The translucent zone or ring which appeared bright under transmitted light, was usually narrower, and was assumed to have formed during the winter months, a period of slower growth.

Growth rings were present in all fin sections examined and increased in number with increasing section width and fish size. Annuli were more widely spaced near the origin and usually tightly grouped toward the outer edge, especially in larger, older fish (Fig. 3.2). Incorporation of secondary fin rays into the posterior lobe of the first ray, a phenomenon which has not been described previously for the Stellate Sturgeon, Beluga, Russian Sturgeon and Persian Sturgeon, also reduced the readability of fin sections because of crowding of annuli (Fig. 3.3). This incorporation often appeared in Russian Sturgeon but was less frequent in Persian Sturgeon. This could potentially lead to errors in age determination. The seasonality of deposition patterns is often determined by characterizing the clarity of the edge during the course of the year. It was difficult, however, to determine whether the edge was translucent or opaque in fin ray sections from these species. This was particularly true in larger (older) fish that tended to have more narrowly spaced annuli in the posterior portion of the fin ray section. The application of glycerol was most often required for larger (thicker) samples that had less discernible early rings and bands, and more closely spaced marginal rings and bands. Occasionally, the thinnest sections became too transparent when the glycerol was applied. Under these circumstances, glycerol was not used, or a thicker section was selected. In order to produce a higher degree of differentiation between the translucent and opaque zones, Probest and Cooper (1955) immersed the cut sections in a 50% ethyl alcohol bath immediately prior to examination. They also used glycerol and xylene for differentiation, but neither was as satisfactory as ethyl alcohol. In this study, these methods were tested and the best clearing agent was found to be glycerol.

Large cavities in the centre of fin rays (Fig. 3.4) were often observed in the Beluga and Russian Sturgeon, which limited their use for age determination, especially in the earlier years. The occurrence of discrepancies between me and the other reader was not recorded, but they never exceeded one or two years plus or minus. Age determination was easiest in Stellate and Persian Sturgeons (Figs 3.5 and 3.6), more difficult in Beluga and Russian Sturgeon (Figs 3.7 and 3.8). The ray sections of old Beluga are less distinct making age determination difficult, and errors occurred in counting the narrow, closely-set annuli of larger old fish. The annuli located at the outer edges of pectoral fin rays were very difficult to read. Translucent rings located at the edge of the section, were usually very narrow compared with opaque rings, and it was therefore difficult to distinguish them at the outer edge, especially if the outer ring pairs were narrowly spaced, as in larger fish. In addition opaque ring widths varied within samples and were generally wider in early years and narrower and more closely spaced in later years, probably because of different growth rates for each individual.

3. 4 Discussion

Age determinations of Russian Sturgeon, Persian Sturgeon, Stellate Sturgeon and Beluga were accomplished as described. Brennan and Cailliet (1989) compared growth patterns of clavicles, cleithra, opercula, medial nuchals, dorsal scutes, and pectoral fin ray sections from White Sturgeon *(A. transmontanus)* in California. The legibility and interpretation of growth patterns, ease of collection and processing, and relative precision of age estimates have been evaluated for each. According to these authors, pectoral fin ray sections were the most practical aging structure in terms of ease of collection, processing, legibility, and precision of interpretation.

However, the precision of pectoral fin ray age estimates for White Sturgeon (*Acipenser transmontanus*) from the Columbia River has been questioned by Rien and Beamesderfer (1994). Multiple readings and recapture of marked fish were used to estimate the precision and accuracy of age estimates from cross sections of pectoral fin rays. They concluded that age estimates were neither precise nor accurate and recommended the development of alternative methods for aging White Sturgeon.

In the present study the accuracy and ease of age estimation from pectoral fin rays were different for each species and depended on the age and size of the fish. Delineation of annuli was most difficult in older fish, probably because of slow growth: fish that grow slowly do not appear to form a detectable growth zone every year. Accuracy of age estimation of these sturgeon declines with increasing size and age of fish. The readability of fin sections also was hindered by the incorporation of secondary rays into posterior lobes of the first fin rays. In some cases, especially in smaller fish where growth rings are more easily distinguished, the secondary fin rays could be used for verification. Difficulties in the interpretation of growth rings in fin ray sections of Russian Sturgeon, Persian Sturgeon, Stellate Sturgeon and Beluga included the variability of spacing between successive annuli, the incorporation of secondary rays, and indistinct marginal annuli.

However, because of the migrations of sturgeon, growth from year to year can vary greatly, depending on the time they spend at sea, ecological conditions in the water body (primarily food supply and competition, water temperature) (Sokolov and

Akimova, 1976, Raspopov 1993), and age estimation is more difficult than in non migratory fish. Raspopov (1993), compared data from the 1930 collected by Babuskhin (1964) and between 1970-1987, collected by himself, he concluded that for example Belugas caught in 1970 differed in having the highest growth rate than of Belugas, caught in 1930 and 1980.

It is concluded that, despite the reservations of Rien and Beamesderfer (1994), fin-ray sections remain the only practical way of aging sturgeons. Nevertheless, because of the variability and difficulties described, there will inevitably be a degree of error in aging, especially with older fish.

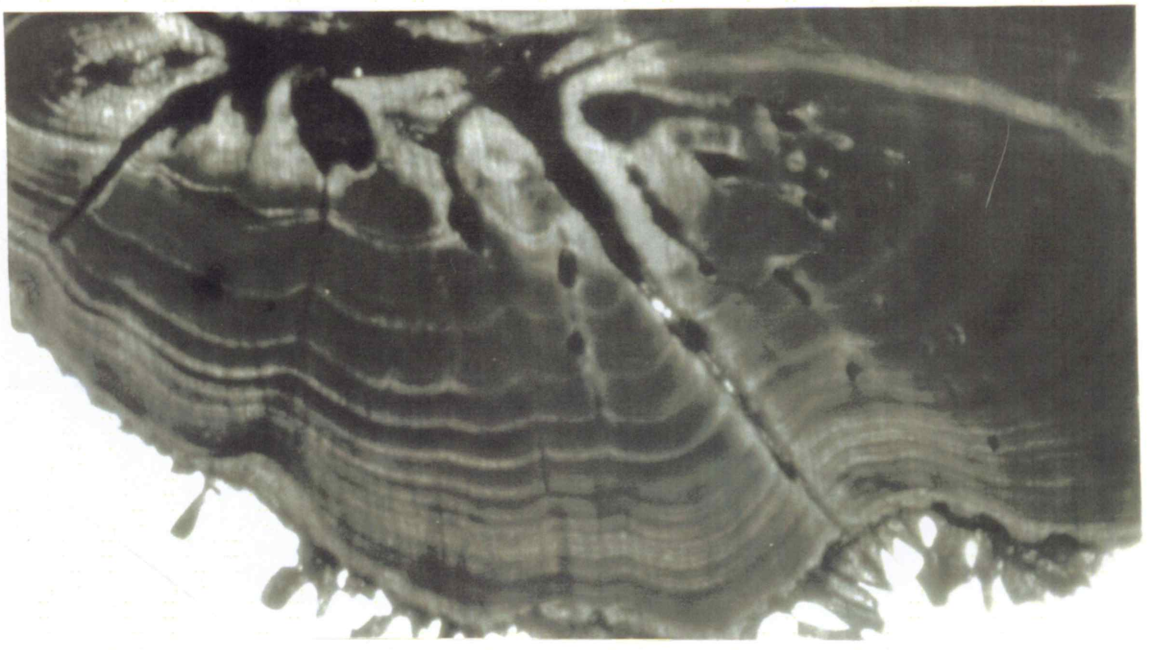


Fig 3. 1: Transverse section of the pectoral fin ray of the Beluga (13 years old), lateral lobe showing the annuli. Dark zones are summer-formed dense bones; translucent zones, winter period (x70 magnification).

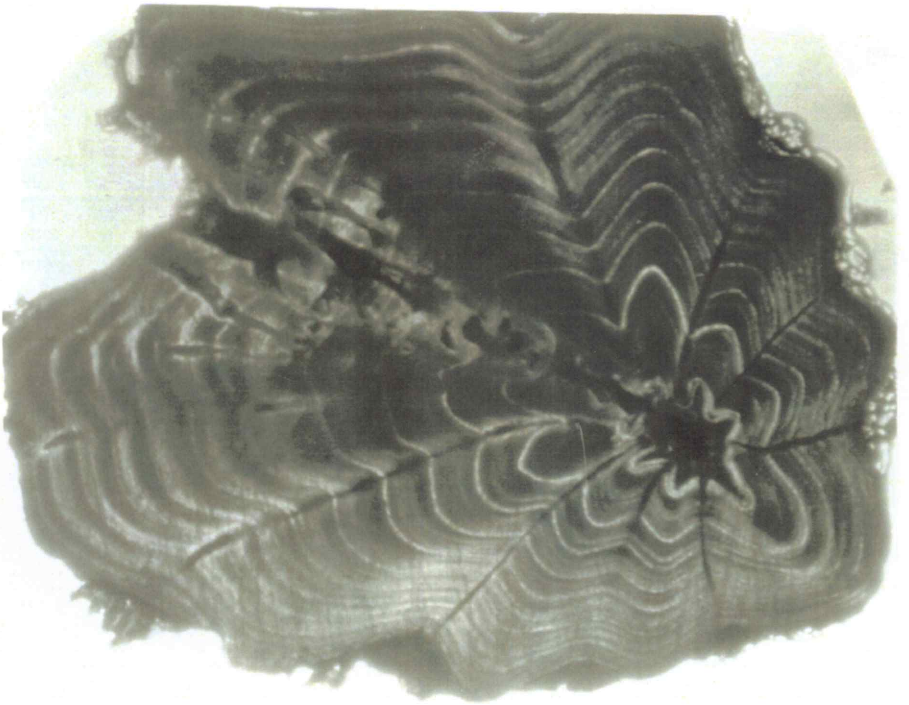


Fig 3. 2: Transverse section of the pectoral fin ray of the Persian Sturgeon, showing that the annuli were more widely spaced near the origin and tightly grouped toward the outer edge (x70 magnification).

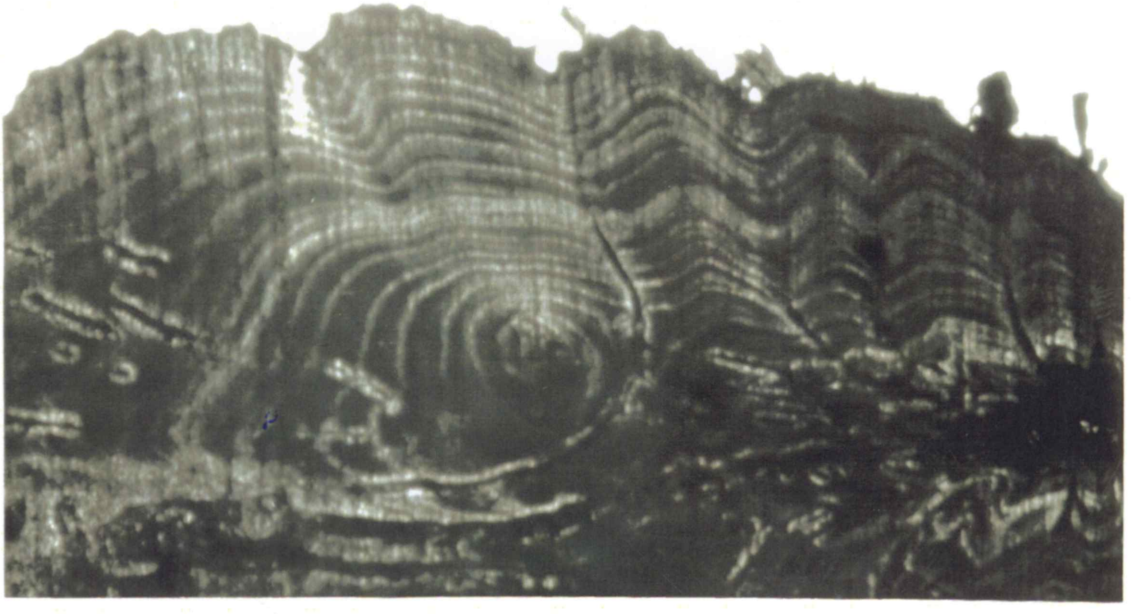


Fig 3. 3: Transverse section of the first pectoral fin ray of the Persian Sturgeon, which has incorporated secondary ray (x70 magnification).

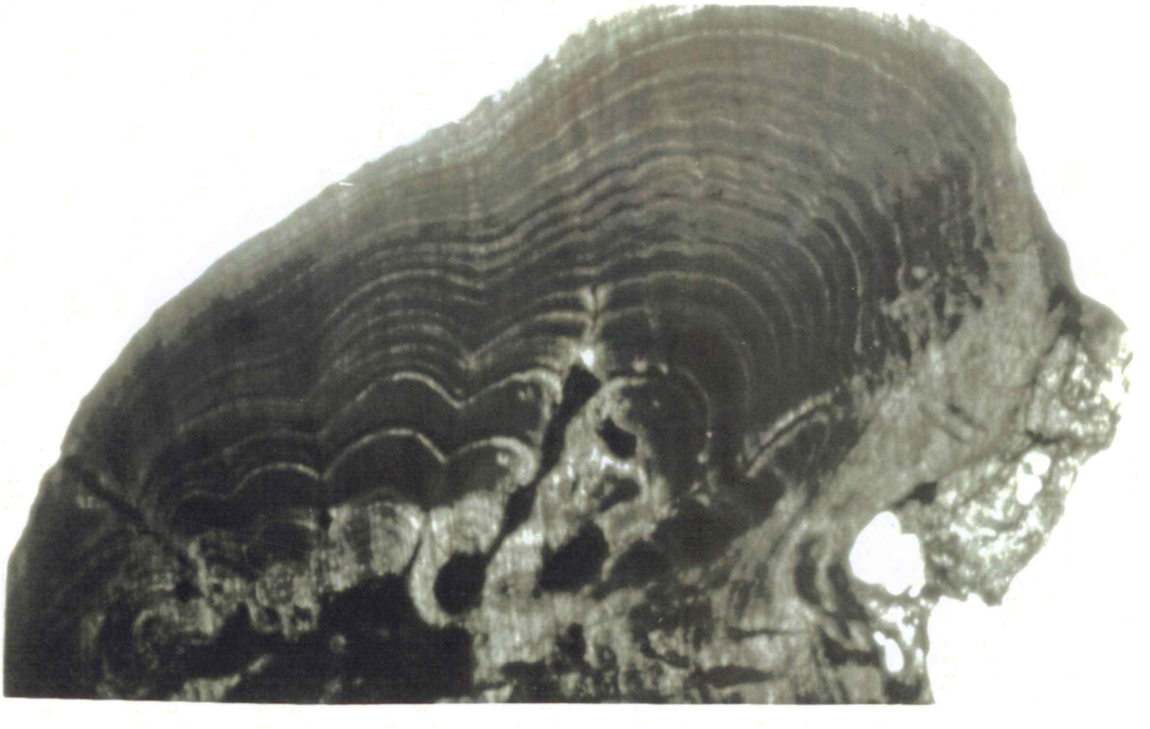


Fig 3. 4: Transverse section of the pectoral fin ray of the Beluga showing the appearance of cavities in the centre of fin ray (x70 magnification).

Fig 3. 5: Transverse section of the pectoral fin ray of the Stellate Sturgeon. Tl = 143 cm, Fl = 123 cm, W = 11.5 kg, 14 years old female (x70 magnification).

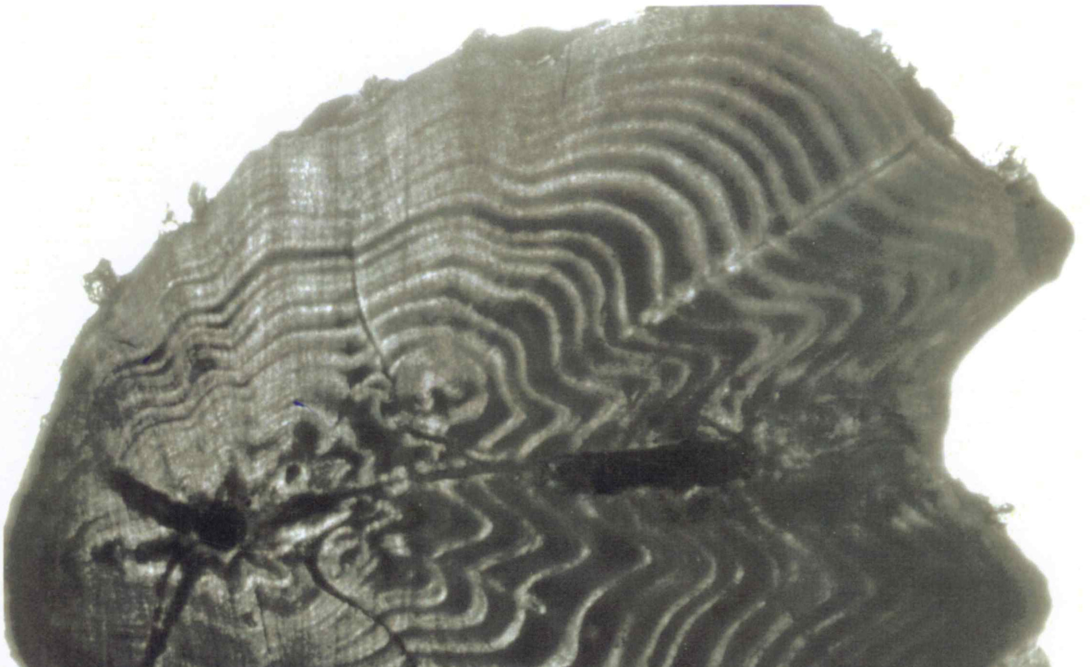


Fig 3. 6: Transverse section of the pectoral fin ray of the Persian Sturgeon. Tl = 162 cm, Fl = 150 cm, W = 22.5 kg, 19 years old, female (x70 magnification).

Fig 3. 7: Transverse section of the pectoral fin ray of the Beluga. Tl = 149 cm, Fl = 143 cm, 15 year old, female (x70 magnification).

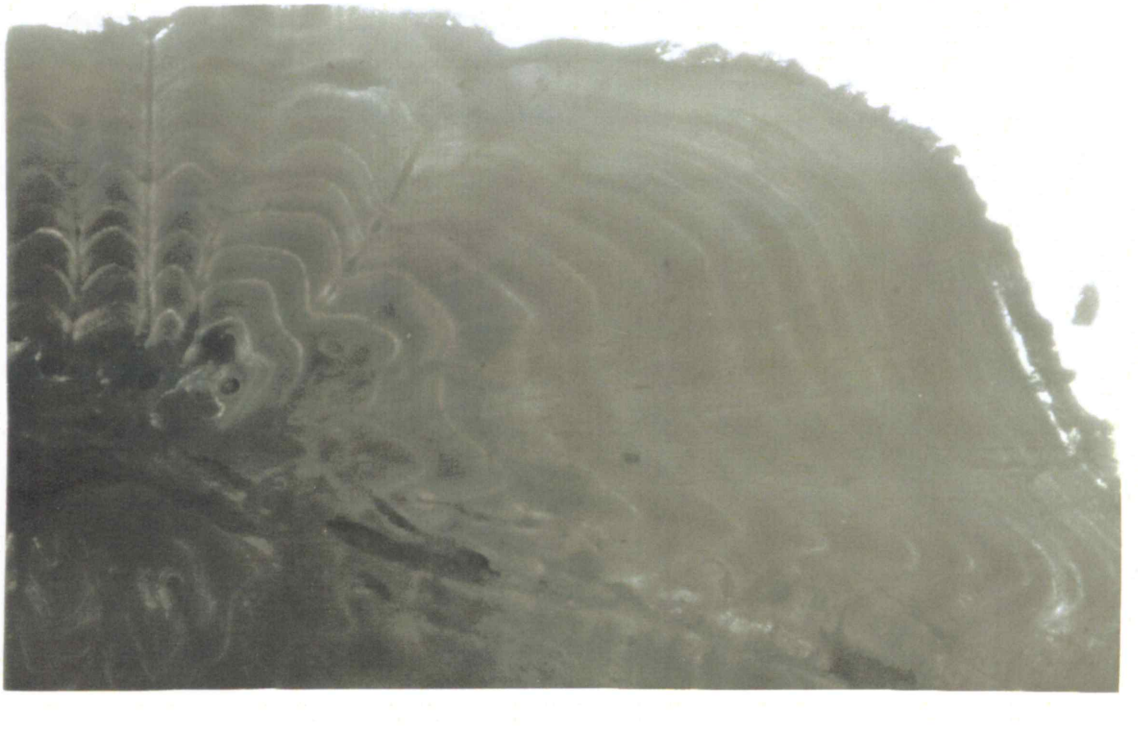


Fig 3. 8: Transverse section of the pectoral fin ray of the Russian Sturgeon. Tl = 140 cm, Fl = 124 cm, W = 25 kg, 18 years old, female (x70 magnification).

CHAPTER 4

Systematics and some basic biology of Beluga, *Huso huso*, Stellate Sturgeon, *Acipenser stellatus*, Persian Sturgeon, *A. persicus*, and Russian Sturgeon, *A. guldenstadti.*

4. 1 Systematics of the species

The sturgeons belong to the family Acipenseridae, order Acipenseriformes, subclass Chondrostei and class Actinopterygii. According to Berg (1940) the order Acipenseriformes are distinguished by following characteristics (Table 4.1).

Table 4.1: Distinguishing characteristics of the order Acipenseriforms.

1- Elongate snout;
2- the body covered with five rows of bony scutes (except the upper lobe of caudal fin, which is always covered with rhombic scales);
3- a heterocercal caudal fin;
4- the premaxillary fused with maxillary;
5- the endocranium cartilaginous, containing few endochondral ossifications;
6- both palatoquadrate arches meeting in the midline, not articulating with the endocranium;
7- the maxillary firmly connected with palatoquadrate;
8- a cartilaginous symplectic; 9- the hyomandibula without an opercular process;
10- clavicle and cleithrum both present;
11- no myodome; 12- no interoperculum;
13- the preoperculum absent or rudimentary;
14- the supraorbital sensory canal passing between the two narial openings of each side, posteriorly anastomizing with the infraorbital canal;
15- no vertebral centra; and
16- the supporting skeleton of the dorsal and anal fins not ossified, with several rays set close to gather on each of the supporting radials.

Two families belong to the Acipenseriformes, the Acipenseridae and the Polyodontidae. In the Caspian Sea, only the former are found.

The characters of the Acipenseridae can be summarized as: elongate spindle-shaped body covered with five rows of bony scutes, one dorsal, two lateral, and two ventral (the ventral scutes sometimes disappearing in old individuals); small bony granules and plates (shields) usually scattered between the rows of scutes; and the head covered with bony shields touching or almost touching in the upper part (Berg 1911, 1940).

A classification of the species investigated in this study is given below:

Classification of Acipenseriformes

Order Acipenseriformes

Suborder Acipenseroidei

Family Polyodontidae

Family Acipenseridae

Subfamily Husinae

Genus *Huso: H. huso*

Subfamily Acipenserinae

Tribe Acipenserini

Genus *Acipenser: A. guldenstadti*

A. persicus

A. stellatus

Three genera are found in the previous U. S. S. R., and key out as follows (Berg. 1948):

1. Spiracle present, snout moderately elongate 2

- No spiracle present. Snout strongly elongate and flattened.................................

.... ***Pseudoscaphirhynchus* Nikol'skii**

2. Branchiostegal membranes coalesced, forming a free fold below the isthmus. Mouth large, crescentic...***Huso*Brandt**

- Branchiostegal membranes attached to isthmus, not forming a fold underneath. Mouth relatively small, transverse............................ ***Acipenser* Linnaeus**

The four species studied belong to two of the above genera and can be keyed out as follows:

1. Mouth large, crescentic; laterally flattened barbels................***Huso huso* (Linnaeus)**

- Small transverse mouth; cylindrical barbels..2

2. Elongate snout; 26 - 43 lateral scutes; the body between the rows of scutes, covered by star-shaped plates...***A. stellatus* Pallas**

- Short, rounded, obtuse snout; 21 - 50 lateral scutes...3

3. Lateral scutes 24-50, gill rakers 16-31, less elongated body, wider and upward curving snout and darker colouration..***A. guldenstadti* Borondt.**

4. Lateral scutes 23-50 and smaller number of gill rakers, more elongated body, narrower and downward-curving snout and lighter colouration..................***A. persicus* Borodin.**

4. 2 Beluga, *Huso huso*

Species of *Huso* are large predatory fishes. Fossils are known from the Lower Pliocene deposits (Obruchev 1964). The genus comprises two species. The Kaluga, *H. dauricus* (Georgi 1775), is an eastern species inhabiting the Amur River system (in Russia) and occurs in two forms: one semi-diadromous, inhabiting the Gulf of Amur; the other non-migratory, continuously dwelling in fresh water. The second species is the Great Sturgeon, or Beluga, *H. huso* (Linnaeus,1758), which occurs in Europe, and is a typical diadromous fish. The Beluga differs from the Kaluga, *H. dauricus*, in that the first scute of the dorsal row is the smallest, the barbels possess foliate appendages, and dorsal fin usually contains more than 60 rays (Holci'k 1989).

The Latin name *huso* is derived from the Greek word hus, which means "swine". The dorsal scutes are oval, provided with a longitudinal denticulate comb; in sexually mature specimens they are covered with a soft skin. The gill rakers are rod-shaped. The barbels are long, laterally compressed, and bear foliate appendages (Berg 1948; Abdurakhmanov 1962; Elanidze 1983). These fish grow to approximately 6 m and a weight exceeding 1000 kg (Berg 1948; Tsepkin and Sokolov 1971). In exceptional cases, lengths of 8 m and weights of 3200 kg have been reported (Adamovich 1884), but according to Holci'k (1989) these are doubtful. The body is massive, spindle-shaped, and narrows towards the tail. Its height varies from 9.0-22% of total length. It is white ventrally, ashen gray dorsally and the snout is yellowish (Sal'nikov and Malyatskii 1934; Berg 1948; Abdurakhmanov 1962; Banarescu 1964; pers. obs).

4. 2. 1 Distribution

The Beluga inhabits the Black, Azov, Caspian, and Adriatic Seas (Holc'ik 1989). In the Caspian watershed, the main spawning river used to be the Volga, where 90% of the stock reproduced (Derzhavin 1947). The fish travelled far upstream, almost reaching the headwaters (Fig 4.1), and entered tributaries including the Oka, Sheksna, Kama, and Sura (Berg 1948). A second river known to be inhabited is the Ural, which they ascended as far as the town of Magnitogorsk (Severtsov 1863) and from which they reached a tributary, the Sakmara River (Berg 1948). They also inhabited the Kura River, as far as Tbilisi city and the Gurgen and Sefid Rud Rivers in Iran (Rudin 1966).

4. 2. 2 Migrations

Beluga are anadromous; fully grown fish migrate from the sea into the rivers, and return to the sea after the completion of spawning, and the passive or drifting migration of juveniles down the rivers after hatching (Holci'k 1989). In the Caspian there are two anadromous migrations, the spring run occurring in March and April, and the autumn run during September and October (Babushkin 1964). Throughout its whole range of migration, the Beluga races termed winter and spring by Berg (1934). Members of the spring race reproduce the same year in which they enter the rivers, while those of the winter race spend the winter in fresh water and reproduce there in spring of the next year. The winter race is dominant in the Volga and, in contrast, the spring race predominates in the Ural (about 70%: Peseride 1961). In the Caspian Sea, most of the Beluga remain on their feeding grounds in the northern part during the summer, where they are encountered at the end of the summer or beginning of autumn. When water temperature falls below 10°C, they descend to depths of 100 to 140 m (Legeza 1973). In the early spring, they return to shallow water and, as the water becomes warmer, they gradually move toward the northern part of the Sea (Holci'k 1989). The Beluga migrate most intensively beneath ice in the winter (Pavlov and Slivka 1971), and Beluga and Russian Sturgeon of both sexes migrate from the north Caspian Sea at the same time. According to Raspopov and Putilina (1989) the spawning migration of sturgeons during the autumn-winter period is uninterrupted, but its intensity decreases. The peak of the spawning migration of Beluga from the Caspian is at the end of March. Beluga of both sexes migrate at the same time in the Volga, but females predominate in January the spawning migration of sturgeons, and males in February-March (Raspopov and Putilina 1989).

4. 2. 3 Biology

Beluga begin preying on vertebrates at an early age (Ber 1860). In the Sea of Azov, the piscivorous feeding habits are generally more active and adopted earlier than in Caspian Sea (Korobochkina 1951). In the Caspian Sea the main items included in the diet of Beluga are gobies (Gobiidae), " kil'ka" herrings (*Clupeonella* spp.), and shad (*Alosa* spp) but the list of fishes consumed is long, with more than thirty species (Antipa 1933; Ambroz 1960; Babushkin 1964; and Svetovidov 1964). Beluga in the Caspian watershed also eat a small quantity of invertebrates, such as large crustaceans and molluscs (Babushkin 1964; Zheltenkova 1964).

The Beluga is a very long-lived fish with a life span that can exceed 100 years. A female of 490 cm total length weighting 1004 kg, found in the northern Caspian in 1937, was estimated to be 91 to 101 years old. The age of a male of 400 cm and 726 kg caught in the northern Caspian in 1940 was estimated to be 107 to 118 years (Babushkin 1964). At present, the greatest age being recorded for Beluga in the Black and Azov Seas is 36 years (Kirilyuk 1972). In the Caspian Sea, it is 60 years (Pashkin 1972a; Kazancheev 1981). Sexual maturity is attained very late, the males of the Volga population first reaching this stage in their eleventh year, but many only maturing at 14 to 16 years old. The females can become sexually mature during their sixteenth year, but most of them first reach this stage at 19 to 22 years (Pashkin 1972a). On average, every 1,000 kg of female mass includes 161 kg of eggs (Berdichevskii and Petrenko 1979). The Beluga is the most fecund of all the sturgeons, the number of eggs laid being dependent on the size of the female. In general, females from the Caspian Sea produce a significantly greater quantity of eggs than those of comparable weight from the Black Sea (Ambroz 1960).

Juvenile Beluga grow rapidly. One year old fish in the Caspian Sea have an average total length of 51 cm and weight of 571g (Babushkin 1964). Their growth rate in the Caspian watershed has decreased since 1938, owing to the decrease in the number of shad (*Alosa* spp.), the main food item (Babushkin 1964). Differences are also observed in the growth attained in different parts of the same water body. For example, Belugas in the Volga system are characterized by a faster growth rate than those in the Kura River (Babushkin and Borzenko 1951; Babushkin 1964). Several researchers have mentioned that females grow faster than males (e.g. Babushkin 1964). In recent years, the spawners entering the rivers from the Caspian Sea tend to be younger. According to the findings of Gorbachev *et al.* (1984), the predominant age classes in the Volga during 1983 were 14 to 28 years for females and 11 to 16 years for males. The biology of the Beluga differs from that of other species in its longer life span and in its spawning migration into rivers being spread over the entire year, peaking in spring and the fall. Thus, Common Sturgeon (*A. guldenstadti*) has peaks in July, less often in June and August (Pavlov 1971), and the Stellate Sturgeon runs in May and June into the upper delta of the Ural River (Shubina 1967).

4. 2. 4 Economic Importance

The Beluga is one of the major commercial fish species of inland water bodies and is the third most important sturgeon (Mil'shtin 1972). The larger stocks are concentrated in the Caspian region with considerably small stocks in the Black and Azov Seas. Catches in Caspian waters were greatest between 1902 and 1907. For the whole watershed, excluding the Iranian part, these ranged from 10,830 tonnes in 1907 to 14,850 tonnes in 1903. In 1936, the total catch in the region was 6,410 tons, of which 98% was taken in the former U.S.S.R. and 2% in Iran (Korobochkina 1964b). By the beginning of the 1980's the catch had stabilized at approximately 1,600 to 2,000 tonnes annually (Kazancheev 1981).

The Beluga fishery began in 1865 (Rapopov 1992). However, by the 1980's dams, river regulation, and pollution had caused significant reduction in natural reproduction. In general, the Beluga spawn farther upstream in all rivers than any other migratory sturgeon, and therefore the regulation of the water flow and construction of dams have had the greatest impact on the natural reproduction of this species (Holci'k 1989). Consequently, the Beluga has suffered a sharp decline and, at the present time, its movements are confined by the dams. It has lost many of its natural spawning grounds, and its stock is now maintained by numerous fish farms. Caspian Sea catches are accounted for mainly by natural spawning in the Ural River and by artificial propagation in the sturgeon hatcheries and farms of the Caspian watershed. Between 1963 and 1975, with the development of freshwater aquaculture, an average of about 12,000,000 cultured juveniles have been released annually in the northern Caspian Sea (Pirogovskii 1983).

4. 3 The Stellate Sturgeon, *Acipenser stellatus*

The specific name *stellatus* is a Latin word meaning 'covered with stars'. This name was apparently given to the Stellate Sturgeon because the plates covering its body between the rows of scutes have a star like shape (Holci'k, 1989). There are different local names; in Iran they call it 'Dracul', and 'Ozoonberoon', and in the former Soviet Union they call it 'Sevryuga'. There are two ecological forms of the Stellate Sturgeon in the Caspian Sea (Borzenko 1942, 1964). One is the North Caspian or typical subspecies, *A. stellatus stellatus*, and the other is the South Caspian or so-called Kura form, which Berg (1932) considered a valid race, *Acipencer* *stellatus stellatus* natio *cyrensis*. Based on a thorough analysis of both forms, Borzenko (1942) concluded that they are morphologically similar but differ in biological features. The South Caspian sturgeons mature later, have lower growth rate and fecundity. The validity of both forms was latter confirmed by Luk'yanenko *et al.* (1972), who investigated their serum proteins and found that they are genetically distinct. As in the case of other sturgeons, there are biological groups of the Stellate Sturgeon which differ in the timing of their migrations up the rivers, ripening of the gonads, spawning time, and water temperature requirement, and spawning grounds, (Barannikova 1972, 1975; Kazanskii 1962).

4. 3. 1 Distribution

The Stellate Sturgeon inhabits the basins of the Black Sea, Sea of Azov, and Caspian within which several stocks are localized (Holci'k, 1989). The largest populations are concentrated in the Caspian Sea, from which they ascend the Volga, Ural, Terek, Sulak, Samur, and Kura Rivers (Fig 4.1) (Berg 1948). They also enter the Sefid-Rud and Gorgan rivers along the southern Caspian coast (Rostami 1961). In the past, they ascended the Volga as far the city of Rybinsk (Kessler 1877) and, in its tributary the Oka, they migrated to the mouth of Dzhindra and entered the Moskva and Klyaz'ma Rivers (Sokolov and Tessler 1969). At the present time, they ascend as far as Volgograd, where some of them are transferred into the Volgograd Reservoir for aquaculture (Kazancheev 1981). In the Ural river, they are found beyond the city of Ural'sk. They reach the upper section of the Terek River and in the Kura they travel as far as the mouth of the Alazani River. From the Sea of Azov, they ascend the Don and Kuban Rivers, and from the Black Sea, they enter the Danube. Isolated individuals of this species have been caught at Zadar in the Adriatic Sea (Berg 1948).

At the present time, as a result of construction works and damming of the rivers, the range of the Stellate Sturgeon in the Caspian, Azov and Black Sea watersheds has decreased considerably. Thus, it has become rare in the Sefid-Rud and Gorgan Rivers, in which migration is hindered by impoundments and water control facilities (Rudin 1966). Most ascend the Danube only as far the dam at the Iron Gate and the Djerdap reservoir 942 km upstream, but some individuals succeed in passing this dam through the shipping locks (Djisalov 1983). The last Stellate Sturgeon found in the Czechoslovakian section of the Danube was captured at Koma'rno in 1926 (Holci'k 1959)

4. 3. 2 Migration

The Stellate Sturgeon is a migratory fish which travels considerable distances in the sea, in which it feeds and spends the winter, and in rivers, where it reproduces.

The damming of some of the rivers in the Caspian, Azov, and Black Sea watersheds has reduced the extent of the spawning grounds and caused changes to the time and route of the migrations. There are two phases of spawning migrations: movements in the sea and river mouths and the upstream run up the river bed. In the sea, the Stellate Sturgeons move onto the shelf, closer to the shore. When the sea temperature decreases to between 4 and 6°C, the Stellate Sturgeons congregate in the deep furrows and troughs in the northern part of the Caspian Sea. The juveniles move into the deep zones of the northern and central Caspian during autumn and winter. A considerable proportion of the adults also spend the winter in the central Caspian, where feeding can continue despite water temperatures declining to between 0.9 and 1.4 °C (Derzhavin 1922; Pavlov and Zakharov 1968; Zakharov 1975; Fadeeva 1980). Those individuals which mature sexually in winter were found to move to depths of 1.8 to 3.6 m in the northern Caspian. The spawning migrations of the Stellate Sturgeon in the Kura and Sefid-Rud Rivers are the same, occurring from late March till the end of the April or occasionally in May (Kazancheev, 1981).

The Stellate Sturgeon prefers warmer habitats than the other species. Its spawning runs in the rivers occur at water temperatures higher that those prevailing during the migrations of *Huso huso* and other sturgeons. The migration of the Stellate Sturgeon from the Caspian Sea into the Volga begins during April, after the water has warmed to between 6°C and 9°C. The peak period of the run is usually in May, when the water temperature reaches 10°C to 15°C and the water level in the river is rising rapidly. The spring migration occurs in very rapidly flowing, turbid water. The run declines in June but slightly increases again as the water cools during August, September, and October, ceasing by December (Pavlov 1964; Shubina 1967b; Slivka and Dovgopol 1979). The Stellate Sturgeon runs in the Volga, Terek, and Sulak Rivers take place under more severe conditions than those in the Kura and Sefid-Rud. Migration in the Kura River can occur throughout the year, but its intensity shows two peaks: one in April-May and other in September-October (Derzahvin 1922, 1947;

Borzenko 1932, 1964). The first run begins in mid-late March, when the river water has warmed to 10 °C. It peaks at the end of April and beginning of May, when temperatures reach about 18 °C. In July and August, the intensity declines. As the water cools, the migration intensity increases, and a second maximum is reached at the end of September and beginning of October. In winter, there is insignificant migration in the rivers . In both the Volga and Kuban Delta, the peak of migration coincides almost exactly with the high water flow in May and June. All main stages of the spawning run of the Azov and Volga Stellate Sturgeons occur at higher temperatures than those of other sturgeons, including *Huso huso* (Holci'k 1989). According to Kirilyuk and Rovnin (1983), quoted in Holci'k (1989), the Stellate Sturgeons, like other acipenserids, enter the Danube to spawn throughout almost the entire year, but two peak periods are evident: the first one begins in March at a water temperature of 8 to 10° C, has a peak intensity in April, and continues through May. A second, more intense migration begins in August and lasts until October.

4. 3. 3 Biology

The reproduction and general biology of the Stellate Sturgeon have been studied by Fadeyeva (1981), Slivka and Pavlov (1981), Pirogovskiy and Fadeyeva (1982), Veshchev and Nivikova (1986), Barnnikova (1987), Veshchev and Novikova (1987), Altuf 'ev and Romanov (1988), Artyukhin (1988) and Holci'k (1989). Most of this information concerns its biology in the Volga River and concentrates on size-age composition, distribution in the spawning grounds, gonad development and reproduction. After the construction of a series of reservoirs on the Volga downstream of Volgograd electric power station, 40% of the spawning grounds were lost (Veshchev and Novikova 1983). Spawning efficiency under the present conditions is undergoing significant change and is dependent on factors related to the volume of discharge during the low flow period in summer and on the number of spawners. The most unfavourable conditions for Stellate Sturgeon reproduction were observed in 1982 and 1984, when the lowest mean daily water levels were recorded in April and July, and did not exceed 148-175 cm (Veshchev and Novikova 1987). The temperature regimes in different years had a definite effect on spawning (and also as subsequent larval migration). The intensity of spawning decreases with increasing distance from the major spawning grounds.

Male Stellate Sturgeon mature at 9 years old and females at 11 years old in the Volga River (Borzenko 1942), whereas in the Ural River males mature at 4 years and females at 9 years (Petrov 1927). They are not mature every year; the period between spawnings is shorter for males than females (Avedikova and Rekov 1981). For the Caspian population the interval between the successive spawnings is three to four years (Kazancheev 1981).

The absolute fecundity of Stellate Sturgeon increases proportionally with increase in fish weight, but fish of the same weight often differ significantly in fecundity; the range of variation is greater in older fish (Veshchev and Novikova 1986). The absolute fecundity for Volga spawners was recorded by Veshchev (1979) as 103,700 to 465,800 eggs (in fish of total length 118-182 cm) and for the Ural

48,200 to 950,000 eggs for females of 95-153.6 cm total length (Nevskaya and Zakharov 1981). The males and females show differences in growth which become apparent after the onset of sexual maturation (Holcik 1989). According to Shubina (1967), among 17 and 18 year old speciments from the Volga, the males and females differed in length by an average of 12 cm and in weight by 4.4 kg. In the Kura, 12 year old females exceed males of the same age in length (Borzenko 1932).

The Stellate Sturgeon, like most other acipenserids, is a typical benthic inhabitant of coastal waters and the lowland sections of rivers, but unlike the other species, it intensively utilizes the middle and upper water layers (Borzenko 1964; Levin *et al.* 1981). In the Caspian Sea during the 1930's, its main foods were crustaceans and fishes (Shorygin 1952). The younger individuals fed primarily on crustaceans, while fishes became more important in the diet as the sturgeons grow older. According to Tarverdieva (1967, 1968 cited in Holci'k 1989) the main food items of the Stellate Sturgeon now are crustaceans and worms. These changes are correlated with a general change in the food supply in Caspian Sea. Following studies on sturgeon feeding habits and food preferences, *Syndesmya* and *Nereis* were introduced from the Azov Sea into the Caspian Sea from 1939-1941 (Zenkevich, 1952). At present, these two species whose amount of biomass has increased more than three times constitute about 70% of the reserves of available prey organisms,. The food consumed by juvenile sturgeons of the different species is similar during early ontogeny but diverges with growth. Adult Stellate Sturgeon eat crustaceans, worms and small fish (Barannikova 1987).

4. 3. 4 Economic importance

The Stellate Sturgeon is commercially one of the most important of the five sturgeon species which inhabit the Caspian Sea. Sturgeons, including the Stellate Sturgeon, were commercially exploited in the Caspian itself during the second half of the nineteenth century, first in the coastal waters and later at the feeding grounds in the northern part of the sea. At the beginning of the century, total annual catches amounted to 10,800 tonnes (Pirogovskiy and Fadeyeva, 1982). The majority of that catch came from the Caspian region, where a sturgeon fishery existed as long ago as the second century (Korobochkina 1964). About 45-60% of the Iranian caviar production, come from Stellate Sturgeon (Rezvani 1989).

4. 4. The Persian sturgeon, *Acipenser persicus*

The name "persicus" was chosen because of the frequent occurrence of this sturgeon in the southern Caspian Sea, along the shores of Iran (Holci'k, 1989), where it is called 'Gharaboroon'.

The Persian Sturgeon was described from the Caspian Sea by Borodin (1897), who separated it from the Russian sturgeon, *A. guldenstadti*. Subsequently, Berg (1933, 1948) regarded the Persian Sturgeon only as a subspecies, *A. guldenstadti persicus*. Recent analysis of the morphological, ecological and immunological characters of the Russian and Persian Sturgeons, absence of intermediate or transitional populations between the sturgeons of the Volga and Sefid - Rud, and reproductive isolation when spawning in same rivers, confirm the conclusion of

Borodin that the Persian Sturgeon is a valid species (Luk'yanenko *et al.*, 1974; Artyukhin, 1979, 1983). However, two subspecies occur, separable by the following external characters (Artyukhin and Zarkua 1986):

A. persicus persicus Borodin, 1897: The length of the snout averages 5.6% of total length, while its width at the mouth is 37% of head length. The colour of the back varies from grayish-blue to dark blue, and the head and sides below the lateral scutes are noticeably lighter than back. Longitudinal rows of bony plaques are usually found only on the dorsal surface. Found in Caspian Sea.

A. persicus colchicus Marti 1940: The length of the snout averages 6.9% of total length. Its width at the mouth is 30% of head length. The position of the snout is horizontal, and the transition from the tip of the snout towards the head follows a smooth concave line. The colour of the back varies from dark blue to black, the head and sides immediately beneath the line of lateral scutes are only slightly lighter than the back. Longitudinal rows of fairly large bony plaques are, as a rule, located on the back as well as below the lateral scutes. Found in the Black Sea (Marti 1940).

4. 4. 1 Distribution

In the Caspian watershed *A. persicus persicus* enters the Kura and Ural Rivers to spawn, and less frequently other rivers including the Terek, Sulak, and Samur. At the present time, it ascends the Kura as far as the Varvarin Reservoir (Zakharyan, 1972; Mailyan and Makhmudbekov, 1970) (Fig 4.1). In the Volga, it can proceed as far as the Volgograd Reservoir (Khoroshko, 1970) and in the Ural, to the town of

Orenburg (Peseridi, 1966, 1971). In the Terek it ascends as far as the Kargalin Dam (Musaev, 1972). Small numbers enter rivers along the Iranian coast, especially the Sefid - Rud and Gorgan - Chaii (Derzhavin, 1947; Berg, 1948; Babushkin and Borzenko, 1951; Rostami, 1961). In the north Caspian rivers, Volga, Ural, and Terek, the Persian Sturgeon is far less plentiful than the Russian Sturgeon (Borodin, 1981; Artyukhin, 1983).

4. 4. 2 Migrations

A. persicus undertakes long spawning migrations up rivers. It may enter the Kura River at any time of year, but 60% of the migrations occur from April through June (Legeza, 1967; Kazancheev, 1981), with most at the river mouth during April (Mageramov 1968). In the Volga, its spring migration occurs during April and May, with a peak during the second half of May. Spawning of the Persian Sturgeon occurs at higher water temperatures than in the Russian Sturgeon, and thus their spawning is mainly associated with southern rivers of the mountain type: Sefid-Rud, Kura, and Sulak (Derzhavin, 1947; Babuskin and Borzenko, 1954; Rostami, 1961). The migration in the Dagestan, Terek and Sulak rivers is observed from April to June, with a peak in May (Derzhavin 1947). According to Rostami (1961), Persian Sturgeon migrate to the spawning sites in Sefid-Rud at the end of April and in May, and also in autumn, during September and October. As the rivers along the Iranian coasts become shallow during the summer, the spawning migration and reproduction are interrupted.

4. 4. 3 Biology

Persian Sturgeon is widely distributed in all parts of the Caspian Sea, but it feeds and spends the winter in the southern and central Caspian, mainly near the south and south-eastern coasts (Kazancheev, 1981).

During their migrations in the rivers, these fish remain close to the bottom. For spawning, short, fast-flowing mountain rivers are preferred (Artyukhin and Zarkua, 1986). Spawning occurs at 15-25°C, through the entire period of the "hydrological summer" (Derzhavin, 1947; Borzenko, 1954, 1961). The diet changes with age; fish form the larger part of the diet in younger age groups in the sea, while the fully-grown individuals consume molluscs, crabs (*Rhithropanopeus harrisii*), and fish.

Length and weight are strongly dependent on age and sex, and on the feeding conditions in the habitat. Females are always larger than males of the same age, especially after reaching sexual maturity (Legeza and Voinova, 1966). *A. persicus* has a faster rate of growth than *A. guldenstadti* but, in the southern Caspian region, it has decreased since the 1930's and 1940's (Legeza, 1967). According to the literature, *A. persicus* reaches sexual maturity somewhat later than *A. guldenstadti* (Derzhavin, 1947; Babushkin and Borzenko, 1951; Rostami, 1961). In the Kura River, males mature at the age of 8 years, females at 12 years. In the Volga and Ural Rivers, maturity is reached somewhat later, at 15 for males and 18 for females. Like *A. guldenstadti*, *A. persicus* does not spawn every year. The period before the fish become ripe again is apparently two to four years (Povlov and Elizarov, 1970).

4. 4. 4 Economic importance

A. persicus constitute at least one third of the annual Iranian catch of sturgeon. However, Iranian catch records do not distinguish between the two species *A. persicus* and *A. guldenstadti*. From 1970-1992, the catches of these species in the Iranain coast was about 10,000 tonnes (annual report of Gilan Research Centre, 1992). There were no data available from other part of the Caspian Sea.

4. 5 The Russian Sturgeon, *Acipenser guldenstadti*

The species was named after Johann Anton Guldenstadt (1745-1781), an outstanding naturalist and member of the St. Petersburg Academy of Sciences. In Iran it is called "Chalbash".

4. 5. 1 Distribution

The range of *A. guldenstadti* encompasses the Black, Azov and Caspian Seas, and the rivers that empty into them. In addition to the main diadromous form, a non-migratory freshwater form has been reported from various rivers (Lukin 1937; Manea 1966; Tespkin and Sokolov 1970). In the Caspian watershed the Volga is the river most abundantly inhabited by the Russian Sturgeon and it formerly ascended as far as the town of Rzhev (Berg 1948). The second most important river is the Ural, which, during the first half of this century, they ascended as far as Orenburg (Fig 4.1) and there entered a tributary, the Ilek River (Kirikov 1966). They are now very rarely encountered in the Terek River (Kazancheev, 1981), although they were formerly caught almost as far upstream as its headwaters (Tsepkin and Sokolov 1970). At the beginning of the 20th century, they ascended the Kura as far as the mouth of the Aragva River (Berg 1948). A negligible number of Russian Sturgeons enter the Samur, Lenkoranka, and Astara Rivers along the southern Caspian coast.

4. 5. 2 Migration

The anadromous migrations of the Russian Sturgeon in the Caspian and Black Sea watersheds are similar in many ways. Usually, the spawning run into the rivers begins in early spring, reaches its peak in mid or late summer and ceases by late autumn (Holci'k 1989). According to Grimm (1893), the run has two peaks, one in spring and the other in autumn, the former being longer.

The large migration of the Russian Sturgeon in the Volga occurs during falling water levels and at water temperatures of 9-12° C. Thereafter, when the water temperature has decreased to between 6-8° C, the spawning migration gradually declines and, by November, has practically ceased (Batychkov 1963; Pavlov and Elizarov 1969). In the Ural River, the Russian Sturgeons also migrate from spring through autumn. The maximum spawning run of the summer spawning race occurs at the end of April, then decreases. In June and July, the winter spawning race arrives in the river (Peseridi 1971).

The migration in the Terek River takes place from March through November (Musaev 1972). The run in the Kura River is very evident during the spring, in April and May, even though the sturgeon may be captured from January through October

(Abdurakhmanov 1962).

4. 5. 3 Biology

During the period of life in the sea, the Russian Sturgeon inhabits shallow inshore waters, where there are large concentrations of invertebrates, mainly molluscs, or small benthic fishes, mainly gobiids (Chuguvov 1928; Ambroz 1964; Piskunov 1965, 1970; Pavlov and Zakharov 1971; Legeza 1973).

The Russian Sturgeon reaches sexual maturity in third place among the acipenserid species, after *Acipenser ruthenus* and *A. stellatus*. The majority of males begin to reproduce at an age of 11 to 13 years, while the equivalent age of the females is 12 to 16 years (Berg 1948; Amborz 1964; Chugunov and Chugunov 1964; Kozhin 1964; Makarov 1964; Pavlov *et al.* 1986; Peseridi 1986). It is thought that males in the Volga River require two to three years after spawning for the gonads to ripen again, while the females take four to five years (Krasikov 1981). The temperature range in which the spawning takes place is fairly wide. According to Kazanskii (1979), the early spring sturgeons enter the Volga from March through to May, migrate in the river for a period from a few days to 1.5 months, and reproduce from mid-May through to early June, at water temperatures 9-12° C. The summer run of the winter spawning sturgeons takes place in May and June, and the fish remain thereafter in fresh water for 10-11 months, and spawn the following year from the end of April through to May at water temperatures of 8-15° C. The autumn run of the winter race in the Volga occurs from August through to October. The fish stay in the river for six to nine months, spending the winter there, reproducing when the water temperature is between 8° and 15 ° C at about the same as the winter sturgeons that participated in the summer run. According to Raspopov and Putilina (1989), Russian Sturgeon, like Beluga, migrate under the ice and those spawners migrating in the Volga from January to March are more mature than those which migrate from April to October.

The age of the Russian Sturgeon in the catches from the Caspian region, particularly the Volga River, does not exceed 38 years at the present time (Pavlov and Zhuravleva 1984) but, in the past, individuals were encountered of age of 46 to 48 years or even older (Petrov 1927; Lukin 1949; Babuskin and Borzenko 1951; Chugunov and Chugunov 1964). The analysis of archaeological material has shown that the life span of the Russian Sturgeon from the Sea of Azov (Don River) and the Caspian Sea (Volga River) could exceed 50 years (Tsepkin and Sokolov 1970). The fastest growth was recorded for sturgeons from the Sea of Azov; while those in the Caspian and Black Seas grow considerably more slowly. Within any one age group, the females usually have a greater average length and weight than the males (Tsepkin and Sokolov 1970). The Russian Sturgeon, like other migratory acipenserids, is characterized by a complex, multi-aged population sturucture. In the Volga River from 1981 through 1985, the spawning populations consisted of 32 age groups between 7 and 38 years. A large number (48%) of the males were 15 to 18 years old, while 53% of the females were 19 to 23 years old (Povlov and Zhuravleva 1986a). The sex ratio varies but, in the Caspian Sea, trawl catches showed that females were more numerous than males (73% of the population in 1981 and 58.5 % in 1984: Krasikov and Krasavtsev 1986).

4. 5. 4 Economic Importance

The Russian Sturgeon catch is largest among the acipenserids. Most of them are caught in the Caspian, and considerably fewer come from the Black and Azov Sea watersheds (Holci'k 1989). Russian Sturgeon make up only about 20% of the annual Iranian catch (where Persian Sturgeon predominate) but they comprise 40% to 50% of the acipenserid catch in the northern Caspian region (Kosarev and Yablonskaya, 1994). The catches of the Russian Sturgeon in north part of the Caspian Sea during 1974 to 1978 were recorded as 51,140 tonnes of which 99.5% came from the Volga (Kazancheev 1981). According to Khodorevskaya (1984, 1986b) the total number of Russian Sturgeon in the Caspian watershed at that time, based on trawling surveys, was 47,700,000. This total included all individuals, from the first year of life to their maximum age. To compensate for the decrease in natural reproduction in the regulated sections of the rivers in the Caspian Sea, from 1951 to 1982, about 20 million juveniles Russian Sturgeons have been released into the rivers (Vlasenko 1986).

Fig 4.1: Geographical distribution of the Beluga, Stellate Sturgeon, Persian Sturgeon and Russian Sturgeon living in the Caspian Sea.

CHAPTER 5

Length, weight and age relationships of the Beluga, *Huso huso*, in the Caspian Sea

5. 1 Introduction

Beluga is the largest sturgeon living in the Caspian Sea, and reaches a length of up to 425 cm and a weight of 725 kg. In the past, individuals have been found to have reached the age of 100 to 120 years, but the present life-span does not exceed 50 to 55 years (Kosarev and Yablonkaya 1994). At the beginning of the 20th century (1904-1913) it accounted for about 40% of the sturgeon catch. At present the catch is no more than 10%. In 1971, 18% of the Iranian caviar came from Beluga, at the present this has decreased to 1.3% (Rezvani 1989). The minimum length for catching the Beluga in southern Caspian is 165 cm total length.

5. 2 Results

5. 2. 1 Sex composition

Five years of catch data were analysed to establish the situation of the sturgeon population. Most of the sturgeons were caught in the sea, and therefore much of the catch was made up of immature males and females. Nevertheless, two different stages of maturity were recognized for each sex: immature (or maturing) females, in which the caviar was not ready for processing, and mature females, in which the caviar was ready for processing. Immature and mature males were distinguished by looking at the testes. Tables 5.1-5.5 show, the mean age, mean fork length, mean total weight and final proportions of the sexes in the catches of 1990-1994.

Table 5. 1: Sex composition, mean age, mean fork length, and mean weight of the Beluga catch from the south part of the Caspian in 1990.

sex	mean age (years)	mean fork length (± SD) (cm)	mean weight (± SD) (kg)	number	percentage %
Immature female	13.0	189.0 ±32.4	62.9 ±40.8	94	47.2%
Mature female	18.5	225.0 ±54.2	121.5 ±125.5	33	16.6%
Immature male	11.6	179.0 ±18.3	49.6 ±16.5	46	23.1%
Mature male	14.6	196.0 ±23.9	64.4 ±35.5	26	13.1%
Total	13.8	193.6 ±36.6	69.7 ±64.1	199	100%

Table 5. 2: Sex composition, mean age, mean fork length, and mean weight of the Beluga catch from the south part of the Caspian in 1991.

sex	mean age (years)	mean fork length (± SD) (cm)	mean weight (± SD) (kg)	number	percentage %
Immature female	15.4	192.4 ± 27.0	78.5 ± 44.4	276	39.4%
Mature female	16.9	206.6 ± 39.5	104.4 ± 79.6	136	19.4%
Immature male	14.9	185.8 ± 20. 7	65.9 ± 28.7	150	21.4%
Mature male	14.7	182.2 ± 14.9	60.0 ± 14.4	139	19.8%
Total	15.4	192.0 ± 28.1	77.2 ± 49.6	699	100%

Table 5. 3: Sex composition, mean age, mean fork length, and mean weight of the Beluga catch from the south part of the Caspian Sea in 1992.

sex	mean age (years)	mean fork length (± SD) (cm)	mean weight (± SD) (kg)	number	percentage %
Immature female	14.4	194.4 ± 26.6	80.2 ± 39.0	225	38.1%
Mature female	15.6	203.9 ± 33.8	100.7 ± 66.6	123	20.8%
Immature male	13.9	187.1 ± 13.5	68.8 ± 20.8	160	27.1%
Mature male	13.7	184.0 ± 14.2	64.2 ± 14.0	83	14 %
Total	14.4	192.9 ±25.1	79.1 ±42.4	591	100%

Table 5. 4: Sex composition, mean age, mean fork length and mean weight of the Beluga catch from the south part of the Caspian Sea in 1993.

sex	mean age (year)	mean fork length (± SD) (cm)	mean weight (± SD) (kg)	number	percentage %
Immature female	15.6	203.2 ± 31.9	99.2 ± 57.0	73	29.6%
Mature female	15.7	200.3 ± 33.7	98.9 ± 66.0	86	34.8%
Immature male	14.2	193.3 ± 16.0	80.1 ± 16.0	65	26.3%
Mature male	14.4	194.1 ± 14.0	77.5 ± 14.0	23	9.3%
Total	15.2	198.7 ± 28.1	92.1 ±52.4	239	100%

Table 5. 5: Sex composition, mean age, mean fork length and mean weight of the Beluga catch from the south part of the Caspian Sea in 1994.

sex	**mean age (years)**	**mean length (± SD) (cm)**	**mean weight (± SD) (kg)**	**number**	**percentage %**
Immature female	15.5	199.8± 23.5	88.4 ± 37.1	161	35.3%
Mature female	17.0	205.5 ± 37.8	103.1 ±76.1	128	27.9%
Immature male	15.0	192.0 ± 16.6	74.1± 26.5	158	34.6%
Mature male	14.4	196.0 ± 21.3	71.1 ± 22.3	10	2.2%
Total	15.7	198.6 ± 27.0	87.2 ± 49.8	458	100%

Data from five years' catches (1990-1994) of Beluga in the southern part of the Caspian Sea were combined to calculate total sex composition (Table 5.6). Female Beluga exceeded males in the catches of 1990-1994 and were on average older, larger and heavier. Immature females were also older, longer and heavier than mature males. The numbers of females were higher than of the males in each year. More than 60% of the fish captured were female, approximately 38% immature.

Table 5. 6: Sex composition, mean age, mean fork length and mean weight of the Beluga catch from the south part of the Caspian Sea (1990-1994).

sex	mean age (years)	mean fork length (± SD) (cm)	mean weight (± SD) (kg)	number	percentage %
Immature female	14.9	194.9 ± 27.8	80.9 ± 43.4	825	37.8%
Mature female	16.5	205.8 ± 38.2	103.2 ± 77.3	507	23.1%
Immature male	14.3	188.1 ± 17.5	69.3 ± 25.7	579	26.4%
Mature male	14.3	185.5 ± 17.5	63.5 ± 18.5	281	12.8%
Total	15.0	194.5 ± 28.1	80.8 ±50.0	2194	100%

Analysis of five years' data (Table 5.6) has shown that the female Beluga were always predominant, and the mean age, mean fork length and mean weight of mature females were higher (t-test, t-value = 9.3, 11.1 and 12.0 respectively, $P<0.01$) than those of the mature male. Mean age, mean fork length and mean weight of immature females were significantly higher than mature males (t-test, t-value= 3.4, 6.8 and 9.3 respectively, $P<0.01$) implying earlier maturation of males and faster growth rates of females.

5. 2. 2 Age composition

The combined data from 1990-1994 (Table 5.7) shows that the minimum age was eight and the maximum 46 years, but 83% consisted of fish aged 12 to 17 years. No Beluga less than 8 years of age were caught and, because of selectivity of the net mesh size, the numbers of younger age groups (e.g. eight and nine-year-olds) were very low.

Females varied between 8 and 46 years, males between 8 and 31 years. Most of the catches (females and males separately) were made up of fish 12-18 (84%) and 11-17 (92.5%) years respectively. The age range of females in each year was more than for males, sometimes double. The maximum age of females and males did not exceed 46 and 31 years respectively. The percentage of males was higher in younger age groups (11-15), while females predominated in older age groups.

Table 5.8: Age composition of Beluga, from the south part of the Caspian Sea; 1990-1994.

age (years)	**Females**			**Males**		
	number	**percentage**	**mature %**	**number**	**mature %**	**percentage**
8	1	0.1	100.0	2	50.0	0.2
9	9	0.7	100.0	7	14.3	0.8
10	29	2.2	13.8	18	11.1	2.1
11	43	3.2	23.3	36	33.3	4.2
12	93	7.0	22.6	80	28.8	9.3
13	137	10.3	35.0	124	29.8	14.4
14	251	18.8	33.1	188	36.9	21.9
15	247	18.5	37.2	205	36.6	23.8
16	205	15.3	41.2	121	37.2	14.1
17	124	9.3	45.2	41	19.5	4.8
18	61	4.6	44.3	16	18.8	1.9
19	32	2.4	62.5	11	27.3	1.3
20	23	1.7	52.2	5	0.0	0.6
21	10	0.7	40.0	1	0.0	0.1
22	9	0.7	55.6	3	0.0	0.3
23	11	0.8	36.4			0.0
24	8	0.6	37.5			0.0
25	5	0.4	60.0			0.0
26	10	0.7	60.0			0.0
27	3	0.2	66.7			0.0
28	6	0.4	100.0			0.0
29	2	0.1	100.0	1	100.0	0.1
30	2	0.1	50.0			0.0
31	2	0.1	100.0	1	100.0	0.1
32	0	0.0				
33	2	0.1	100.0			
34	2	0.1	50.0			
35						
36	3	0.2	66.7			
37	1	0.1	100.0			
38	1	0.1	100.0			
39	1	0.1	100.0			
40						
41						
42	1	0.1	100.0			
43						
44						
45	1	0.1	100.0			
46	1	0.1	100.0			
mean age	**15.50**			**14.32**		

The age distribution of the Beluga caught in the south part of the Caspian Sea was different in each year, but the fish between 12 and 16 years are always under most pressure from fishing activity. The number of fish which were more than 20 years old in the catches was incredibly low, which indicates that the Beluga population in the south part of the Caspian Sea is becoming younger, a recognized indicator of overfishing. The mean age of females and males seemed to increase from 1990 to 1994, the correlation coefficients were significant only in females (df = 3, r = 0.959, P<0.01 for females; df = 3, r = 0.687, P>0.05 for males). The increase in mean age of females might be related to the increase of mature females in the catch (16.6% in 1990, 27.9% in 1993). Figure 5.1 shows the age distribution of female and male Beluga in the catches of 1990 to 1994. The differences between the age distribution of male and female Beluga for successive years were examined, using the Kolmogorov-Smirnov 2-sample test (Table 5.8). In both sexes the differences are significant for all years except for 1992 to1993.

Fig 5.8: Kolmogorov-Smirnov 2-sample test for age distribution of male and female Beluga (1990-1994).

year	**female**		**male**	
	number	**K-S Z**	**numbers**	**K-S Z**
1990-1991	127, 411	3.795**	72-288	3.768**
1991-1992	411, 348	2.878**	288-243	2.917**
1992-1993	348, 159	0.950	243-88	0.957
1993-1994	159, 290	1.619*	88-168	1.694*

(* P<0.05, ** P<0.01)

The differences between mean ages for each year of the catch were examined using Tukey's T (Sokal and Rohlf, 1995) (Table 5.9): mean age of females in 1990 was significantly different from years 1991, 1993 and 1994; year 1991 was different from 1992; and year 1992 was different from 1994. For males, mean age in the year 1990 was significantly different from years 1991, 1992, 1993 and 1994; year 1991 was different from 1992; and year 1992 was different from 1994.

Table 5.9: Statistical analysis of male Beluga mean age (1990-1994). Females above the diagonal, males below it.

	1990 (F)	**1991 (F)**	**1992 (F)**	**1993 (F)**	**1994 (F)**
1990 (M)		n = 127, 411 $\bar{x}$ = 14.4, 15.9 MSD = 1.0344 *	n = 127, 348 $\bar{x}$ = 14.4, 14.8 MSD = 1.0562	n = 127, 159 $\bar{x}$ = 14.4, 15.7 MSD = 1.2125 *	n = 127, 290 $\bar{x}$ = 14.4, 16.1 MSD = 1.0841 *
1991 (M)	n = 72, 288 $\bar{x}$ = 12.7, 14.8 MSD = 0.7139 *		n = 411, 348 $\bar{x}$ = 15.8, 14.8 MSD = 0.7422 *	n = 411, 159 $\bar{x}$ = 15.8, 15.6 MSD = 0.9515	n = 411, 290 $\bar{x}$ = 15.8, 16.1 MSD = 0.7813
1992 (M)	n = 72, 243 $\bar{x}$ = 12.7, 13.8 MSD = 0.7271 *	n = 243, 288 $\bar{x}$ = 14.8, 13.8 MSD = 0.4720 *		n = 348,159 $\bar{x}$ = 14.8, 15.6 MSD = 0.9752	n = 348, 290 $\bar{x}$ = 14.8, 16.1 MSD = 0.8101 *
1993 (M)	n = 72, 88 $\bar{x}$ = 12.7, 14.3 MSD = 0.8611 *	n = 288, 88 $\bar{x}$ = 14.8, 14.2 MSD = 0.6600	n = 243, 88 $\bar{x}$ = 13.8, 14.2 MSD = 0.6741		n = 159, 290 $\bar{x}$ = 15.6, 16.1 MSD = 1.0054
1994 (M)	n = 72, 168 $\bar{x}$ = 12.7, 14.9 MSD = 0.7646 *	n = 288, 168 $\bar{x}$ = 14.8, 14.8 MSD = 0.5280	n = 243, 168 $\bar{x}$ = 13.8, 14.9 MSD = 0.5456 *	n = 88, 168 $\bar{x}$ = 14.2, 14.9 MSD = 0.7145	

* $P \leq 0.050$

The difference between two means is significant if, [Mean (I) - Mean (j)] $\geq$ MSD.

5. 2. 3 Length composition

Fork length means (±SD) and ranges of Beluga caught in 1990-1994 are given in Tables 5.10 for sexes combined and for males and females separately.

From the combined data for 1990 to 1994, the mean length of the entire population of the Beluga was 194.5 cm. Fork length in the catches ranged from 89 to 420 cm, but the majority of the catch (73%) consisted of fish with length classes from 150 to 215 cm. Female Beluga in each year were longer than males, and their length range was greater than that of males. The mean length of females and males seemed to increase from 1990 to 1994, but the correlation coefficients were not significant (df = 3, r = 0.824, P>0.05 for females; df = 3 r = 0.858, P>0.05 for males).

Table 5. 10: Mean length (fork length) of the Beluga, south part of the Caspian Sea 1990-1994.

year	Females			Males		
	number	mean length ± SD (cm)	range (cm)	number	mean length ± SD (cm)	range (cm)
1990	127	198.4±42.1	118 - 420	72	185.2±21.9	121 - 284
1991	411	197.1±32.3	108 - 348	288	184.1±18.2	107 - 267
1992	348	197.7±29.7	148 - 347	243	186.1±13.8	135 -238
1993	159	201.6±32.8	89 - 320	88	193.5±15.4	165 - 248
1994	290	202.4±30.8	100 - 343	168	192.2±16.9	148 - 274
all years	1335	199.1±32.5	89-420	859	187.3±17.2	107-284

There were no significant differences between the mean lengths of the female

Beluga for the years under study (Tukey's T, Table 5.11). Among males, significant differences in mean fork length occurred between 1990 and 1993 and 1994; between 1991 and 1993, 1994; and between 1992 and 1993, 1994.

Table 5.11: Statistical analysis of female and male Beluga mean length (1990-1994).

	1990 (F)	1991 (F)	1992 (F)	1993 (F)	1994 (F)
1990 (M)		n =127,411 x̄ =198.4,197.3 MSD =8.9973	n =127,348 x̄ =198.4,197.7 MSD = 9.1876	n = 127, 159 x̄ = 198.4, 201.6 MSD = 10.5470	n = 127, 290 x̄ = 198.4, 202.4 MSD = 9.43
1991 (M)	n = 72, 288 x̄ = 185.2, 184.3 MSD = 6.0125		n = 411,348 x̄ = 197.3, 197.7 MSD = 6.4559	n = 411, 159 x̄ = 197.3, 201.6 MSD = 8.2768	n = 411,290 x̄ = 197.3, 202.4 MSD = 6.7965
1992 (M)	n = 72, 243 x̄ = 185.2, 186.1 MSD =6.1228	n = 288, 243 x̄ = 184.3, 186.1 MSD = 3.9748		n = 348,159 x̄ = 197.7, 201.3 MSD = 8.4832	n = 348, 290 x̄ = 197.7, 202.4 MSD = 7.0469
1993 (M)	n = 72, 88 x̄ =185.2, 193.5 MSD =7.2513 *	n = 288, 88 x̄ = 184.3, 193.5 MSD = 5.5581 *	n = 243, 88 x̄ = 186.1, 193.5 MSD = 5.6772 *		n = 159, 290 x̄ = 201.6, 202.4 MSD = 8.7452
1994 (M)	n = 72, 168 x̄ = 185.2, 192.2 MSD = 6.4392 *	n = 288, 168 x̄ = 184.3, 192.2 MSD = 4.4468 *	n = 243, 168 x̄ = 186.1, 192.2 MSD = 4.5948 *	n = 88, 168 x̄ = 193.5, 192.2 MSD = 6.0171	

* $P \leq 0.050$

The difference between two means is significant if

[Mean (I) - Mean (j)] $\geq$ MSD

5. 2. 4 Weight composition

Normally, sturgeons are weighed when the fish are delivered by the fishermen, before removing the caviar. Weights are given for each year of sampling and for males and females separately (Table 5.12).

Mean fish weight for the entire catch for the combined years 1990 - 1994 in the south region of the Caspian Sea was 80.8 kg. The weight ranged from nine to 725 kg, but 85% of the catch consisted of fish of 45 to 110 kg, with only 4% of 205 to 725 kg. Both ranges and means of the weight of females were greater than those of males in each year of the catch. Eighty percent of the catch consisted of fish weighing from 40 to 110 kg. Mean weights of both females and males increased 1993, but fell slightly in 1994. Overall, the trends of decreasing mean weight over 5 years were significant (df = 3, r = 0.882 and $P \approx 0.05$, for females; df = 3, r = 0.906, $P < 0.05$, for males).

Table 5.12: Mean weights of Beluga caught in the south part of the Caspian Sea during the years 1990 to 1994.

years	Females			Males		
	number	mean weight (kg)	range (kg)	number	mean weight (kg)	range(kg)
1990	127	78.4 ±76.8	9-725	72	55.0 ±25.8	90-220
1991	411	87.1 ±59.7	31.5-510	288	63.1 ± 23.2	32.5-205
1992	348	87.5 ±51.4	27-460	243	67.2 ± 18.9	38-230
1993	159	99.1 ±61.8	29-376	88	79.4 ± 23.1	49-180
1994	290	94.4 ±58.0	20-458	168	74.0 ± 26.2	25-270
all years	1335	89.4 ±59.6	9-725	859	67.3 ±23.8	9-270

The differences between mean weight of the Beluga for each year of the catch were examined using Tukey's T. Differences are significant only between the years

1990 and 1993. For males the differences are significant between 1990 and 1992, 1993 and 1994; between 1991 and 1993 and 1994; and between 1992 and 1993 and 1994 (Table 5.13).

Table 5.13: Statistical analysis of female and male Beluga mean weight (1990-1994).

	1990 (F)	**1991 (F)**	**1992 (F)**	**1993 (F)**	**1994 (F)**
1990 (M)		n = 127, 411 $\bar{x}$ = 78.1, 87.1 MSD =16.4792	n = 127, 348 $\bar{x}$ = 78.1, 87.4 MSD = 16.8277	n = 127, 155 $\bar{x}$ = 78.1, 99.0 MSD = 19.4279 *	n = 127, 289 $\bar{x}$ = 78.1, 95.0 MSD = 17.2808
1991 (M)	n = 72, 288 $\bar{x}$ = 55.0, 63.1 MSD = 8.1380		n = 411, 348 $\bar{x}$ = 87.1, 87.4 MSD = 11.8244	n = 411, 155 $\bar{x}$ = 87.1, 99.0 MSD = 15.2999	n = 411, 289 $\bar{x}$ = 87.1, 95.0 MSD = 12.4609
1992 (M)	n = 72, 243 $\bar{x}$ = 55.0, 67.2 MSD = 8.2873 *	n = 288, 243 $\bar{x}$ = 63.1, 67.2 MSD = 5.3799		n = 348, 155 $\bar{x}$ = 87.4, 99.0 MSD = 15.6746	n = 348, 289 $\bar{x}$ = 87.4, 95.0 MSD = 12.9181
1993 (M)	n = 72, 84 $\bar{x}$ = 55.0, 79.4 MSD = 9.9193 *	n = 288, 84 $\bar{x}$ = 63.1, 79.4 MSD = 7.6588 *	n = 243, 84 $\bar{x}$ = 67.2, 79.4 MSD = 7.8173 *		n = 155, 289 $\bar{x}$ = 99.0, 95.0 MSD = 16.1601
1994 (M)	n = 72, 168 $\bar{x}$ = 55.0, 74.0 MSD = 8.7155 *	n = 288, 168 $\bar{x}$ = 63.1, 73.9 MSD = 6.0187 *	n = 243, 168 $\bar{x}$ = 67.2, 74.0 MSD = 6.2191 *	n = 84, 168 $\bar{x}$ = 79.4, 74.0 MSD = 8.2699	

* $P \leq 0.050$

The difference between two means is significant if, [Mean (I) - Mean (j)] $\geq$ MSD

5. 2. 5 Weight-length relationship

Since the weight of fish is usually proportional to some power (approximately the cube) of the length, the relationship expressed as

$$w = a l^{b}$$

where b is an exponent usually between 2 and 3. A logarithmic transformation gives the straight line relationship

$$\log w = \log a + b \log l,$$

the regression of log w on log l being calculated by standard methods. This will give a value of b that is close to, but rarely exactly equal to 3 (Ricker 1973; Bagenal and Tesch, 1978; Gulland 1983).

The weight-length relationship for the Beluga was calculated for each year for females and males separately (Table 5. 14-15 and Figures 5.2 and 5.3).

Table 5.14: Weight-length relationships of the female Beluga (W = total weight, FL = fork length).

years	**number**	**weight-length relationships & equation LogW / LogFL**	**correlation coefficient (r)**
1990	127	LogW = 3.11 (log FL) - 5.33	0.973
1991	411	LogW = 3.10 (log FL) - 5.11	0.949
1992	348	LogW = 2.95 (log FL) - 4.87	0.924
1993	159	LogW = 2.5 (log FL) - 3.86	0.869
1994	290	LogW = 2.74 (log FL) - 4.40	0.859
90-94	1336	LogW = 2.9 (log FL) -4.75	0.908

Table 5.15: Weight-length relationships of the male Beluga (W = total weight, FL = fork length).

year	number	weight-length relationships & equation Log W/ LogFL	correlation coefficient (r)
1990	72	LogW = 3.27 (log FL) - 5.69	0.934
1991	288	LogW = 2.70 (log FL) - 4.40	0.867
1992	243	LogW = 2.50 (log FL) - 3.84	0.793
1993	88	LogW = 2.84 (log FL) - 4.61	0.859
1994	168	LogW = 3.10 (log FL) - 5.15	0.907
90-94	860	LogW = 2.8 (log FL) - 4.55	0.843

The correlation coefficients (r) estimated are high in both sexes but higher in females in most of the years. There is no indication of growth stanzas (Cushing 1981, Parker and Larkin 1959) in the relationship.

5. 2. 6 Length-age relationship

The relationship between age and length of Beluga was calculated for each year's catch for the sexes separately (Figs 5-4-5-27). Length at age in fish generally displays a 'decaying exponential' trend, usually well described by the von Bertalanffy (1934) growth equation, see Chapter 9. This relationship does not show clearly in many of the Beluga catches, especially for males (see Figs 5.15), presumably because there were errors in aging older fish and/or a consequence of the very small sample sizes involved for fish older than about 20 years. If the apparent relationship displays same degree of convex curvature it will be adequately described by a quadratic equation of the type

$$Y = a + bx + cx^2$$

If no convexity can be observed it will be described by a standard equation

$$Y = a + bx$$

In view of the form of the data both equations were tried (Tables 5.16-5.17). In many instances, the equation of best fit (highest r) was found to be the quadratic. However, quadratic curves cannot be extrapolated beyond the data points, as the relationship (as in Fig. 5.23) becomes clearly impossible. Moreover, in some instances, the unexplained error in the data yields a best fit quadratic equation that is concave (as in Fig 5.11) which cannot possibly be a correct representation of fish growth.

Table 5.16: Length-age relationships of female Beluga
(Y = fork length (cm), X = age (t, years), Fig = Figures).

year	N	equation (quadratic)	Fig	r	equation (linear)	Fig	r
1990	127	$Y = 86.9660 + 7.8185X - 0.0056X^2$	5.5	0.93	$Y = 88.9012 + 7.5940X$	5.4	0.93
1991	411	$Y = 79.8697 + 6.2584X + 0.0692X^2$	5.9	0.85	$Y = 56.2065 + 8.9033X$	5.8	0.85
1992	348	$Y = 51.8920 + 11.4376X - 0.1031X^2$	5.13	0.73	$Y = 90.9857 + 7.2090X$	5.12	0.72
1993	159	$Y = 13.9880 + 16.1643X - 0.2454X^2$	5.17	0.82	$Y = 117.061 + 5.4007X$	5.16	0.75
1994	290	$Y = 104.942 + 6.3844X - 0.0199X^2$	5.21	0.72	$Y = 114.370 + 5.4588X$	5.20	0.71
90-94	1336	$Y = 71.3384 + 9.2330X - 0.0598X^2$	5.25	0.78	$Y = 94.9504 + 6.7270X$	5.24	0.77

Table 5.17: Length-age relationships of male Beluga
(Y = fork length (cm), X = age(t, years), Fig = Figures).

year	N	equation (quadratic)	Fig	r	equation (linear)	Fig	r
1990	72	$Y = 113.324 + 5.7618X - 0.0093X^2$	5.7	0.79	$Y = 116.021 + 5.4480X$	5.6	0.79
1991	288	$Y = 257.56 - 16.177X + 0.7461X^2$	5.11	0.69	$Y = 87.1297 + 6.5625X$	5.10	0.65
1992	243	$Y = 153.07 + 0.1055X + 0.1627X^2$	5.15	0.59	$Y = 120.023 + 4.7794X$	5.14	0.59
1993	88	$Y = 213.791 - 7.4109X + 0.4127X^2$	5.19	0.58	$Y = 129.141 + 4.5156X$	5.18	0.56
1994	168	$Y = 205.144 - 4.9860X + 0.2711X^2$	5.23	0.54	$Y = 130.708 + 4.1222X$	5.22	0.49
90-94	860	$Y = 161.587 - 0.9628X + 0.1886X^2$	5.27	0.60	$Y = 117.867 + 4.8484X$	5.26	0.58

5. 2. 7 Annual increment in length

The annual increment in length of Beluga was studied in an attempt to define its growth. Analysis of covariance of length-age relationships in males and females (Tables 5.16 and 5.17) shows that the differences between the two means and slopes are significant (Table 5.18 below). Therefore, annual increments in length have been estimated for each sex separately.

Table 5.18: Summary of Analysis of Covariance

Source	df	SS	MS	F	P
		Differences Among Adjusted Means			
Source	df	SS	MS	F	P
Adjusted means	1	9430.28087	9430.28087	28.557	$1.007*10^{-7}$
Within	2191	723537.00122	330.23140		
		Differences Among Slopes			
Source	df	SS	MS	F	P
Among slopes	1	11139.37176	11139.37176	34.244	$5.594*10^{9}$
Sum of grp.dev.	2190	712397.62946	325.29572		

Table 5. 19 shows the annual increments in length for males and females for the year 1990. The annual increment in length differs between the sexes. For example, the annual increment in 12-year-old females averaged 13.5 cm, but the increment in 12 year-old males was 5.1 cm. The differences between annual increment of males and females (from 11 to 15 years old where n is high) were tested using paired-samples t-tests and found not significant (t-value = 0.66, P>0.05). The number of older age group male Beluga (greater than 16 years old) in the catch was so small that it is impossible to draw any conclusions on annual increment of this age group. The annual increment in length fluctuates in both male and female and there is no regular trend. However, the data from remaining years were also analysed to provide a baseline.

Tabla 5.19: Annual increment in length of female and male Beluga, 1990.

Age	Females			Males		
	number	mean length cm	annual increment	number	mean length cm	annual increment
8				1	160.0	
9	9	156.2		6	168.0	8.0
10	19	167.5	11.3	8	162.6	-5.4
11	16	171.8	4.3	14	177.6	15.0
12	11	185.3	13.5	12	182.7	5.1
13	10	184.6	-0.7	5	189.2	6.5
14	15	191.9	7.3	8	197.0	7.8
15	7	203.4	11.6	8	193.1	-3.9
16	10	210.8	7.4	7	201.0	7.9
17	7	211.3	0.5	2	214.0	13.0
18	4	199.7	-11.5			
19	3	250.7	50.9			
20	1	236.0	-14.7			
21	2	259.5	23.5			
22	3	256.7	-2.8			
23	2	286.5	29.8			
24	1	278.0	-8.5			
25	2	292.0	14.0			
26	3	284.3	-7.7			
27						
28	1	300.0	7.8			
29						
30						
31				1	284.0	5.0

Results for 1991 are given in Table 5.20. For females the annual increment was greatest in 15-18 year old fish, and was less in males. The differences between males and females (from 13 to 17 years old where n is high) were tested using paired-samples t-tests and found to be significant (t-value = 3.2, $P<0.05$).

Table 5.20: Annual increment in length of male and female Beluga, 1991.

Age	Females			Males		
	number	mean length cm	annual increment	number	mean length cm	annual increment
9				1	191.0	
10	2	179.0		2	166.5	-24.5
11	5	187.0	8.0	6	187.7	21.2
12	21	172.9	-14.0	12	165.2	-22.5
13	24	172.3	-0.7	35	171.3	6.1
14	85	178.6	6.4	69	176.1	4.8
15	95	184.0	5.4	74	182.5	6.4
16	66	196.1	12.2	55	191.5	9.0
17	47	208.6	12.5	16	199.4	7.9
18	17	219.3	10.7	8	211.6	12.2
19	11	236.0	16.6	5	216.6	5.0
20	13	239.0	3.0	2	260.5	44.0
21	1	220.0	-19.0	1	263.0	2.0
22	2	262.5	42.0	2	228.5	-34.5
23	7	267.4	4.3			
24	3	279.0	11.6			
25	1	268.0	-11.0			
26	4	301.7	33.7			
27	2	295.0	-6.7			
28	2	319.0	24.0			
29						
30	1	304.0	-7.5			
31	1	320.0	16.0			
32						
33	1	325.0	2.5			

Annual increment in fork length for 1992 is shown in Table 5. 21. Comparing 13 and 16 year old females and males, in females the annual increments were 9.1 and 11.7 cm, and in males 7.1 cm and 4. 8 cm respectively. The differences between increments in females and males (11 to 17 year old) were tested by paired-samples t-tests and found not significant (t-value = 1.85, P>0.05).

Table 5.21: Annual increment in length of male and female Beluga, 1992.

Age	Females			Males		
	number	mean length cm	annual increment	number	mean length cm	annual increment
8				1	177.0	
9						
10	1	194.0		2	159.5	-8.8
11	11	172.9	-21.1	9	173.3	13.8
12	35	174.0	1.1	40	177.0	3.7
13	70	183.2	9.1	57	184.1	7.1
14	65	190.1	7.0	58	184.1	-0.0
15	56	197.7	7.5	41	192.7	8.7
16	50	209.3	11.6	24	197.5	4.8
17	31	215.5	6.1	7	199.1	1.6
18	12	225.3	9.8	1	225.0	25.9
19	4	239.7	14.4	1	173.0	-52.0
20	6	250.0	10.2	1	238.0	65.0
21	2	259.5	9.5			
22	1	260.0	0.5	1	235.0	-1.5
23						
24						
25						
26						
27						
28	1	282.0	3.7			
36	2	338.5	7.1			
38	1	316.0	-11.5			

Annual increments for 1993 are shown in Table 5.22. The differences between annual increment in length of males and females (12 to 16 year old) were tested by paired samples t-tests and no significant differences were found (t-value = 1.5, $P>0.05$).

Table 5.22: Annual increment in length of male and female Beluga, 1993.

Age	Females			Males		
	number	mean length cm	annual increment	number	mean length cm	annual increment
10	4	163.2		3	184.3	
11	4	168.2	5.0	3	176.3	-8.0
12	21	181.3	13.1	8	182.2	5.9
13	10	179.5	-1.8	15	187.7	5.5
14	34	192.5	13.0	21	193.6	5.9
15	33	193.7	1.2	20	193.1	-0.5
16	21	203.7	10.0	8	202.4	9.3
17	9	208.6	4.9	5	213.4	11.0
18	5	232.4	23.8	2	175.5	-37.9
19	3	251.3	18.9	3	235.3	59.8
20	2	253.5	2.2			
21						
22	1	265.0	5.7			
23	1	289.0	24.0			
24	1	288.0	-1.0			
25	1	310.0	22.0			
26	2	249.5	-60.5			
27	1	282.0	32.5			
28						
29	1	283.0	0.5			
30						
31	1	320 .0	9.3			
32						
33						
34	2	289.0	-15.5			
35						
36	1	286.0	-1.5			
37						
38						
39	1	214.0	-24.0			

Annual increments for the year 1994 are given in Table 5.23. Comparing annual increments between females and males (for 13 to 17 years old) with paired samples t-tests, no significant differences were found (t-value = 2.3, P>0.05).

Table 5.23: Annual increment in length of male and female Beluga, 1994.

Age	Females			Males		
	number	mean length cm	annual increment	number	mean length cm	annual increment
8	1	172.0				
9						
10	3	195.7	11.8	3	201.3	
11	7	192.1	-3.5	4	188.7	-12.6
12	5	184.6	-7.5	8	183.5	-5.2
13	23	186.2	1.6	12	183.7	0.2
14	52	188.2	2.0	31	185.8	2.1
15	56	189.2	1.0	62	189.5	3.7
16	57	198.7	9.4	27	196.8	7.3
17	30	212.8	14.2	11	206.0	9.2
18	23	221.4	8.6	5	196.0	-10.0
19	11	219.5	-1.9	2	240.5	44.5
20	1	163.0	-56.5	2	219.0	-21.5
21	5	222.6	59.6			
22	2	267.5	44.9			
23	1	209.0	-58.5			
24	3	254.0	45.0			
25	1	301.0	47.0			
26	1	272.0	-29.0			
27						
28	2	280.0	4.0	1	274.0	6.9
29	1	300.0	20.0			
30	1	275.0	-25.0			
31						
32						
33	1	318.0	14.3			
34						
35						
36						
37	1	305.0	-4.0			
38						
39						
40						
41						
42	1	320.0	3.0			
43						
44						
45						
46	1	343.0	5.75			

Data from five years' catches (1990-1994) of the Beluga in the southern part of the Caspian Sea were combined and the annual increments in length calculated (Table

5.24). Annual increments were greatest in year classes 15-19. In a comparison of females and males, the differences between annual increments in males and females (10 to 19 years old) were tested using paired samples t-tests and it was found that, in contrast with individual years, the differences, were significant (t-value = 2.27, $P<0.05$).

The results show clearly that, after about 10 years of age, when substantial numbers of Beluga are caught, females grow faster than males. However, increments vary considerably between years and do not clearly display the expected trend of diminishing year by year. The variation and lack of trend make the analysis of growth difficult (Chapter. 9), and the underlying reasons are not readily apparent. Error in aging is a possible explanation though there is no evidence for any consistent age-related source of error. With the older year classes the sample sizes are small. Further sources of error in females might be related to fish maturity and subsequent spawning (see discussion). Fig 5.28 shows plots of mean length at age in six cohorts (1975-1980) followed through the years 1990-1994. Although the trend of growth can be seen, the increases are still erratic with apparent decrements in some years.

Table 5. 24: Annual increment in length of male and female Beluga (1990-1994).

Age	Females			Males		
	number	mean length cm	annual increment	number	mean length cm	annual increment
8	1	172.0		2	168.5	
9	9	156.2	-15.8	7	171.3	2.8
10	29	171.5	15.3	18	172.8	1.5
11	43	176.8	5.3	36	179.3	6.6
12	93	177.3	0.5	80	177.3	-2.1
13	137	181.6	4.3	124	181.1	3.8
14	251	186.3	4.7	188	183.0	1.9
15	247	190.1	3.9	205	188.1	5.1
16	205	201.5	11.4	121	195.1	7.0
17	124	211.5	9.9	41	203.6	8.4
18	61	221.1	9.6	16	203.1	-0.5
19	32	233.6	12.5	11	222.1	19.0
20	23	239.7	6.1	5	239.4	17.3
21	10	237.1	-2.6	1	263.0	23.6
22	9	261.7	24.7	3	230.7	-32.3
23	11	267.5	5.9			
24	8	270.6	3.1			
25	5	292.6	22.0			
26	10	283.1	-9.5			
27	3	290.7	7.7			
28	6	296.7	6.0			
29	2	291.5	-5.2	1	274.0	6.2
30	2	289.5	-2.0			
31	2	320.0	30.0	1	284.0	0.5
32						
33	2	321.5	0.8			
34	2	289.0	-16.2			
35						
36	3	321.0	15.0			
37	1	305.0	-16.0			
38	1	316.0	11.0			
39	1	214.0	-102.0			
40						
41						
42	1	320.0	35.3			
43						
44						
45	1	420.0	25.0			
46	1	343.0	-77.0			

5. 2. 8 Weight-age relationship

The linear relationship between log weight and age of the Beluga was also calculated. The results of ANCOVA show that the differences between means and slopes of male and female weight-age relationships were significant (for means, $F = 8.14$, $P \approx 0$, for slopes, $F = 26.3$ and $P = 0$), therefore the weight-age relationships were estimated separately for each sex.

The relationships estimated for females and males separately are presented in Tables 5.25 and 5.26 below.

Table 5.25: Weight-age relationships of the female Beluga (W = total weight, t = age (years), Fig = Figures).

years	number	weight-age relationships & equation	Fig	r
1990	127	$\text{Log } W = 1.1452 + 0.0451t$	5.29	0.90
1991	411	$\text{Log } W = 0.9852 + 0.0564t$	5.31	0.84
1992	348	$\text{Log } W = 1.2509 + 0.0434t$	5.32	0.67
1993	159	$\text{Log } W = 1.3793 + 0.0359t$	5.35	0.84
1994	290	$\text{Log } W = 1.3621 + 0.0351t$	5.37	0.72
90-94	1336	$\text{Log } W = 1.2282 + 0.0429t$	5.39	0.77

Table 5.26: Weight-age relationships of the male Beluga (W = total weight, t = age (years), Fig = Figures).

years	number	weight-age relationships & equation	Fig	r
1990	72	$\text{Log } W = 1.2295 + 0.0375t$	5.30	0.67
1991	288	$\text{Log } W = 1.0679 + 0.0480t$	5.32	0.68
1992	243	$\text{Log } W = 1.3919 + 0.0306t$	5.34	0.52
1993	88	$\text{Log } W = 1.4221 + 0.0326t$	5.36	0.57
1994	168	$\text{Log } W = 1.3807 + 0.0314t$	5.38	0.51
90-94	860	$\text{Log } W = 1.2881 + 0.0363t$	5.40	0.58

Figs 5.29 to 5.40 show the plots of log weight vs age for each year of the catch. The logarithmic plots are of specific growth rate, which should decline during growth but rarely appears to do so, although such a trend is apparent for the combined years' data for females (Fig 5.41). The data suggest only that the weight is directly related to the age in both male and female and the correlation coefficients were higher in females.

5. 2.9 Annual increments in weight

Annual increments in weight (total weight, including gonads) of the Beluga were calculated for each year (1990-1994) (Tables 5.27-31). The data for all the years combined are in Table 5.32.

Table 5.27: Annual increment in weight of male and female Beluga (1990).

Age	Females			Males		
	number	mean weight kg	annual increment	number	mean weight kg	annual increment
8				1	35.0	
9	9	32.1		6	39.5	4.5
10	19	38.3	6.2	8	35.6	-3.9
11	16	43.2	4.9	14	44.9	9.2
12	11	53.6	10.5	12	52.4	7.6
13	10	55.1	1.5	5	56.6	4.2
14	15	61.7	6.6	8	64.4	7.8
15	7	81.1	19.4	8	60.5	-3.9
16	10	79.7	-1.4	7	66.0	5.5
17	7	83.9	4.2	2	90.0	24.0
18	4	66.8	-17.1			
19	3	148.7	81.9			
20	1	78.0	-70.7			
21	2	167.0	89.0			
22	3	151.7	-15.3			
23	2	214.0	62.8			
24	1	156.0	-58.5			
25	2	202.0	46.5			
26	3	219.0	16.5			
27						
28	1	242.0	11.5			
29						
30						
31				1	220.0	9.3

Table 5.28: Annual increment in weight of male and female Beluga (1991).

Age	Females			Males		
	number	mean weight kg	annual increment	number	mean weight kg	annual increment
9				1	70.0	
10	2	63.0		2	47.2	-22.7
11	5	56.6	-6.4	6	66.9	19.7
12	21	52.9	-3.7	12	44.0	-22.9
13	24	51.1	-1.8	35	48.0	4.0
14	85	58.0	6.9	69	54.0	5.8
15	95	64.4	6.3	74	60.0	6.2
16	66	80.2	15.9	55	69.0	9.0
17	47	97.0	16.8	16	83.6	14.6
18	17	106.1	9.1	8	99.7	16.1
19	11	146.6	40.5	5	98.8	-0.9
20	13	156.8	10.2	2	183.8	85.1
21	1	118.8	-38.0	1	162.0	-21.8
22	2	222.7	103.9	2	148.1	-13.8
23	7	223.2	0.5			
24	3	228.0	4.8			
25	1	165.0	-63.0			
26	4	337.6	172.6			
27	2	282.0	-55.6			
28	2	389.0	107.0			
29						
30	1	323.0	-33.0			
31	1	369.5	46.5			
32						
33	1	319.0	-25.5			

Table 5.29: Annual increments in weight of male and female Beluga (1992).

Age	Females			Males		
	number	mean weight kg	annual increment	number	mean weight kg	annual increment
8				1	60.0	
10	1	75.0		2	41.6	-18.3
11	11	54.9	-20.1	9	54.0	12.3
12	35	52.5	-2.4	40	58.3	4.3
13	70	65.9	13.4	57	64.7	6.4
14	65	75.5	9.5	58	64.6	-0.2
15	56	83.9	8.5	41	74.0	9.5
16	50	102.4	18.4	24	74.3	0.3
17	31	108.4	6.0	7	77.2	2.9
18	12	117.9	9.5	1	230.5	153.6
19	4	176.5	58.6	1	51.0	-179.5
20	6	175.2	-1.4	1	170.0	119.0
21	2	198.2	23.1	1	134.0	-36.0
22	1	194.0	-4.2			
23						
24						
25						
26						
27						
28	1	270.0	12.6			
29						
30						
31						
32						
33						
34						
35						
36	2	397.5	15.9			
37						
38	1	370.0	-13.7			

Table 5.30. Annual increment in weight of male and female Beluga (1993)

Age	**Females**			**Males**		
	number	**mean weight kg**	**annual increment**	**number**	**mean weight kg**	**annual increment**
10	4	44.6		3	74.0	
11	4	47.6	3.0	3	55.3	-18.7
12	21	63.8	16.2	8	65.4	10.1
13	10	62.7	-1.1	15	72.2	6.8
14	34	76.4	13.7	21	76.0	3.8
15	33	90.3	13.8	20	78.3	2.3
16	21	91.9	1.6	8	89.4	11.1
17	9	93.6	1.7	5	99.6	10.2
18	5	133.8	40.3	2	91.0	-8.6
19	3	172.7	38.8	3	151.0	60.0
20	2	175.0	2.3			
21						
22	1	173.0	-1.0			
23	1	174.5	1.5			
24	1	278.0	103.5			
25	1	376.0	98.0			
26	2	199.0	-177.0			
27	1	246.0	47.0			
28						
29	1	254.0	4.0			
30						
31	1	375.0	60.5			
32						
33						
34	2	330.0	-15.0			
35						
36	1	295.0	-17.5			
37						
38						
39	1	225.0	-23.3			

Table 5.31: Annual increment in weight of male and female Beluga (1994).

Age	Females			Males		
	number	mean weight kg	annual increment	number	mean weight kg	annual increment
8	1	48.1				
10	3	73.7	25.6	3	95.0	
11	7	79.4	5.6	4	64.7	-30.2
12	5	59.4	-20.0	8	64.6	-0.1
13	23	69.5	10.1	12	61.5	-3.1
14	52	68.5	1.0	31	65.3	3.7
15	56	71.5	3.0	62	68.8	3.5
16	57	84.1	12.5	27	78.4	9.6
17	30	110.0	25.9	11	89.3	10.9
18	23	119.8	9.7	5	79.8	-9.5
19	11	120.8	1.0	2	147.0	67.2
20	1	46.0	-74.8	2	134.0	-13.0
21	5	147.8	101.8			
22	2	242.5	94.7			
23	1	120.0	-122.5			
24	3	243.0	123.0			
25	1	237.0	-6.0			
26	1	241.0	4.0			
27						
28	2	265.0	12.0	1	270.0	17.0
29	1	305.0	40.0			
30	1	212.0	-93.0			
31						
32						
33	1	341.0	43.0			
34						
35						
36						
37	1	351.0	2.5			
38						
39						
40						
41						
42	1	432.0	16.2			
43						
44						
45						
46	1	458.0	6.5			

Table 5.32. Annual increment in weight of Beluga and incidence of female maturity (1990-1994).

Age	Females			Males		
	number	mean weight (kg)	annual increment	number	mean weight (kg)	annual increment
8	1	48.1		2	47.5	
9	9	32.1	-16.0	7	43.9	-3.6
10	29	45.8	13.7	18	53.9	10.0
11	43	54.1	8.2	36	53.9	0.0
12	93	55.6	1.6	80	56.6	2.7
13	137	62.9	7.3	124	60.3	3.6
14	251	67.4	4.4	188	61.9	1.7
15	247	74.3	7.0	205	67.0	5.1
16	205	87.9	13.5	121	73.3	6.3
17	124	102.2	14.3	41	86.3	13.0
18	61	113.3	11.1	16	100.6	14.3
19	32	144.1	30.8	11	117.4	16.9
20	23	154.9	10.8	5	161.1	43.7
21	10	158.8	3.9	1	162.0	0.9
22	9	194.7	35.9	3	143.4	-18.6
23	11	207.8	13.1			
24	8	230.9	23.1			
25	5	236.6	5.7			
26	10	264.6	28.0			
27	3	270.0	5.4			
28	6	311.0	41.0	1	270.0	21.1
29	2	279.5	-31.0			
30	2	267.5	-12.0			
31	2	372.2	104.5	1	220.0	-16.6
32						
33	2	330.0	-21.1			
34	2	330.0	0.0			
35						
36	3	363.3	16.6			
37	1	351.0	-12.3			
38	1	370.0	19.0			
39	1	225.0	-145.0			
40						
41						
42	1	432.0	69.0			
43						
44	1	725.0	146.5			
45						
46	1	458.0	-133.5			

During the fishing seasons from 1990 to 1994 the heaviest Beluga, weighing 725 kg, was caught in 1990, and was female (45 year old).

It is clear from the data that weight increments of Beluga in the catches fluctuate from age to age. Comparison between females and males shows a significantly higher average increment in the female (paired sample t-test, t-value = 2.5, $P<0.05$).

Examination of the growth in weight graphs suggests that, rather than specific rate declining steadily (as discussed in Chapter 9), two different growth stanzas (Parker and Larkin 1959) occur during the sampling period, the younger fish having the higher rate. Figure 5.41 illustrates these two growth stanzas, which can also be seen, though less clearly, in the graphs of growth in length of the Beluga (Fig 5.42). Inspection of these graphs indicates that the inflexion between the two stanzas may be at about age 25. The correlation coefficients (r) for the first stanza for total weight and fork length were found to be 0.989 and 0.975 respectively. However, the values were lower for the second stanza (0.587 and 0.476 respectively) where the means are unreliable owing to small sample sizes. The first stanza in the female largely spans the immature stage in which, as expected, growth rate is very high. The second stanza, which shows a lower growth rate, accords with higher incidence of maturity (Cushing 1981, Jones 1976).

This lower growth rate of the mature Beluga is likely to be a consequence of the high investment in eggs and ovarian tissue made by mature females, especially as they do not feed during the spawning period.

5. 3 Discussion

5. 3. 1 Sex composition

Studies made on catches taken over the five years from 1990 to 1994 show a higher number of females than males. There are no earlier data on the sex ratio of Beluga in the southern Caspian Sea but, according to Emadi (1989), there has been an increasing trend in the ratio of females to males since the fishing year 1962. As the fishermen are paid for both mature males and females, the higher percentage of females is not likely to be due to a preference for obtaining caviar. The males were predominant (70.6%) in the Volga River (winter catch) during 1969-1970 (Pavlov and Slivka 1971) and later (Raspopov and Putilina 1989).

In the present study of, both mean length and upper range of females were higher than of males. Raspopov and Putilina (1989) studied the winter spawning migration of the Beluga in the Volga River between 1980 and 1985, and concluded similarly (higher mean and upper range length of females) for the winter spawners. Comparing the mean length of the Beluga in the south part of the Caspian Sea with data for the Volga River, the mean lengths of the winter spawning females (241.8 cm), and males (223.3 cm) in the Volga were higher than of females and males in the southern part of the Caspian Sea. For the southern Caspian Sea, mean length of females and males was calculated as 205.8 and 185.5 cm respectively.

Mean weights of female Beluga were also greater than of males in each year's catch. The mean weight of the females caught in Volga was 123.6 kg, of males 86.3 kg; for the southern Caspian, mean weights were 103.2 kg and 63.5 kg respectively. It is possible, however, that the results are affected by the selectivity of fishing gear, since in the southern Caspian some of the Belugas were caught by gill nets set for other species; another reason might be that most of the Beluga entering the Volga for spawning are older than those caught in southern Caspian Sea. The latter is supported by the work of the Raspopov and Putilina (1989), who calculated that the average age of females was 23.7 years and males 14.8 years; for the southern Caspian, mean ages of females and males were 16.3 and 14.3 years respectively.

5. 3. 2 Age composition

The age range of Beluga examined during the present study was 8-46 years. The percentage of fish in the catches aged more than 20 years was very low, which suggests that the population is becoming younger.

Female maturity showed a steady increase through the early age classes, from 9 to 18 years, with then an apparent dip at 22-23 years (Table 5.8); thereafter the percentage of mature females is higher (but based on small sample sizes). Raspovov (1993) examined the long-term data (1970-1987) from the Volga and concluded that the first maturation of females occurred at approximately 15-16 years, the second at 21-22 years, with subsequent spawning at 30, 34-35, 39-40, 45 and, finally, 48-49 years. It is difficult to reconcile the present results with those of Raspopov. With 20% of fish mature at 10 y, it is clear that most Beluga have already spawned by the time they are 14. Certainly there is no peak at 15-16. If the view is correct that several years elapse between spawning, then there is clearly a peak return at 18-21, and another at 24-28. First maturity and subsequent maturation cycles occur earlier in the southern Caspian than they do in the Volga. For males according to Raspovov (1993), the first maturation occurs at 11 years then at 18, 23, 29, 33, and a sixth time at 37 - 38 years of age. The present catch contains mature males of nine, and females of eleven years old.

Anadromous migration begins at the end of January or during February and ends in November or December. The Beluga races are termed winter and spring by Berg (1934). Members of spring race reproduce the same year they enter the rivers, while those of the winter race spend the winter in fresh water and reproduce there in the spring of the next year. The migrations of the Caspian Beluga (both South and North) are clearly defined, the spring run occurring in March and April, and the autumn migration during September and October (Babushkin 1964). The winter race is dominant in the Volga (Peseridi 1961). According to Raspovov (1993) the spawning Beluga in the river period of life do not feed, and the winter part of the stock remains in the river for up to two years, which is responsible for the slowdown in growth rate which evidently coincides with the spawning period. The present catches (1990-1994) of both female and male Beluga comprised mostly the first or second time spawning fish.

The age range of females was higher than of males, as also noted by Raspopov (1993). The mean age of females was greater than the mean age of males. The higher mean ages of immature as well as of mature females suggest both an earlier maturation for males and a faster growth rate for females. Raspopov (1993) confirms this by comparing the mean length of males and females of the same age. Raspopov

(1992) investigated changes in the age structure of spawning Beluga migrating into the Volga River from April 1965 through October 1987 and found that the Beluga spawning runs had a multi-age structure, females aged 15 to 56 years, and males 11 to 53 years. Most of the mature females (74.3%) were 17-27 years old, most males (77.5%) 11-20 years old. The present study found that the age structure of Beluga in the southern Caspian is younger than that of the Volga; whether the same decreasing trend in age structure of the Beluga occurs in the Volga River after 1987 is not known (no published data).

The mean age for the period 1965-1987 of the Volga population varied from 20.9 to 26.3 years for females and from 17.0 to 20.0 years for males. Mean age for the period 1990-1994 of the southern Caspian Sea population varied between 14.5 and 16.1 years for females, and 12.7 to 14.9 years for males. The higher mean age in the Volga is expected because only spawners enter the river but, despite this, the differences between the populations from the two locations are very high in both sexes.

Analysis of five years' catches from the southern Caspian shows that the age structure of the Beluga has changed and that a trend is apparent for fish of both sexes to become younger. For instance the percentage of females more than 20 years old has deceased from 10.5% in 1990 to 5.5% in 1994. Overfishing of the Beluga stocks is also indicated from data on age structure and abundance.

5. 3. 3 Length composition

The mean annual length of the Beluga for the 1990-1994 period varied between 197.1 cm and 202.4 cm for females, and from 184.1 cm to 193.5 cm for males. The female lengths ranged from 89 to 420 cm, those of males from 107 to 284 cm. There are no comparative data from other years for Beluga in the southern Caspian Sea. According to Pavlov and Slivka (1971), the average total length of Beluga in the catches of the Volga during 1969-1970 was 219.0 cm for females and 206.6 cm for males.

The lengths of the migrating females in the Volga were 174-347 cm, of the males 158-333 cm (means 241.8 and 223.3 cm, respectively) (Raspovop and Putilina 1989). The data from five years' catches in the southern Caspian show that the range of lengths represented in the catches decreased between 1990 and 1994, but the mean length actually increased slightly. The minimum length for catching the Beluga in the southern Caspian is 165 cm total length. While the present (1990-1994) catches of the Beluga consisted of 86% fish larger than 165 cm, but still contained many immature individuals.

5. 3. 4 Weight composition

Weight of individual Beluga caught in the southern Caspian from 1990 to 1994 was 9-720 kg (mean 87.1 to 99.1 kg) in females, and 9-270 kg (55.0-79.4 kg) in males. There are no comparative data from earlier years but according to Emadi (1989) the average weight of Beluga, for both sexes combined, has decreased over the last 25 years (1962 to 1988). In the fishing year 1962-1963, the average weight was 90.5 kg, for 1974-1975, 97.0 kg (equalling the highest for 1962-1988); 1987-1988, the average weight was 51.3 kg (all records were for males and females together). The average weight of Beluga in the Volga River was 123.6 kg for females and 86.3 kg for males. The weight range of females was 40-347, of males 32 to 260 kg (Raspopov and Putilina 1989). Comparing the data from the southern Caspian with those from the Volga, the average weights of the Volga fish were higher.

5. 3. 5 Annual increment in length and weight

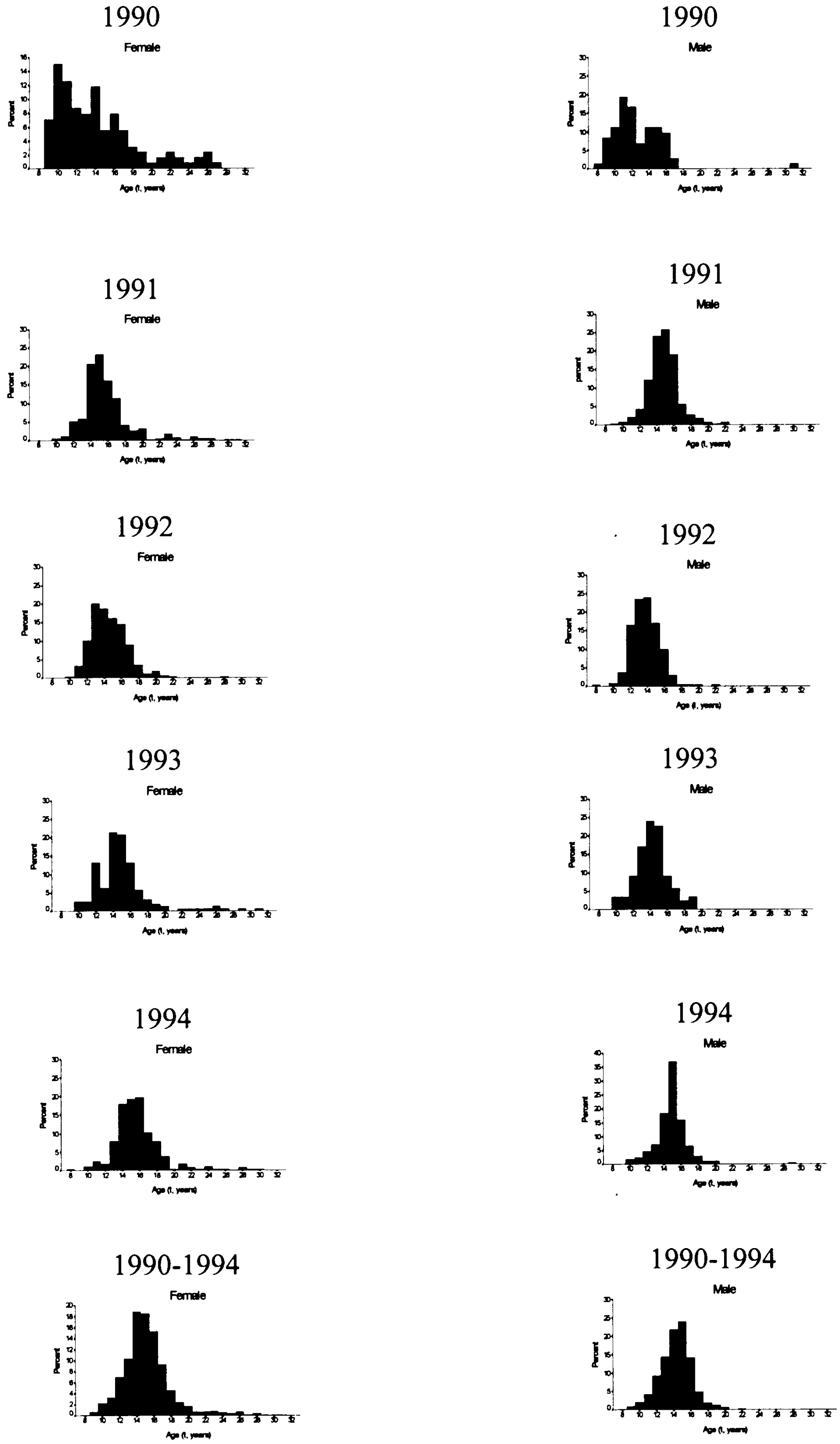
Biotic and abiotic environmental factors have a great effect on the growth rate and development of fishes, and sturgeons are not exceptions (Romanov and Altuf 'ev 1985). Any improvement or deterioration of conditions gives rise to corresponding changes in growth and maturation (Altuf 'ev and Romanov 1989). The only growth rate data in the literature of the Beluga over 50 years is the work of the Raspopov (1993). His data were collected during river runs and there are no previous studies on the growth rate of the Beluga from the southern Caspian. Altuf'ev and Romanov (1988) studied the growth of various juvenile sturgeon up to 7+ years in hatchery ponds and from the north and middle region of the Caspian. They found significant differences in the growth rates of *Acipenser guldenstadti*, *A. stellatus*, and *Huso huso* in different environments. They noted that, of the three species, Beluga grows fastest, with which the present results agree.

Unfortunately, the graph of length-at-age in Beluga is not clearly of the decaying exponential type usual for most fish (Fig 5.7 to 7.42). This seems most likely because the Beluga is so long-lived (probably potentially over 100 years). Although it is such a large fish, with L_{max} in the region of 4 -5 m, its longevity means that, after initial rapid growth (Chugunova, 1940; Nikolskii, 1961), its annual increments are relatively small. Sampling errors, compounded by the fact that fish mature only at intervals of several years, result in apparently erratic variations in mean length. At best the data cover only a small segment of the life span, with sample sizes of ages >25 years being small, and about half the potential life span (45 years upwards) being under represented, probably because of the high fishing pressure. Also, the data suggest three distinct growth stanzas during the Beluga's life. Initially, before it enters the fishery, growth rate is high; from 9 to 24 years, in the classes that dominate the fishery, growth rate is intermediate; and from about 25 onwards it appears slower. Therefore one single equation does not describe growth throughout the entire life span particularly well. The closest fit is obtained by considering only the middle stanza. Raspopov (1993) examined the relationship between weight at age and length at age of Beluga from the Volga. The equation he used and the correlation (r) obtained are different from in the present study. He used the cubic parabola for weight-age and length-age in both males and females, r = 0.997 and 0.995 for females, 0.996 and 0.095 for males. Altuf 'ev and Romanov (1988) described the weight-length relationship of the Beluga as a second-order parabola (quadratic) equation, which has also been tried for length-age, in the present study. In general, little seems clear except the positive relationship between weight and age, and length and age of the Beluga. The main distinctive feature of growth increment in length is that it fluctuates from year to year, without a clearly declining pattern, even when cohort based (Fig 5.28).

Some workers (Tereshchenko 1917; Vasnetsov 1934, 1947) have associated a sharp change in growth rate with attainment of a particular physiological condition, especially with the onset of sexual maturity. Others, using the same examples, claimed that this is incorrect (Biliy 1950; Mina and Klevezal 1976). However, the present results seem to indicate clearly a change in growth rate at about age 24 (Figs 5.84, 5.85), which cannot be explained simply by decreasing sample sizes. Some workers have explained the changes in growth rate by a change in the environment (Yegelskiy 1970; Vinberge 1971). Altuf 'yev and Romanov (1988) examined juvenile development in sturgeons and did not associate changes in growth rate with the onset of sexual maturity. Raspopov (1993), who studied the growth rate of Beluga caught in Volga River, compared his result with that of other authors, e.g. N. Ya. Babushkin (obtained in 1912-1924 and 1928-1930 from the Caspian Sea) and suggested that the differences in the growth rates were related to environmental conditions. According to Rospopov (1993), the rate of growth greatly depends upon the time the fish spends at sea, and ecological conditions, population size, and food supply in the sea. If his assumption is to be accepted, the fluctuations in annual increment of the Beluga until the first maturation (16 years old) should not be high, because they do not migrate to the river before spawning. Alternatively, one could suppose that Beluga caught in the southern Caspian come from different parts of the sea, each part having different ecological conditions.

The present study shows that the average length and weight increment of female Beluga (Figs 5.41, 5.42) is roughly constant, despite the fluctuations, between 10 and about 24 years. The graphs also show, however, that growth rate prior to age 8-9 must be markedly higher than this, since extrapolation of growth curves to age zero provides a length at hatching of almost 1 m and a weight of 13 kg (see Chapter 9). Comparing the growth of males and females, the data also show that, age for age, females are larger than males.

Fig 5.1: Age distribution of female and male Beluga 1990-1994.



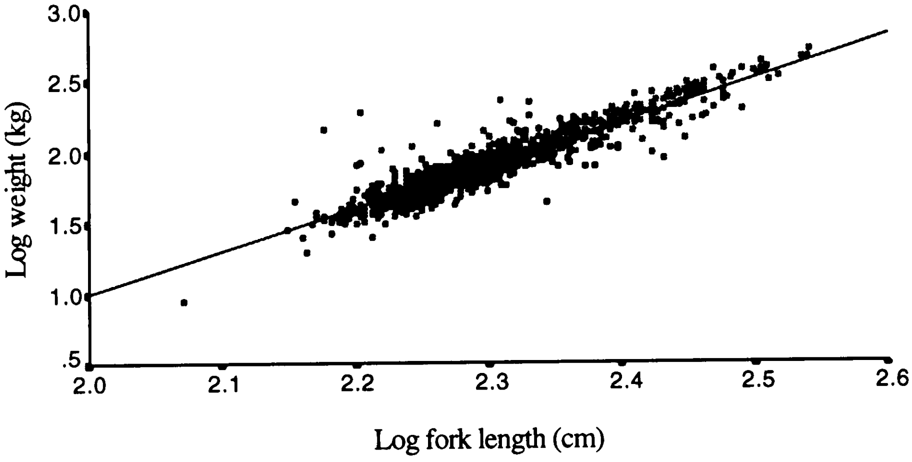


Fig 5. 2: Plot of log weight vs log length of the female Beluga 1990-1994.

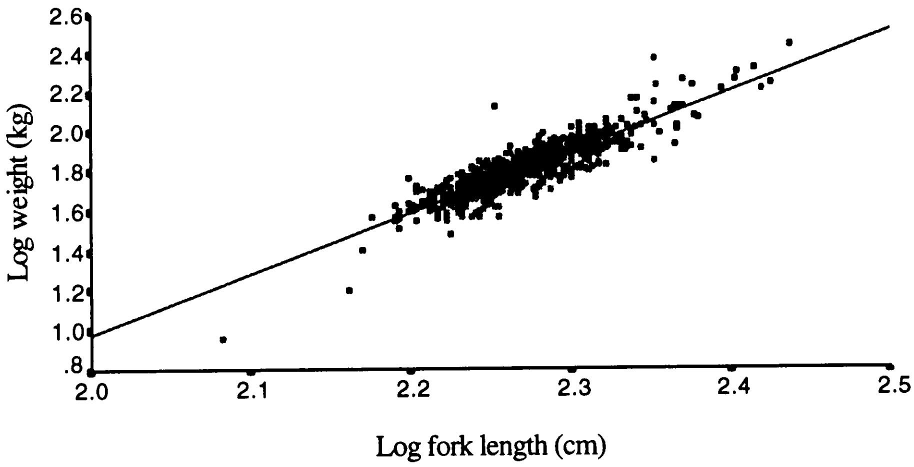


Fig 5.3: Plot of log weight vs log length of the male Beluga 1990-1994.

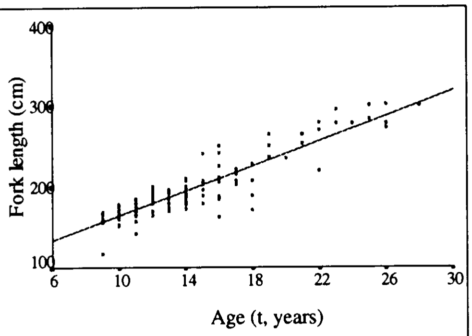


Fig 5.4: Length-age relationship of the female Beluga 1990 (linear plot).

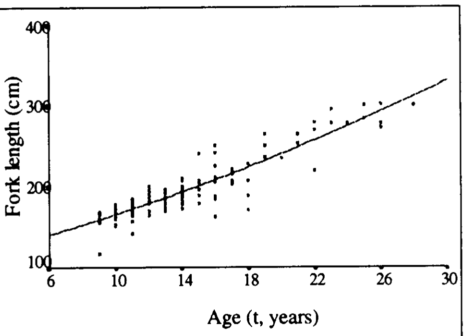


Fig 5.5: Length-age relationship of the female Beluga 1990 (quadratic plot).

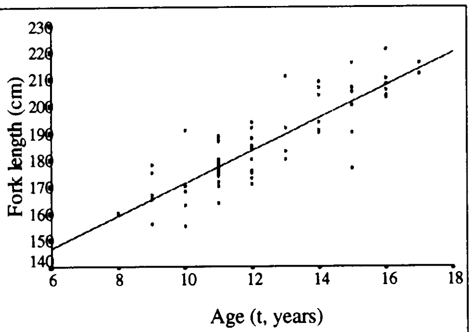


Fig 5.6: Length-age relationship of the male Beluga 1990 (linear plot).

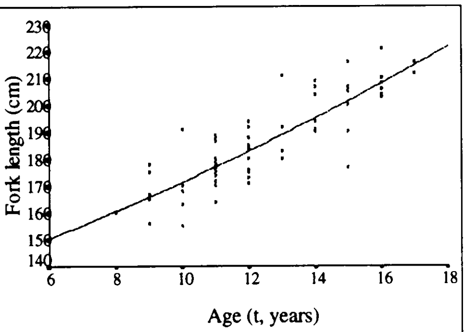


Fig 5.7: Length-age relationship of the male Beluga 1990 (quadratic plot).

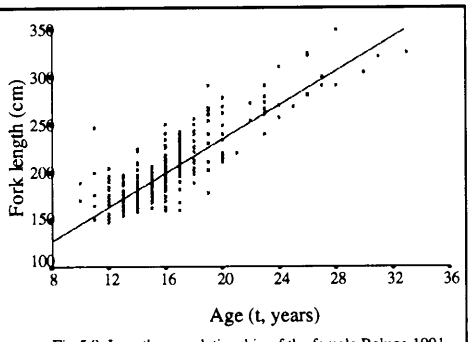


Fig 5.8: Length-age relationship of the female Beluga 1991 (linear plot).

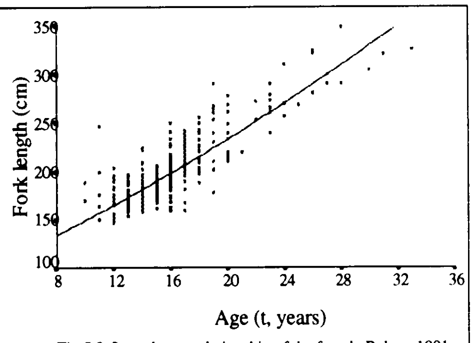


Fig 5.9: Length-age relationship of the female Beluga 1991 (quadratic plot).

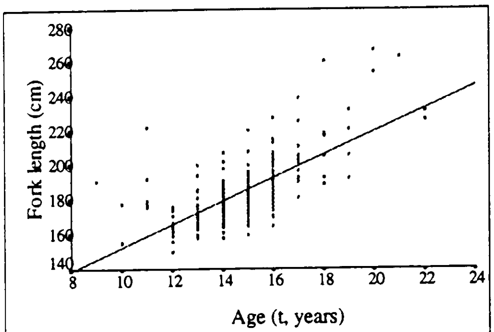


Fig 5.10: Length-age relationship of the male Beluga 1991 (linear plot).

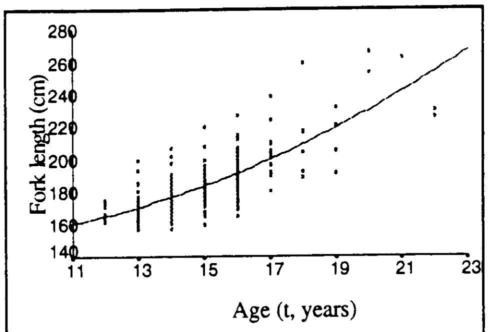


Fig 5.11: Length-age relationship of the male Beluga 1991(quadratic plot).

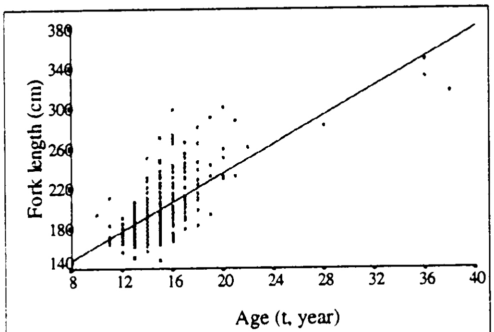


Fig 5. 12: Length-age relationship of the female Beluga 1992 (linear plot).

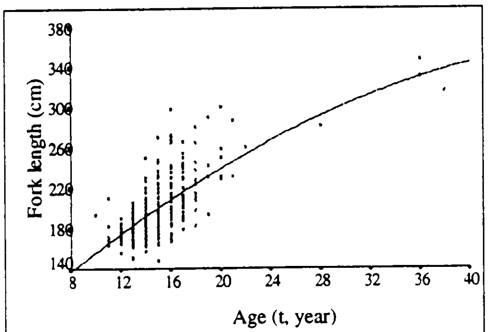


Fig 5. 13: Length-age relationship of the female Beluga 1992 (quadratic plot).

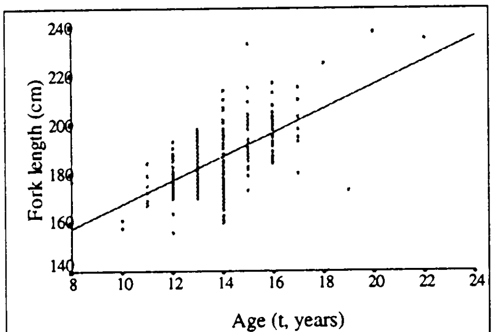


Fig 4.14: Length-age relationship of the male Beluga 1992 (linear plot).

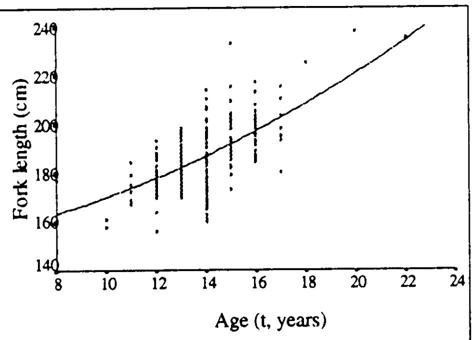


Fig 4.15: Length-age relationship of the male Beluga 1992 (quadratic plot).

Fig 5.16: Length-age relationship of the female Beluga 1993 (linear plot).

Fig 5.17: Length-age relationship of the female Beluga 1993 (quadratic plot).

Fig 5. 18: Length-age relationship of the male Beluga 1993 (linear plot).

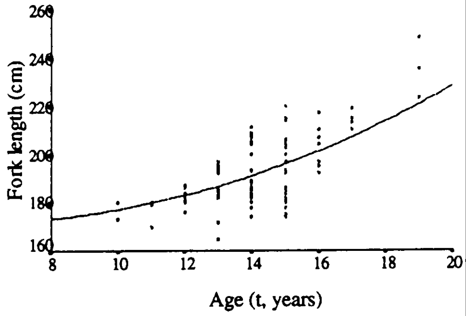


Fig 5. 19: Length-age relationship of the male Beluga 1993 (quadratic plot).

Fig 5.20: Length-age relationship of the female Beluga 1994 (linear plot).

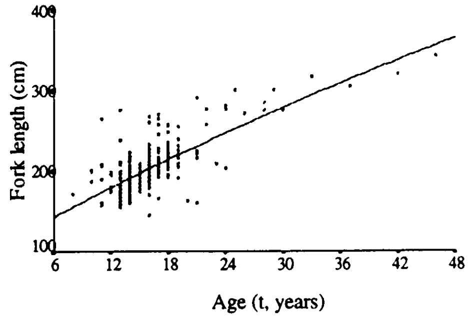


Fig 5.21: Length-age relationship of the female Beluga 1994 (quadratic plot).

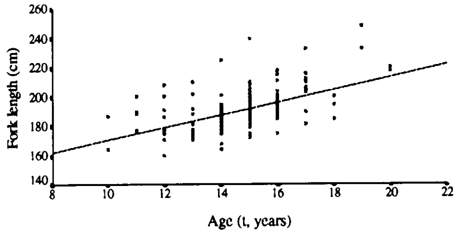


Fig 5.22: Length-age relationship of the male Beluga 1994 (linear plot).

Fig 5.23: Length-age relationship of the male Beluga 1994 (quadratic plot).

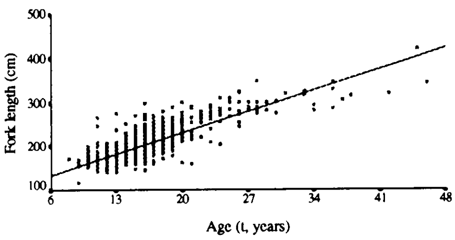


Fig 5.24: Length-age relationship of the female Beluga 1990-1994 (quadratic plot).

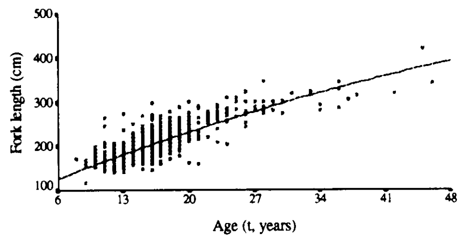


Fig 5.25: Length-age relationship of the female Beluga 1990-1994 (quadratic plot).

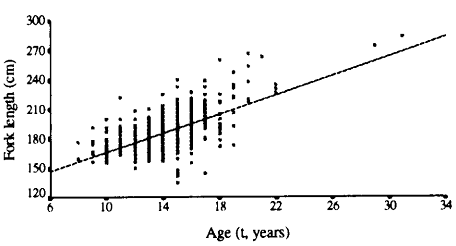


Fig 5. 26: Length-age relationship of the male Beluga 1990-1994 (linear plot).

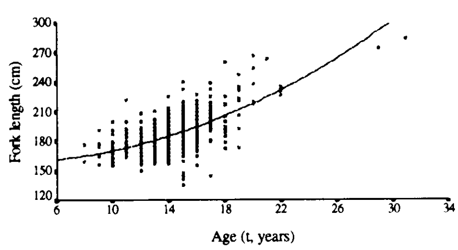


Fig 5. 27: Length-age relationship of the male Beluga 1990-1994 (quadratic plot).

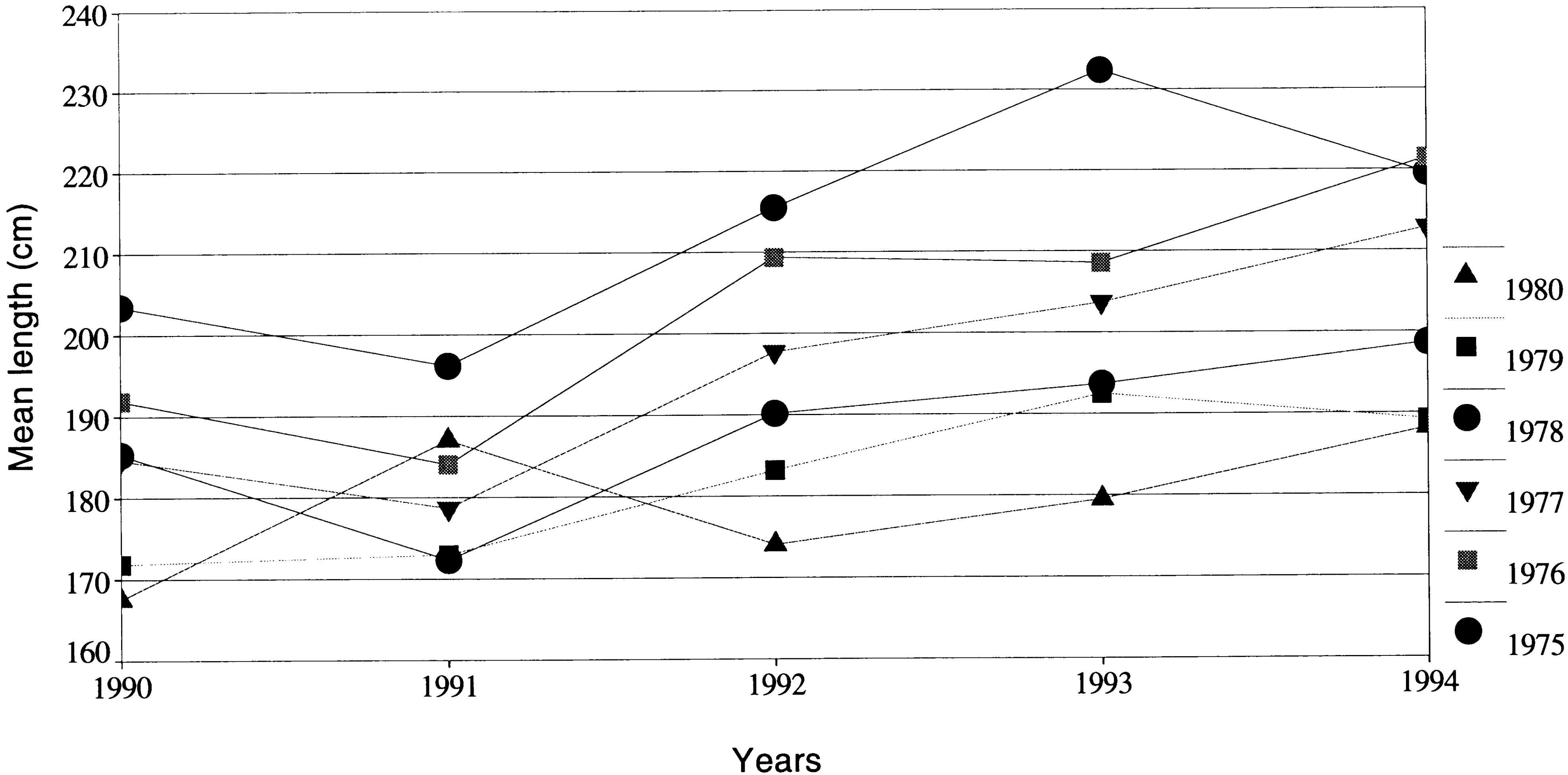


Fig 5. 28: Female Beluga mean length at age by cohorts.

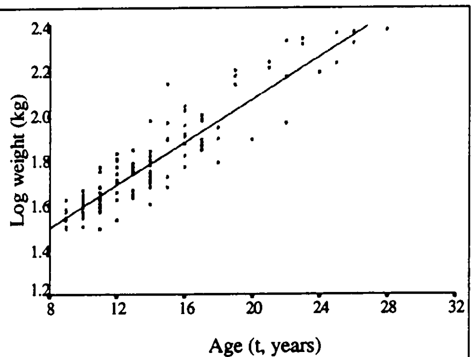


Fig 5. 29: Plot of log weight vs age of the female Beluga 1990.

Fig 5. 30: Plot of log weight vs age of the male Beluga 1990.

Fig 5. 31: Plot of log weight vs age of the female Beluga 1991.

Fig 5. 32: Plot of log weight vs age of the male Beluga 1991.

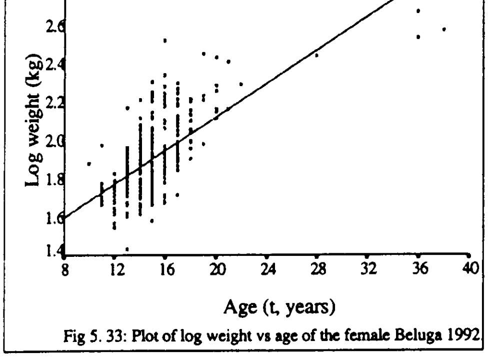


Fig 5. 33: Plot of log weight vs age of the female Beluga 1992.

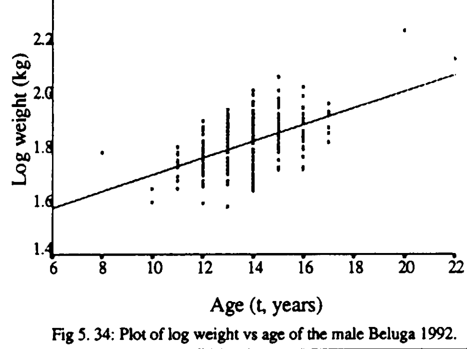


Fig 5. 34: Plot of log weight vs age of the male Beluga 1992.

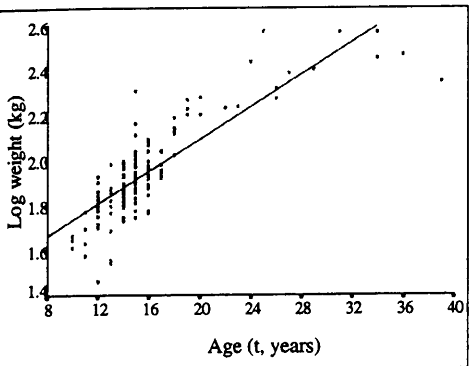


Fig 5. 35: Plot of log weight vs age of the female Beluga 1993

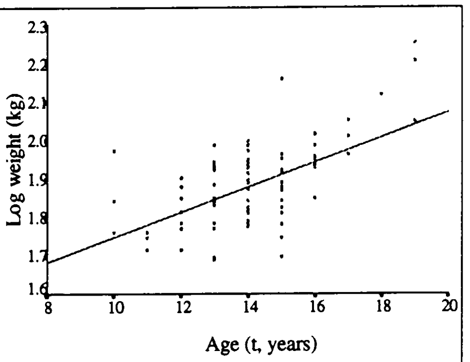


Fig 5. 36: Plot of log weight vs age of the male Beluga 1993.

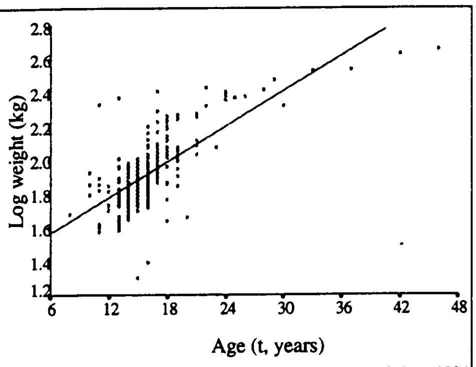


Fig 5. 37: Plot of log weight vs age of the female Beluga 1994

Fig 5. 38: Plot of log weight vs age of the male Beluga 1994.

Fig 5. 39: Plot of log weight vs age of the female Beluga 1990-1994.

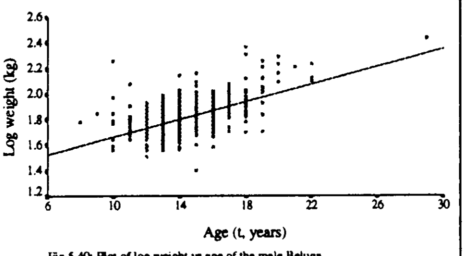


Fig 5.40: Plot of log weight vs age of the male Beluga 1990-1994.

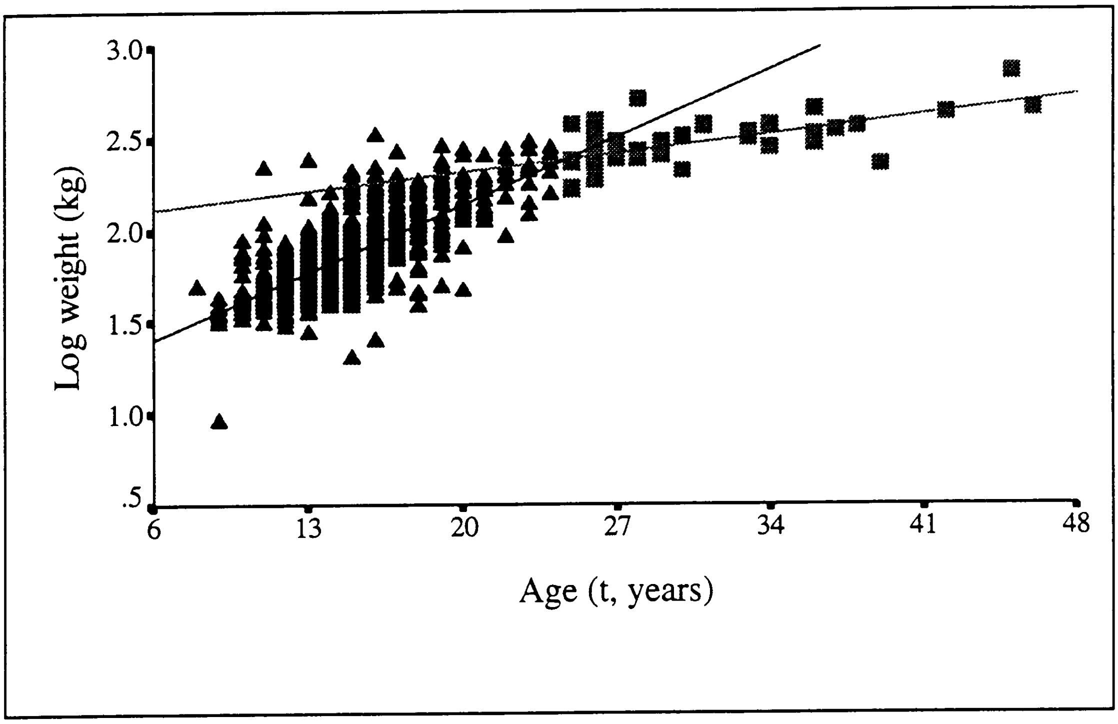


Fig 5.41: Stanzas of growth-in-weight of the female Beluga 1990-1994.

Graph showing log growth-in-weight data regarded as stanzas rather than as a decaying exponential. The graph shows the periods from age 8 to 24 with fitted straight line (log W = 1.05850 + 0.0526t) and from 24 to 46 with another (log W = 2.0244 = 0.0147t). It should be noted that the sample sizes during the second stanza tend to be very small (Table 5. 32).

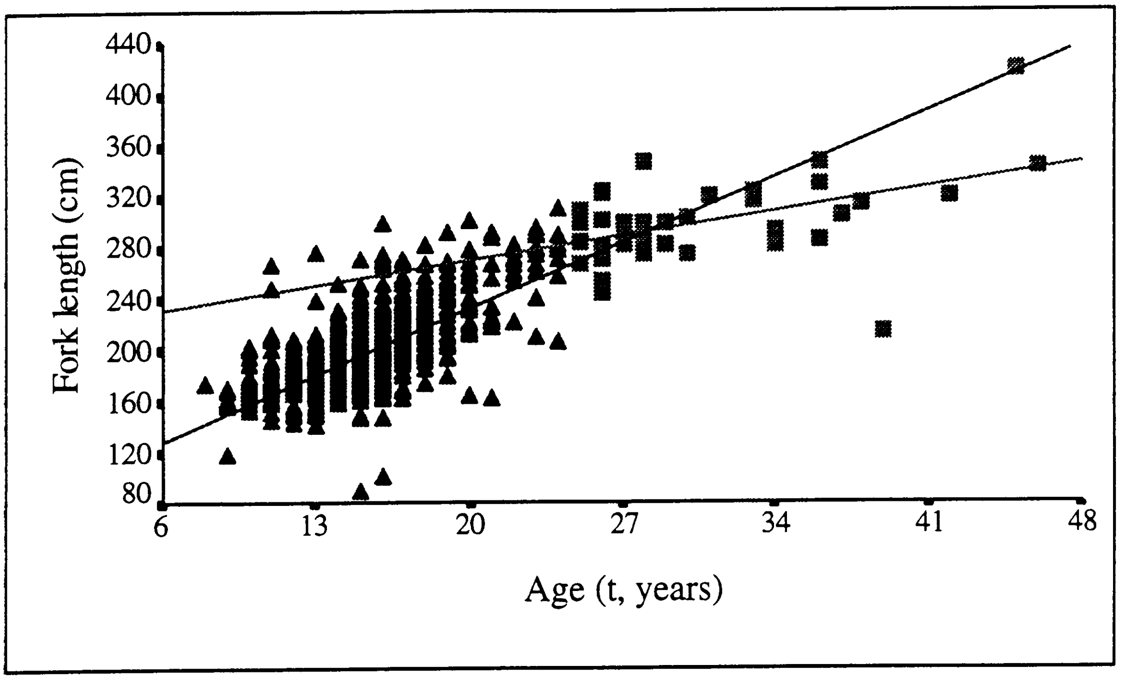


Fig 5.42: Stanzas of growth-in-length of the female Beluga 1990-1994.

Graph showing growth-in-length data regarded as stanzas rather than as a decaying exponential. The graph shows the periods from age 8 to 24 with fitted straight line ($L = 84.9681 + 7.3980t$) and from 24 to 46 with another ($L = 215.917 + 2.7364t$). It should be noted that the sample sizes during the second stanza tend to be very small (Table 5. 24).

CHAPTER 6

Length, weight and age relationships of the Stellate Sturgeon, *Acipenser stellatus*, in the Caspian Sea

6.1 Introduction

The Stellate Sturgeon, *Acipenser stellatus,* inhabits the basins of the Black Sea, Sea of Azov, and Caspian. The largest population of Stellate Sturgeon is concentrated in the Caspian Sea. From there, they ascend the Volga, Ural, Terek, Sulak, Samur, and Kura Rivers (Berg 1948). The species is anadromous and enters rivers to spawn; it is the smallest sturgeon in the Caspian Sea, where it is caught by anchored gill nets; in rivers, the fish is caught mainly with swim-nets and seines. The standard mesh size (knot-to-knot) for *A. stellatus* is 100 mm, and the length of the nets is 18m and the width is 21mesh. At the end of the nineteenth and beginning of the twentieth centuries, the fishery was extended to the central and southern Caspian Sea. The intensification of the river fishery and the growth of the fishing industry in the sea led to a temporary increase in the catch of sturgeons, including *A. stellatus.* In 1899 and 1900 the catches of this species amounted to 10,300 and 10,800 tonnes respectively (Korobochkina 1964). From 1900 to 1913 the annual catch decreased to 6,000-7,000 tonnes. From 1904 to 1913, *A. stellatus* accounted for 25% of the total sturgeon catch by weight (Kozhin 1964). The increase in the sea fishery had a negative effect on the sturgeon populations and, after 1915, the catch sharply decreased. During the 1930's, the Stellate Sturgeon catch improved slightly, but this was due almost exclusively to increased yields from the sea fishery, and it later declined again (Korobochkina 1964).

The government of the former Soviet Union established limits to regulate the fish catch in Caspian Sea. Thus, in 1962, the sea fishery for diadromous and semi-diadromous fishes, including sturgeons, had been banned, and the fishery was permitted only in rivers (Berdichevskii *et al.* 1982). As a result, both the abundance and catch of sturgeons in northern Caspian rose to 10,000-13,200 tonnes. The majority of this catch, 7,000 and 9,900 tonnes, came from the Ural River (Kazancheev 1981). A total of 312 tonnes of *A. stellatus* was caught in 1956-1957 by Iranian fishermen along the southern Caspian coast (Kozhin 1964). Damming of the rivers has reduced the access of the Stellate Sturgeon to their spawning grounds, and the conditions for their natural reproduction have deteriorated, although not as much as for *Huso huso* and other sturgeon species. Stellate Sturgeon populations in the Caspian, Azov, and Black Sea watersheds have been supported by stocking since 1973. The methods of its artificial propagation are now well established, and this species has become important in commercial production (Mil'shtein 1964). In the Caspian watershed, especially in the Volga region, 6.3 to 23 million Stellate Sturgeon were cultured annually between 1973 and 1975 (Kazancheev 1981). Today, the culture of Stellate Sturgeons is well developed in both Iran and the former Soviet Union countries, but the reserves of this fish in the Caspian Sea are fairly exhausted and, like most other members of the sturgeon family, this species needs protection, particularly at the spawning grounds in the rivers and during spawning. The minimum length for catching the Stellate Sturgeon in the southern Caspian Sea is 93 cm total length.

6. 2 Results

6. 2. 1 Sex composition

Table 6.1-6.5 shows the mean age, mean fork length, mean total weight and proportion of different sexes in the catch between 1990 and 1994.

Table 6.1: Mean age, mean fork length, mean weight and proportion of male and female Stellate Sturgeon, catch from the south part of the Caspian Sea 1990.

sex	mean age (years)	mean fork length (± SD) (cm)	mean total weight (± SD) (kg)	number	percentage
Immature female	9.6	119.7 ± 12.5	8.0 ± 4.0	896	13.2%
Mature female	12.5	113.9 ± 7.0	11.7 ± 3.3	4190	61.7%
Immature male	8.3	111.5 ± 10.2	6.1 ± 2.1	346	5.1%
Mature male	10.1	119.7 ± 9.3	7.8 ± 2.5	1356	20%
Total	11.4	128.0 ± 12.7	10.2 ± 3.8	6785	100%

Table 6.2: Mean age, mean fork length, mean weight and proportion of male and female Stellate, catch from the south part of the Caspian Sea 1991.

sexes	mean age (years)	mean fork length (± SD) (cm)	mean total weight (± SD) (kg)	number	percentage
Immature female	10.1	118.42 ± 13.5	8.12 ± 3.5	1848	17.4%
Mature female	12.4	131.25 ± 9.3	11.80 ± 2.7	6513	61.3%
Immature male	9.3	113.21 ± 10.6	6.88 ± 2.6	526	4.9%
Mature male	10.0	116.43 ± 8.9	7.28 ± 2.0	1745	16.4%
Total	11.5	125.7 ± 12.4	10.2 ± 3.4	10632	100%

Table 6.3: Mean age, mean length (fork length), mean total weight and proportion of the females and males, catch from the south part of the Caspian Sea 1992.

sexes	**mean age (year)**	**mean fork length (± SD) (cm)**	**mean weight (± SD) (kg)**	**number**	**percentage**
Immature female	10.2	117.7 ± 12.3	8.0 ± 3.0	1292	18.7%
Mature female	12.3	132.6 ± 10.0	12.1 ± 2.8	4308	62.6%
Immature male	9.6	114.2 ± 11.2	7.2 ± 3.3	198	2.9%
Mature male	9.8	117.6 ± 8.9	7.6 ± 1.9	1079	15.9%
Total	11.5	126.9 ± 12.7	10.5 ± 3.4	6877	100%

Table 6.4: Mean age, mean length (fork length), mean total weight and proportion of the females and males, catch from the south part of the Caspian Sea 1993.

sexes	**mean age (year)**	**mean fork length (± SD) (cm)**	**mean total weight (± SD) (kg)**	**number**	**percentage**
Immature female	11.1	121.3 ± 11.8	9.2 ± 3.2	604	14.40%
Mature female	12.4	130.5 ± 9.8	11.7 ± 2.5	2833	67.40%
Immature male	9.7	112.5 ± 9.3	7.1 ± 2.1	188	4.5%
Mature male	10.3	116.9 ± 8.4	7.7 ± 1.9	579	13.8%
Total	11.8	126.5 ± 11.6	10.6 ± 3.2	4198	100%

Table 6.5: Mean age, mean length (fork length), mean total weight and proportion of the females and males, catch from the south part of the Caspian Sea 1994.

sexes	mean age (years)	mean fork length (± SD) (cm)	mean weigh (± SD) (kg)	number	percentage
Immature female	11.1	123.40± 12.2	9.5 ± 3.4	735	10.1%
Mature female	12.4	130.4 ± 9.5	11.7 ±2.5	5174	71 10%
Immature male	9.9	115.8 ± 9.0	7.5 ± 2.2	1041	14.3%
Mature male	10.3	119.8 ± 8.5	8.4 ± 2.0	310	4.3%
Total	11.8	127.2 ± 11.2	10.7 ± 3.0	6929	100.%

Five years' data of the Stellate Sturgeon catches in the south part of the Caspian Sea were combined and analysed (Table 6.6).

Table 6.6: Mean age, mean length (fork length), mean total weight and proportion of the females and males, catch from the south part of the Caspian Sea 1990-1994.

sexes	mean age (year)	mean fork length (± SD) (cm)	mean weight (± SD) (kg)	number	percentage
Immature female	10.3	119.5 ± 12.8	8.4 ± 3.5	5373	15.00%
Mature female	12.4	131.7 ± 9.7	11.8 ± 2.7	23021	64.3%
Immature male	9.5	114.2 ± 9.9	7.1 ± 2.4	2299	6.4%
Mature male	10.0	117.9 ± 9.0	7.6 ± 2.1	5070	14.2%
Total	11.6	126.6 ± 12.2	10.4 ± 3.4	35416	100%

In all of the five years' catches from the south part of the Caspian Sea females were predominant, and formed 80% of the combined catches. Nearly 22% of the catches were immature.

Mean age, mean fork length and mean weight of mature and immature females of the combined years' data were all higher than in males, suggesting that the males mature earlier than females. The differences between mature females and mature males of mean age, mean length and mean weights were highly significant (t-test, t-values = 95.8, 97.7 and 118.8 respectively, $P<0.01$). Also, the mean age, mean length and mean weight of immature females were significantly higher than mature males (t-test, t-values = 3.4, 4.7 and 11.2 respectively, $P<0.01$).

6. 2. 2 Age composition

Five years' catch data of the Stellate Sturgeon in the south part of the Caspian Sea were combined (Table 6.7) and the age composition was analysed. The mean age of females was 12.0 years, of males 9.9 years; the age of females ranged from five to 27 years, of males four to 21 years. The catch mode for females was as 12 years old (25.9%); for males the mode was as 10 years (25.5%). The catches of Stellate Sturgeon comprised a limited range of age-groups. The age-range of the females was higher than of the males. The number of Stellate Sturgeon older than 18 years in the catches was very low, and there were no fish above 23 apart from a single female aged 27. The percentages of males were higher in younger age groups (6-11 years), while females predominated in older age groups (12-18 years).

Table 6.7: Age composition of Stellate Sturgeon, from the south part of the Caspian Sea 1990-1994; females and males separately.

	Females			Males		
Age (years)	number	percentage	mature %	number	mature %	percentage
4				3	0.0	0.0
5	13	0.0	0.0	16	12.2	0.2
6	112	0.4	4.5.	104	24.5	1.4
7	337	1.2	15.0	409	35.5	5.6
8	703	2.5	18.6	960	34.5	13.1
9	1318	4.7	22.5	1465	39.8	20.0
10	2581	9.2	60.5	1866	64.5	25.5
11	4312	15.3	77.5	1363	77.5	18.7
12	7289	25.9	88.5	776	84.6	10.6
13	6146	21.9	76.8	224	63.5	3.1
14	3545	12.6	88.6	66	75.8	0.9
15	1281	4.6	60.3	30	85.5	0.4
16	336	1.2	95.5	14	95.5	0.2
17	100	0.4	84.5	5	80.0	0.1
18	26	0.1	98.2	1	100.0	0.0
19	7	0.0	75.5	3	100.0	0.0
20	3	0.0	100.0	1	100.0	0.0
21	1	0.0	100.0	1	0.0	0.0
22	1	0.0	100.0			
23	2	0.0	50.0			
24						
25						
26						
27	1	0.0	100.0			
mean age	12.02			9.90		

Fig 6.1 shows the age distribution of the Stellate Sturgeon for each year of the catch. The percentage of older age groups in both sexes decreased by the year; for instance, the percentage of 14 year old females was 15.6% in 1990 but 12.2% in 1994, and 14 year old males comprised 1.3% in 1990 and 0.9% in 1994. The differences between the age distribution of males and females between years were examined using Kolmogorov-Smirnov 2-sample tests (Table 6.8). The differences between all successive years are significant except for females between 1993 and 1994. The mean

age of females and males seemed to increase from 1990 to 1994, but the correlation coefficients were not significant (df = 3, r = 0.0.618, P>0.05 for females; df = 3, r = 0.8, P>0.05 for males).

Table 6.8: Kolmogorov-Smirnov 2-sample test for age distribution of male and female (1990-1994).

year	Females		Males	
	numbers	**K-S Z**	**numbers**	**K-S Z**
1990-1991	5086, 8361	2.2 **	1702, 2271	1.5 *
1991-1992	8361, 5597	3.3 **	2271, 1277	2.1 **
1992-1993	5597, 3437	3.2 **	1277, 767	3.4 **
1993-1994	3437, 5629	1.0	767, 1289	1.5 *

* $P \leq 0.05$; ** $P \leq 0.01$

The differences between the mean age for each year were examined with Tukey's T. Mean age of the males in 1990 was significantly different from 1991, 1992, 1993 and 1994; 1991 differed from 1993 and 1994; and 1992 from 1993 and 1994. For females, mean age significantly differed between 1990 and 1993 and 1994; 1991 differed from 1993 and 1994; and 1992 differed from 1993 and 1994 (Table 6.9).

Table 6.9: Tukey's T for differences between mean age of females and males Stellate Sturgeon (1990-1994).

	1990 (F)	1991 (F)	1992 (F)	1993 (F)	1994 (F)
1990 (M)		n = 5086, 8361 x̄ = 12.0, 11.9 MSD = 0.086 *	n = 5086, 5597 x̄ = 12.0, 11.8 MSD = 0.094 *	n = 5086, 3437 x̄ = 12.0, 12.2 MSD = 0.107 *	n = 5086, 5629 x̄ = 12.0, 12.2 MSD =0.094 *
1991 (M)	n = 1702, 2271 x̄ = 9.7, 9.9 MSD = 0.2310		n = 8361, 5597 x̄ = 11.9, 11.8 MSD = 0.084 *	n = 8361, 3437 x̄ = 11.9, 12.2 MSD = 0.097 *	n = 8361, 5629 x̄ = 11.9, 12.2 MSD = 0.084 *
1992 (M)	n = 1702, 1277 x̄ = 9.7, 9.8 MSD = 0.1693	n = 2271, 1277 x̄ = 9.9, 9.8 MSD = 0.1599		n = 5597, 3437 x̄ = 11.8, 12.2 MSD = 0.1054 *	n =5597, 5629 x̄ = 11.8, 12.2 MSD = 0.091 *
1993 (M)	n = 1702, 767 x̄ = 9.7, 10.1 MSD =0.1989 *	n = 2271, 767 x̄ = 9.9, 10.1 MSD = 0.1910 *	n = 1277, 767 x̄ = 9.8, 10.1 MSD = 0.2089 *		n = 3437, 5629 x̄ = 12.2, 12.3 MSD = 0.105
1994 (M)	n = 1702, 1289 x̄ = 9.7, 10.0 MSD =0.1688 *	n = 2271, 1289 x̄ = 9.8, 10.0 MSD = 0.1595 *	n = 1277, 1289 x̄ = 9.8, 10.0 MSD = 0.1805 *	n = 767, 1289 x̄ = 10.1, 10.0 MSD = 0.2085	

* P≤0.05

The difference between two means is significant if

[Mean (I) - Mean (j)] ≥ MSD

6. 2. 3 Length composition

Mean fork lengths ±SD of the Stellate Sturgeon caught in the south part of the Caspian Sea over a period of five years' were analysed (Table 6.10). The mean length of females was 129.4 cm and males 116.7 cm. The length of females varied between 57 and 213 cm, of males between 82 and 190 cm. The majority (91.6%) of the female catch was 110 to 150 cm, while 91.5% of the males were from 100 to 135 cm. Length range of females was larger than of males in all years. In most of the years the majority (always more than 90%) of the female catch were 110 to 150 cm, while nearly the same percentage of males ranged from 100 to 130 cm. There were no significant trends (increasing or decreasing) in mean length of females and males (for females, df = 3, r = 0.426, P>0.05; for males, df = 3, r = 0.538, P>0.05).

Table 6.10: Mean fork length (cm) ±SD of the Stellate Sturgeon, south part of the Caspian Sea (1990-1994).

years	**Females**			**Males**		
	number	**mean length cm**	**range cm**	**number**	**mean length cm**	**range cm**
1990	5086	131.4 ±11.7	90-198	1702	118.5 ± 10.0	82-157
1991	8361	128.4 ± 11.7	90-213	2271	115.7 ± 9.4	88-188
1992	5597	129.2 ± 12.2	91-207	1277	117.1 ± 9.9	95-190
1993	3437	128.9 ± 11.0	90-173	4205	115.8 ± 8.8	90-157
1994	5629	129.6 ± 11.2	57-180	1289	116.5 ± 9.0	93-170
90-94	28114	129.4 ± 11.5	57-213	7307	116.7 ± 9.5	82-190

The differences between mean lengths for each year were examined statistically (Tukey's T, Table 6.11). Among females, significant differences in the mean fork length occurred between 1990 and 1991, 1992, 1993and 1994; between 1991 and 1992 and 1994; and between 1993 and 1994. For males differences were significant between 1990 and 1991, 1992, 1993 and 1994; between 1991 and 1992; and between 1992 and 1993.

Table 6.11: Tukey's T for differences between mean length of females and males.

	1990 (F)	1991 (F)	1992 (F)	1993 (F)	1994 (F)
1990 (M)		n = 5089, 8361 $\bar{x}$ = 131.4, 128.4 MSD = 0.5548 *	n = 5086, 5597 $\bar{x}$ = 131.4, 129.2 MSD = 0.6045 *	n = 5086, 3437 $\bar{x}$ = 131.4, 128.9 MSD = 0.6890 *	n = 5086, 5629 $\bar{x}$ = 131.4, 129.6 MSD = 0.6037 *
1991 (M)	n = 1702, 2271 $\bar{x}$ = 118.1, 115.7 MSD = 0.8276 *		n = 8361, 5597 $\bar{x}$ = 128.4, 129.2 MSD = 0.5389 *	n = 8361, 3437 $\bar{x}$ = 128.4, 128.9 MSD = 0.6323	n = 8361, 5629 $\bar{x}$ = 128.4, 129.6 MSD = 0.5380 *
1992 (M)	n = 1702, 1277 $\bar{x}$ = 118.1, 117.1 MSD = 0.9557 *	n = 2271, 1277 $\bar{x}$ = 115.7, 117.1 MSD = 0.9029 *		n = 5597, 3437 $\bar{x}$ = 129.2, 128.9 MSD = 0.6762	n = 5597, 5629 $\bar{x}$ = 129.2, 129.6 MSD = 0.5891
1993 (M)	n = 1702, 767 $\bar{x}$ = 118.1, 115.8 MSD = 1.1227 *	n = 2271, 767 $\bar{x}$ = 115.7, 115.8 MSD = 1.078	n = 1277, 767 $\bar{x}$ = 117.1, 115.8 MSD = 1.1793 *		n = 3437, 5629 $\bar{x}$ = 128.9, 129.6 MSD = 0.6755 *
1994 (M)	n = 1702, 1289 $\bar{x}$ = 118.1, 116.5 MSD = 0.9531 *	n = 2271, 1289 $\bar{x}$ = 115.7, 116.5 MSD = 0.9002	n = 1277, 1289 $\bar{x}$ = 117.1, 116.5 MSD = 1.0193	n = 767, 1289 $\bar{x}$ = 115.8, 116.5 MSD = 1.1772	

*$P \leq 0.05$

The difference between two means is significant if

[Mean (I) - Mean (j)] $\geq$ MSD

6. 2. 4 Weight composition

Five years' catches of the Stellate Sturgeon in the south part of the Caspian Sea were combined to analyse the weight structure of the population (Table 6.12). The mean weight of the entire population was 10.4 kg. The weight of fish in the catches varied between 3 and 93 kg, but 99.4% of the catch was between 3 kg and 20 kg. The mean weight of females was 11.2 kg. Minimum weight was 3 kg, maximum 93 kg, but 99.3% were 3 to 20 kg. The weight of the males varied between 3 and 43 kg, with a mean of 7.4 kg, but 99.2% of the male catch weighed from 3 kg to 15 kg. The majority (more than 90%) of the females in most years were 3 to 20 kg, whereas more than 90% of males weighed 3 to 10 kg.

Table 6.12: Mean weight (total weight) ±SD of the Stellate Sturgeon, caught in south part of the Caspian Sea 1990-1994.

	Females				Males		
years	**range**	**number**	**mean weight kg**	**range kg**	**number**	**mean weight kg**	**range kg**
1990	1.2-109	5086	11.1 ± 3.7	1.20-109	1702	7.2 ± 2.5	3-18
1991	3-37	8361	11.0 ± 3.3	3-35	2271	7.2 ± 2.2	3.5-37
1992	3.2-42	5597	11.3 ± 3.3	3.30-34	1277	7.5 ± 2.2	3.20-42
1993	3.2-31.5	3437	11.3 ± 3.0	3.7-31.5	4205	7.6 ± 2.0	3.2-24.8
1994	3.5-33	5629	11.5 ± 2.7	4-33	1289	7.6 ± 2.2	3.5-33
90-94	1.2-109	28114	11.2 ± 3.2	1.20-109	7307	7.4 ± 2.2	3-42

The differences between mean weights for each year of the sampling were examined using Tukey's T (Table 6.13). For females significant differences appeared between 1990 and 1993 and 1994; between 1991 and 1993 and 1994; between 1992 and 1993 and 1994; and between 1993 and 1994. For males the significant differences appeared between 1990 and 1991, and 1994; between 1991 and 1992, 1993 and 1994.

Table 6.13: Tukey's T for differences between mean weight of female and males.

	1990 (F)	1991 (F)	1992 (F)	1993 (F)	1994 (F)
1990 (M)		n= 5084, 8361 $\bar{x}$ = 11.1, 11.0 MSD = 0.1509	n= 5084, 5597 $\bar{x}$ = 11.1, 11.1 MSD = 0.1643	n= 5084, 3430 $\bar{x}$ = 11.1, 11.3 MSD = 0.1874 *	n= 5085, 5629 $\bar{x}$ = 11.1, 11.5 MSD = 0.1641 *
1991 (M)	n= 1699, 2271 $\bar{x}$ = 7.5, 7.2 MSD = 0.1909 *		n= 8361, 5597 $\bar{x}$ = 11.0, 11.1 MSD = 0.1464	n= 8361, 3430 $\bar{x}$ = 11.0, 11.3 MSD = 0.1719 *	n= 8361, 5629 $\bar{x}$ = 11.0, 11.5 MSD = 0.1462 *
1992 (M)	n= 1699, 1277 $\bar{x}$ = 7.5, 7.5 MSD = 0.2204	n= 2271, 1277 $\bar{x}$ = 7.2, 7.5 MSD = 0.2082 *		n= 5597, 3430 $\bar{x}$ = 11.1, 11.3 MSD = 0.1839 *	n= 5597, 5629 $\bar{x}$ = 11.1, 11.5 MSD = 0.1601 *
1993 (M)	n= 1699, 767 $\bar{x}$ = 7.5, 7.6 MSD =0.2589	n= 2271, 767 $\bar{x}$ = 7.2, 7.6 MSD = 0.2486 *	n= 1277, 767 $\bar{x}$ = 7.5, 7.6 MSD = 0.2719		n= 3430, 5629 $\bar{x}$ = 11.3, 11.5 MSD = 0.1837 *
1994 (M)	n= 1699, 1289 $\bar{x}$ = 7.5, 7.6 MSD = 0.2198	n= 2271, 1289 $\bar{x}$ = 7.2, 7.6 MSD = 0.2076 *	n= 1277, 1289 $\bar{x}$ = 7.5, 7.6 MSD = 0.3250	n= 767, 1289 $\bar{x}$ = 7.6, 7.6 MSD = 0.2714	

* $P \leq 0.05$

The difference between two means is significant if

[Mean (I) - Mean (j)] $\geq$ MSD

6. 2. 5 Weight-length relationships

Weight-length relationships for female and male Stellate Sturgeon were calculated for all the years. The relationship was estimated by the standard method, log *W* vs log *L*.

Relationships between the weight and length of female and male Stellate Sturgeon are given in Table 6.14 and 6.15. Figs 6.2 and 6.3 show the relationships calculated for both sexes for combined years.

Table 6.14: Weight-length relationships of female Stellate Sturgeon, south part of the Caspian Sea (W= total weight (kg), FL= fork length (cm).

year	**number**	**weight-length relationships Log W /Log L (F)**	**correlation coefficient (r)**
1990	5089	LogW = 2.6 (log FL) - 4.55	0.805
1991	8361	LogW = 3.1 (log FL) - 5.42	0.895
1992	5600	LogW = 2.9 (log FL) - 5.20	0.897
1993	3438	LogW = 2.7 (log FL) - 4.75	0.873
1994	5640	LogW = 2.7 (log FL) - 4.58	0.859
90-94	28128	LogW = 2.85 (log FL) - 4.99	0.871

Table 6.15: Weight-length relationships of male Stellate Sturgeon, south part of the Caspian Sea (W = total weight (kg), FL = fork length(cm).

year	**number**	**weight-length relationships Log W/Log L (M)**	**correlation coefficient (r)**
1990	1701	LogW = 2.4 (log FL) - 4.20	0.720
1991	2271	LogW = 2.8 (log FL) - 4.98	0.849
1992	1277	LogW = 2.6 (log Fl) - 4.50	0.815
1993	767	LogW = 2.5 (log FL) - 4.28	0.793
1994	1289	LogW = 2.7 (log FL) - 4.72	0.834
90-94	7305	LogW = 2.6 (log FL) -4.57	0.798

As the analyses show, the values of the correlation coefficients (r) were high in both sexes, but higher in females than in males.

6. 2. 6 Length-age relationship

The relationship between length and age of Stellate Sturgeon was calculated for each year's catch, and for the sexes separately (Tables 6.16-6.17, Figs 5-4 to 5-27).

Table 6.16: Length-age relationships of female Stellate Sturgeon, south part of the Caspian Sea (Y= fork length (cm), X= age(t, years), Fig = Figures).

year	**N**	**length-age relationships & equation**	**Fig**	**r**	**length-age relationships & equation**	**Fig**	**r**
1990	5089	$Y = 74.3780 + 4.5268X + 0.0179X^2$	6.5	0.85	$Y = 72.0234 + 4.9437X$	6.4	0.84
1991	8361	$Y = 84.6612 + 1.8208X + 0.1508 X^2$	6.9	0.88	$Y = 65.5801 + 5.2667X$	6.8	0.87
1992	5600	$Y = 60.1504 + 5.5556X + 0.0228X^2$	6.13	0.89	$Y = 57.1359 + 6.0866X$	6.12	0.87
1993	3438	$Y = 67.0347 + 4.0538X + 0.0826X^2$	6.17	0.89	$Y = 55.1712 + 6.0512X$	6.16	0.89
1994	5640	$Y = 63.0884 + 5.3281X + 0.0082X^2$	6.21	0.88	$Y = 61.8980 + 5.5272X$	6.20	0.88
90-94	28128	$Y = 75.0656 + 3.5055X + 0.0825X^2$	6.25	0.86	$Y = 64.0689 + 5.4351X$	6.24	0.86

Table 6. 17: Length-age relationships of male Stellate Sturgeon, south part of the Caspian Sea (Y= fork length (cm), X= age (t, years), Fig = Figures).

years	**N**	**length-age relationships & equation (M)**	**Fig**	**r**	**length-age relationships & equation (M)**	**Fig**	**r**
1990	1701	$Y = 91.3977 + 1.4220X + 0.1305X^2$	6.7	0.74	$Y = 78.8614 + 4.0227X$	6.6	0.72
1991	2271	$Y = 102.701 - 1.7358X + 0.3014X^2$	6.11	0.78	$Y = 73.6155 + 4.2722X$	6.10	0.76
1992	1277	$Y = 95.2678 + 0.9623X + 0.1265X^2$	6.15	0.65	$Y = 82.4823 + 3.5431X$	6.14	0.63
1993	767	$Y = 83.3490 + 1.5058X + 0.1641X^2$	6.19	0.82	$Y = 66.3303 + 4.8815X$	6.18	0.80
1994	1289	$Y = 94.2864 - 0.0754X + 0.2242X^2$	6.23	0.86	$Y = 70.3674 + 4.6195X$	6.22	0.84
90-94	7305	$Y = 97.1882 - 0.2100X + 0.2150X^2$	6.27	0.75	$Y = 75.8281 + 4.1376X$	6.26	0.73

For Stellate Sturgeon, a positive correlation between length and age is characteristic. Using curve-fitting procedures, the equation of best fit (higher r) was found to be the quadratic. However, quadratic curves cannot be extrapolated beyond the data points, as the relationship (as in Fig. 6.11) becomes clearly impossible. In most of years the correlation coefficients were higher in females than of males.

6. 2.7 Annual increment in length

The annual increment of the Stellate Sturgeon sturgeon caught in the southern Caspian Sea was estimated for each year of the catches. Because of high sample number of Stellate Sturgeon in each year of the catch, no program was found able to analyse the differences (ANCOVA) between slopes of length vs age of males and females. However, different statistical analysis in previous sections shows significant differences between different parameters in males and females. Therefore, annual increments have been calculated for females and males separately (Tables 6.18-6.22).

Table 6. 18: Annual increment in length of male and female Stellate Sturgeon, 1990.

age (years)	Females number	Females mean length cm	Females annual increment	Males number	Males mean length cm	Males annual increment
4				1	92.0	
5	5	101.4		6	110.5	18.5
6	31	102.3	0.9	48	104.3	-6.2
7	93	105.9	3.6	127	106.4	2.1
8	155	111.6	5.7	199	111.5	5.1
9	304	116.7	5.1	369	114.4	2.9
10	448	122.1	5.4	411	119.2	4.8
11	780	126.6	4.5	303	124.3	5.0
12	1024	131.3	4.7	138	124.2	-0.1
13	1093	135.4	4.0	63	129.8	5.6
14	789	141.0	5.7	22	136.9	7.1
15	266	148.1	7.1	10	145.7	8.8
16	74	153.6	5.5	4	155.7	10.1
17	12	152.2	-1.4			
18	6	167.8	15.6			
19	3	173.3	5.5			
20	1	172.0	-1.3	1	181.0	6.3
21						
22						
23	1	176.0	1.3			
24						
25						
26						
27	1	188.0	4.0			

Table 6. 19: Annual increment in length of male and female Stellate Sturgeon, 1991.

age (years)	Females number	Females mean length cm	Females annual increment	Males number	Males mean length cm	Males annual increment
4				2	104.5	
5	7	97.1		6	102.5	-2.0
6	70	103.2	6.0	34	104.3	1.8
7	145	105.4	2.2	138	104.9	0.6
8	237	108.6	3.2	291	108.6	3.8
9	447	111.9	3.3	418	111.5	2.9
10	841	118.0	6.1	640	114.9	3.4
11	1116	123.4	5.4	369	120.2	5.3
12	2140	128.1	4.7	269	125.3	5.1
13	1725	134.0	5.9	70	131.2	5.9
14	1110	139.8	5.8	20	138.4	7.3
15	391	146.0	6.2	8	143.9	5.4
16	92	149.8	3.8	5	164.6	20.7
17	34	160.6	10.8			
18	5	162.6	2.0			
19	1	184.0	21.4	1	118.0	-15.5

Table 6. 20: Annual increments in length of male and female Stellate Sturgeon, 1992.

age (years)	Females number	Females mean length cm	Females annual increments	Males number	Males mean length cm	Males annual increments
5	1	105.0		4	101.2	
6	6	100.7	-4.3	14	109.5	8.3
7	59	105.2	4.5	58	107.6	-1.9
8	192	106.8	1.6	225	110.7	3.0
9	302	111.4	4.5	293	115.2	4.7
10	551	117.0	5.6	260	116.3	0.9
11	941	123.8	6.8	234	120.3	4.0
12	1564	129.7	5.9	142	126.0	5.7
13	1208	136.9	7.2	31	131.8	5.8
14	508	143.5	6.6	7	142.0	10.2
15	189	149.2	5.7	3	123.0	-19.0
16	48	153.9	4.7	3	156.7	33.7
17	19	155.1	1.2			
18	6	156.0	0.9	1	117.0	-19.8
19	1	190.0	34.0	2	156.5	39.5
20	1	184.0	-6.0			
21	0.0	0.0	0.0			
22	1	128.0	-28.0			

Table 6. 21: Annual increments in length of male and female Stellate Sturgeon, 1993.

	Females			Males		
age (years)	number	mean length	annual increments	number	mean length	annual increments
6	2	112.0		3	96.7	
7	12	105.6	-6.4	16	103.0	6.3
8	48	108.6	3.0	86	106.4	3.5
9	101	110.7	2.2	133	110.2	4.0
10	300	115.0	4.3	224	113.9	3.5
11	588	120.6	5.6	182	119.8	5.9
12	929	127.2	6.6	97	126.6	6.8
13	810	134.3	7.1	18	131.6	5.1
14	449	141.4	7.2	5	134.8	3.2
15	146	147.0	5.5	1	111.0	-23.8
16	36	148.4	1.2			
17	9	151.1	2.7	2	155.5	22.2
18	5	156.8	5.9			
19	1	157.0	0.2			
20						
21	1	171.0	7.0			

Table 6. 22: Annual increments in length of male and female Stellate Sturgeon, 1994.

			Females			Males
age (years)	number	mean length cm	annual incremen	number	mean length cm	annual increment
6	3	84.0		5	103.6	
7	28	103.7	19.7	70	105.2	1.6
8	71	108.6	4.8	159	108.1	2.9
9	164	112.0	3.4	252	111.7	3.6
10	439	116.6	4.6	331	115.6	3.9
11	886	122.2	5.7	274	120.7	5.0
12	1631	128.1	5.9	130	125.7	5.0
13	1310	134.1	5.9	42	130.1	4.4
14	689	139.7	5.6	12	141.4	11.3
15	289	144.6	5.0	8	149.5	8.1
16	86	148.6	4.0	2	142.0	-7.5
17	26	154.7	6.1	3	165.3	23.3
18	4	164.0	9.3			
19	1	179.0	15.0			
20	1	176.0	-3.0			
21				1	170.0	1.2
22						
23	1	180.0	2.0			

Five years' data of catches of Stellate Sturgeon were combined and the annual increments in length calculated. From 1990 to 1994 (Table 6. 23) the greatest annual increments were observed in 10-15 year old females. In males the highest increments were observed in 14 and 16-year-old fish, averaging 7.2 and 14.2 cm. The higher increments of the females compared with males can be seen in most of the age groups, but when these differences were tested statistically with paired samples t-tests, the differences were not significant (t-value = 0.12, P>0.05). As the data in Tables 6.18-6.22 shows, the length increment fluctuates considerably from year to year and there is no regular trend in the annual increments of either sex.

Fig 5.28 show plots of mean length at age in eight cohorts (1977-1984). As the graph shows, the variations in growth rates are less than when the data are based on a year of capture. However the data in Tables 6.16 to 6.23 and graphs in Figs 6.4 to 6.27 indicate that the annual increment in length is not of the decaying exponential type but that a linear plot gives a good fit to the data.

Table 6. 23: Annual increments in length of male and female Stellate Sturgeon, (1990-1994).

age (years)	Females			Males		
	number	mean length cm	annual increment	number	mean length cm	annual increment
4				3	100.3	
5	13	99.4		16	105.2	4.8
6	112	102.4	3.1	104	104.7	-0.4
7	337	105.2	2.9	409	105.7	1.0
8	703	108.8	3.4	960	109.4	3.7
9	1318	112.8	4.0	1465	113.0	3.5
10	2581	117.9	5.1	1866	116.1	3.1
11	4312	123.4	5.6	1363	121.2	5.1
12	7289	128.8	5.3	776	125.2	4.3
13	6146	134.8	6.1	224	131.3	5.8
14	3545	140.8	6.0	66	138.6	7.2
15	1281	146.7	6.0	30	142.8	4.2
16	336	150.8	4.0	14	157.1	14.3
17	100	156.2	5.4	5	161.4	4.3
18	26	161.4	5.2	1	117.0	-44.4
19	7	175.7	14.3	3	143.7	26.7
20	3	177.3	1.6	1	181.0	37.3
21	1	171.0	-6.3	1	170.0	-11.0
22	1	128.0	-43.0			
23	2	178.0	50.0			
24						
25						
26						
27	1	188.0	2.5			

6. 2. 8 Weight-age relationships

The weight-age relationships (LogW vs age) were estimated for males and females separately and are shown in Tables 6. 24 and 6. 25 below. Figures 6.29 to 6.40 show the weight-age relationship for each year of the catch and for the combined years. The correlation coefficients (r) were high in both sexes but higher in females.

Table 6. 24: Weight-age relationships of female Stellate Sturgeon, south part of the Caspian Sea (W= total weight (kg), t = age (years), Fig = Figures).

year	number	weight-age relationships & equation	Correlation coefficient (r)	Fig
1990	5089	Log W = 0.3831 +0.0535t	0.86	6.29
1991	8361	Log W = 0.3011 + 0.0604t	0.83	6.31
1992	5600	Log W = 0.2333 + 0.0670t	0.83	6.32
1993	3438	Log W = 0.3069 + 0.0600t	0.83	6.35
1994	5640	Log W = 0.3795 + 0.0497t	0.90	6.37
90-94	28128	Log W = 0.3182 + 0.0593t	0.84	6.39

Table 6. 25: Weight-age relationships of male Stellate Sturgeon, south part of the Caspian Sea (W= total weight (kg), t = age (years), Fig = Figures).

year	number	weight-age relationships & equation	correlation coefficient (r)	Fig
1990	1701	Log W = 0 .3851 + 0.0481t	0.71	6.30
1991	2271	Log W = 0.3731 + 0.0474t	0.70	6.32
1992	1277	Log W = 0.4567 + 0.0414t	0.64	6.34
1993	767	Log W = 0.3437 + 0.0514t	0.71	6.36
1994	1289	Log W = 0.3845 + 0.0541t	0.82	6.38
90-94	7305	Log W = 0.3865 + 0.0475t	0.70	6.40

6. 2.9 Annual increments in weight

Annual increments in weight, based on catches between 1990 and 1994 are given in Tables 6.26 to 6.31). Because of the marked differences in growth for males and females, the increments are shown for the sexes separately.

Table 6. 26: Annual increment in weight of male and female Stellate Sturgeon, 1990.

	Females			Males		
age (years)	number	mean weight kg	annual increment	number	mean weight kg	annual increment
4				1	3.0	
5	5	3.8		6	5.0	2.0
6	31	4.8	1.0	48	4.8	-0.2
7	93	5.4	0.7	127	5.2	0.4
8	155	6.1	0.7	199	6.0	0.9
9	304	7.2	1.0	369	6.7	0.6
10	448	8.8	1.6	411	7.7	1.0
11	780	9.9	1.1	303	8.6	0.9
12	1024	11.1	1.2	138	9.0	0.4
13	1093	12.1	1.0	63	9.3	0.3
14	789	13.2	1.1	22	12.0	2.7
15	266	15.2	2.0	10	15.3	3.3
16	74	17.4	2.2	4	18.0	2.7
17	12	19.6	2.2	0	0.0	0.0
18	6	26.5	6.8	0	0.0	0.0
19	3	30.3	3.8	0	0.0	0.0
20	1	40.0	9.7	1	31.0	3.3
21						
22						
23	1	27.0	-4.3			
24						
25						
26						
27	1	34.0	1.7			

Table 6. 27: Annual increment in weight of male and female Stellate Sturgeon, 1991.

age (years)	Females number	Females mean weight kg	Females annual increment	Males number	Males mean weight kg	Males annual increment
4				2	4.0	
5	7	3.9		6	4.5	0.5
6	70	4.9	1.0	34	4.9	0.4
7	145	5.2	0.4	138	5.3	0.4
8	237	6.0	0.8	291	5.9	0.5
9	447	6.8	0.8	418	6.4	0.5
10	841	8.4	1.5	640	7.0	0.6
11	1116	9.6	1.2	369	7.9	0.9
12	2140	10.8	1.2	269	8.9	1.0
13	1725	12.3	1.5	70	10.5	1.6
14	1110	14.0	1.7	20	12.3	1.9
15	391	16.1	2.1	8	16.5	4.1
16	92	18.2	2.1	5	22.6	6.1
17	34	21.7	3.2			
18	5	25.6	3.9			
19	1	35.0	9.4			

Table 6. 28: Annual increment in weight of male and female Stellate Sturgeon, 1992.

age (years)	Females number	Females mean weight kg	Females annual increment	Males number	Males mean weight kg	Males annual increment
5	1	5.7		4	3.8	
6	6	4.6	-1.1	14	5.6	1.8
7	59	5.2	0.5	58	5.6	0.1
8	192	5.7	0.5	225	6.2	0.5
9	302	6.7	1.1	293	7.1	0.9
10	551	8.1	1.3	260	7.4	0.3
11	941	9.6	1.5	234	8.1	0.7
12	1564	11.1	1.5	142	9.1	1.1
13	1208	12.9	1.8	31	11.1	1.9
14	508	14.9	2.0	7	12.9	1.8
15	189	17.0	2.0	3	10.2	-2.7
16	48	19.6	2.6	3	19.5	9.4
17	19	19.8	0.2	0	0.0	0.0
18	6	21.2	1.4	1	7.0	-6.2
19	1	28.0	6.8	2	24.5	17.5
20	1	27.0	-1.0			
21						
22	1	7.0	-10.0			

Table 6. 29: Annual increment in weight of male and female Stellate Sturgeon, 1993.

age (years)	Males			Females		
	number	mean weight kg	annual increment	number	mean weight kg	annual increment
6	2	5.5		3	4.1	
7	12	5.9	0.4	16	5.2	1.1
8	48	6.5	0.6	86	6.0	0.8
9	101	7.2	0.7	133	6.6	0.7
10	300	8.1	1.0	224	7.2	0.5
11	588	9.3	1.1	182	8.0	0.9
12	929	10.7	1.4	97	9.5	1.5
13	810	12.2	1.7	18	11.6	2.1
14	449	14.4	2.0	5	12.3	0.7
15	146	16.5	2.1	1	6.3	-6.0
16	36	17.6	1.1			
17	9	19.1	1.5	2	22.4	8.1
18	5	23.3	4.3			
19	1	21.0	-2.3			
20						
21	1	28.0	3.5			

Table 6.30: Annual increment in weight of male and female Stellate Sturgeon 1994.

age (years)	Females			Males		
	number	mean weight kg	annual increment	number	mean weight kg	annual increment
6	3	5.0		5	5.2	
7	28	5.5	0.5	70	5.9	0.7
8	71	6.4	0.9	159	6.1	0.2
9	164	7.2	0.8	252	6.6	0.5
10	439	8.4	1.2	331	7.4	0.8
11	886	9.7	1.4	274	8.3	0.9
12	1631	11.0	1.3	130	9.4	1.2
13	1310	12.4	1.4	42	10.3	0.9
14	689	14.0	1.6	12	13.7	3.4
15	289	15.3	1.3	8	14.5	0.8
16	86	17.3	2.0	2	14.5	-0.0
17	26	18.2	0.9	3	24.1	9.6
18	4	23.8	5.5			
19	1	27.5	3.8			
20	1	29.0	1.5			
21				1	27.8	0.9
22						
23	1	23.0	-2.0			

The combined data for 1990-1994 are given in Table 6.31. The weight increment fluctuates considerably from year to year, masking any overall trend. The males consistently show smaller increments than the females. The differences between annual increments in weight of females and males (where $n \geq 10$) are significant (paired samples t-tests, t-value =3.04, $P<0.05$).

Table 6. 31: Annual increment in weight of male and female Stellate Sturgeon, 1990-1994.

age (years)	Females			Males		
	number	mean weight (kg)	annual increment	number	mean weight (kg)	annual increment
4				3	3.7	
5	13	4.0		16	4.5	0.8
6	112	4.9	0.9	104	4.9	0.4
7	337	5.3	0.4	409	5.4	0.5
8	703	6.0	0.7	960	6.0	0.6
9	1318	7.0	1.0	1465	6.7	0.6
10	2581	8.4	1.4	1866	7.3	0.7
11	4312	9.7	1.3	1363	8.2	0.9
12	7289	11.0	1.3	776	9.2	1.0
13	6146	12.4	1.5	224	10.5	1.3
14	3545	14.1	1.6	66	12.9	2.4
15	1281	15.9	1.9	30	14.2	1.3
16	336	17.9	2.0	14	19.7	5.5
17	100	20.0	2.1	5	23.4	3.7
18	26	24.1	4.1	1	7.0	-16.4
19	7	28.9	4.9	3	18.7	11.7
20	3	32.0	3.1	1	31.0	12.3
21	1	28.0	-4.0	1	27.8	-3.2
22	1	7.0	-21.0			
23	2	25.0	18.0			
24						
25						
26						
27	1	34.0	2.3			

Graphs of log W vs age and of length vs age (Fig 6.41 and 6.42) suggest that growth in ages greater than 5 comprises two stanzas divided at about age = 18. The sample sizes during the second stanza tend to be very small (Table 6.31). The value of the correlation coefficient for the first stanza is very high in both weight and length (0.999 and 0.996 respectively). During the first stanza the growth of the female in the largely immature stage is very high. The second stanza, in which the sample sizes were very small, might be associated with maturity.

6. 3 Discussion

6.3.1 Sex composition

The present study of the Stellate Sturgeon in the southern part of the Caspian Sea is based on data collected over five years (1990-1994). In the catches, females were predominant, e.g., females comprised about 81% and 79% and males 19% and 21.3% in the catches of 1991 and 1992, respectively. The catches from 1962 to 1982 also contained more females than males (Emadi 1989) although not with such high percentages. An excess of females was also noted by Veshchev (1979) for the Akhtuba and Volga Rivers (northern Caspian) during 1968 to 1974, and for migratory Stellate Sturgeon from the Volga (53.7-67.4%) in catches from 1960 to 1971 (Pavlov 1964, Silvka 1971). The predominance of females in the trawl catches accords with observations made from 1974 to 1978 in the whole Caspian by Pirogovskiy and Fadeyeva (1982). However, according to Veshchev and Novikova (1986), males exceeded females in the spawning grounds of the lower Volga during 1978-1983.

In the present catches of 1990-1994, the sex composition of the southern Caspian population changed with age (Table 6. 8). Males were predominant among the younger age groups, and their proportion was highest (87.9%) among 8-12 year old fish. The number of males declined in the older age groups and the proportion of females increased overall, for instance, to 80.3% in fish aged 11-15.

6.3.2 Age composition

The maximum age recorded for the Stellate Sturgeons is 35, caught between 1976 and 1978 (Pirogovskiy and Fadeyeva 1982). Among subfossil fishes from the Caspian Sea basin, a 41 year-old Stellate Sturgeon was found (Tsepkin and Sokolov 1979). An analysis of the age composition of the catches in 1990-1994 showed fish aged between four and 27 years. Fish aged 8-14 years predominated (92.2%) with twelve-year-old fish the largest single age (22.8%). Fish younger than eight and older than 14 years were represented by only 2.8% and 5% respectively. The age of the females varied between five and 27 years, of males between four and 21 years. Similar age structures were noted for the population of the Stellate Sturgeon on the spawning grounds of the Volga during 1977-1983, 9-27 for females and 7-19 for males (Veshchev and Novikova 1986). Compared with the present study, the major part (75.5%) of catches from the Volga consisted of fish 10-17 years old, with a predominance (24.1%) at ages 12 and 13. In general, the older age groups in the southern Caspian (1990-1994) contributed less than in the Volga spawning ground some years earlier (1977-1983). Markarova and Alekperov (1988) studied the age composition of the sturgeons occurring along the western shores of the south Caspian during 1982-1985, the Stellate Sturgeon showing a similar age structure to those in the present study. They noted an increase of younger age groups (10-15 years) over the years under consideration, a phenomenon which can be seen in the present work. The Stellate Sturgeon catches show that the fishery is restricted to fish aged 7 to 15 years. The age distribution of the Stellate Sturgeon changed significantly during the study period (1990 to 1994) with the percentage of older groups decreasing (Table 6.8). The mean age of females and males seemed to increase from 1990 to 1994, but the correlation coefficients were not significant (df = 3, r = 0.618, P>0.05 for females; df = 3, r = 0.8, P>0.05 for males).

6.3.3 Length composition

The differences in length beween the sexes are small, the females being longer than the males (Shubina 1967a). Stellate Sturgeon in the catches from the southern Caspian during 1990-1994 had a fork length between 82 and 213 cm (mean 126.8 cm). The majority of the fish (90%) were 110 to 150 cm long. The length composition of the Stellate Sturgeon did not change appreciably from year to year, and the largest caught in 1991 was 213 cm. The mean length of females was 129.4 cm, of males 116.7 cm. The mean length of males in the present study was higher than during 1976-1978 (112 and 111.9 cm respectively for the North Caspian and the Middle and South Caspian together)(Fadeyeva (1982). According to Pirogovskiy and Fadeyeva (1982) the mean length of the Stellate Sturgeon feeding in the northern

Caspian and in the Volga spawning grounds was higher than in the central and southern Caspian. The mean total length of females and males in the Volga ranged from 151.4 to 160.3 cm and 132.9 to 138.9 cm respectively during 1977-1983 (Veshchev and Novikova 1986), which is higher than in the present study. The higher mean length for the Volga might be related to the capture of only mature migrating fish in this area, while the catches of the southern part contain both mature and immature fish. While the minimum length for catching the Stellate Sturgeon in the southern Caspian is 93 cm (TL) and more than 87% of the present (1990-1994) catches consisting of fish larger than 115 cm of fork length, but still contained many immature fish. This suggests that minimum length of capturing should be increased to avoid the capture of immature fish.

6.3.4 Weight composition

The weight composition of females for 1990-1994 ranged from 1.2 to 109 kg, and of males from 3 to 42 kg. Among the males, fish with a total weight of 3-10 kg predominated and, among the females, fish with a total weight of 3-20 kg; the mean weight of females was 11.2 kg and of males 7.4 kg. By comparison, larger, mature fish enter the Volga (Veshchev 1979), where the mean weights of females and males were 18.9 kg and 12.1 kg respectively. In trawl catches of 1976-1978, in the whole Caspian Sea, the maximum weight of Stellate Sturgeon caught in the northern part of the sea did not exceed 18.9 kg; in the more southerly parts it was 39.2 kg (Pirogovskiy and Fadeyeva 1982). A considerably higher mean weight was found for females feeding in central and southern Caspian waters in comparison with the northern part. No major changes have occurred in the mean weight of male and female Stellate Sturgeon during the years under consideration and the weight of the fish was more stable than the mean length of the fish.

6.3.5 Annual increment in length and weight

Annual increment in length and weight of the Stellate Sturgeon in the southern Caspian for the years 1990-1994 varied irregularly. Errors in aging could be one of the reasons for this variation; environmental conditions in the sea or possibly other factors such as longevity of this species might be another reason for the fluctuations. According to Chugunov and Chugunova (1964) and Shubina (1964a) the most rapid rate of increase in the length of Stellate Sturgeon occurs during the first years of life, with the maximum rate being observed during the second year. Thereafter, the growth rate steadily decreases until sexual maturity is reached, after which the growth increments remain constant. The present study shows that growth must be rapid during the first years of life before the sturgeon enter the fishery; thereafter growth rate showed only small fluctuations between 7 and 10 years old. The early high rate of growth can be seen in growth curves (Chugunova 1940, Fig. 66) and Nikol'skii (1961). Males and females show small differences in growth apparent at 10 years old (Table 6.23), but the differences are not significant (paired samples t-test, t-value = 0.89, P>0.05). However, Shubina (1967a) noted the differences between growth rates of males and females, especially after the onset of sexually maturity.

Like the Beluga, the graph of length-at-age data is not clearly of the decaying exponential (Figs 6.4 to 6.27) type usual for most fish, with the annual increments remaining more or less the same over several years. This seems likely because of the longevity of this species (probably more than 40 years). The data thus represent little more than half the life span, with very small sample sizes of ages >18 years, and at least one-third of the potential life span (27 years onwards) being poorly represented, probably because of the high fishing pressure. Also, from the changing slope, the data suggest three distinct stanzas during the Stellate Sturgeon's life. Initially, before it enters the fishery, growth rates must be high; from about 7 to 18, in the classes that dominate the fishery, growth rates are intermediate; and from about 18 upwards they appear slower. One single von Bertalanffy equation doesnot describe the growth throughout the entire span of the life. Under these conditions it is necessary to find equations that best fit the middle stanza, for which there are most data, as for the Beluga. According to Nikol'skii (1961), the Stellate Sturgeon reaches sexual maturity at varying times in different reservoirs. In the Kura, males become sexually mature for the first time at the age of 12 to 13, females at 14 to 17; in the Volga males reach sexual maturity at nine to 12, females at 12 to 15. The present study shows the highest correlation coefficient for the second stanza (5 to 18), which includes the years before maturity (Chapter 4).

According to Chugunov and Chugunova (1964) average annual increases in length and weight of the Stellate Sturgeon are 10-13 cm and 0.5-1.2 kg during the first 10 years of life. Regional differences in growth rate of juvenile sturgeons have been studied by Altuf'ev and Romanov (1988) in the north and middle Caspian Sea and in hatchery reared sturgeon. They concluded that different growth rates exist for the same species in different environments.

Table 6. 32, shows that annual lengths of Stellate Sturgeon were higher than of Russian Sturgeon in most age groups and the differences are significant in both males and females (paired samples t-test, t-values for females and males were 14.0 and 5.9 respectively, $P<0.01$). In comparison with Persian Sturgeon in some age groups such as, 12, 13, 14, annual lengths were higher in Stellate Sturgeon. The differences between annual lengths between Stellate and Persian Sturgeons, however, are not significant (paired samples t-test, t-values were, 0.32 and 0.6 for females and males respectively, $P>0.05$).

Table 6 32. Mean length of the Persian, Russian and Stellate Sturgeons, for ages in which n>10.

Age	Persian Sturgeon		Russian Sturgeon		Stellate Sturgeon	
	Female	Male	Female	Male	Female	Male
10	118.2	119.7	112.0	112.0	117.9	116.1
11	124.4	125.4	116.8	114.6	123.4	121.2
12	127.7	129.4	121.5	118.7	128.8	125.5
13	131.3	132.0	126.1	121.0	134.9	131.3
14	139.4	137.9	131.3	126.4	140.8	138.6
15	147.3	143.5	136.7	134.4	146.7	142.8
16	153.5	150.3	142.3	140.6	150.8	157.1

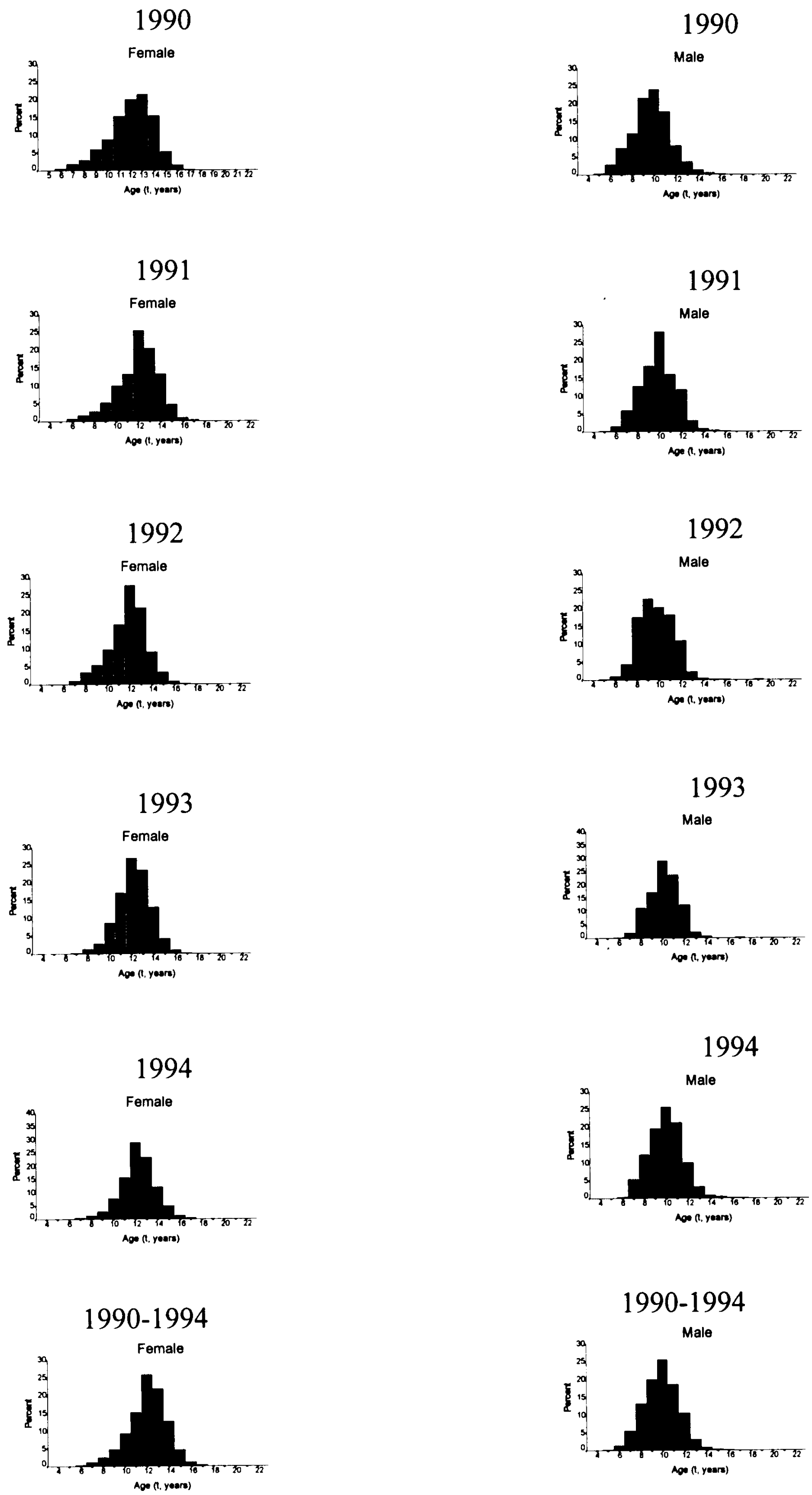
In contrast, the annual weights of Stellate Sturgeon were significantly less than in both Russian and Persian Sturgeon (Table 6. 33; paired samples t-test, t-values for female and male Persian and Stellate Sturgeons was 5.6 and 13.7 respectively, $P<0.01$; for male and female Russian and Stellate Sturgeons, t-values were 8.0 and 13.6 respectively, $P<0.01$).

Table 6 33. Mean weight (kg) of the Persian, Russian and Stellate Sturgeons, for ages in which n>10.

Age	Persian Sturgeon		Russian Sturgeon		Stellate Sturgeon	
(y)	Female	Male	Female	Male	Female	Male
10	11.1	11.5	12.1	12.5	8.4	7.3
11	13.6	13.1	14.5	13.4	9.7	8.2
12	15.7	14.9	16.8	15.0	11.0	9.2
13	17.5	16.3	19.0	16.0	12.4	10.5
14	21.3	19.0	21.4	17.6	14.1	12.9
15	25.1	21.7	24.6	21.4	15.9	14.2
16	28.6	24.5	28.0	23.5	17.9	19.7

In general it seems that between 10 and 16 the growth rate of Stellate Sturgeon is higher than of Russian Sturgeon but similar to Persian Sturgeon. The growth rate is dependent on the sex and age of the fish, and on environmental conditions in the sea.

Fig 6.1: Age distribution of female and male Stellate Sturgeon 1990-1994.



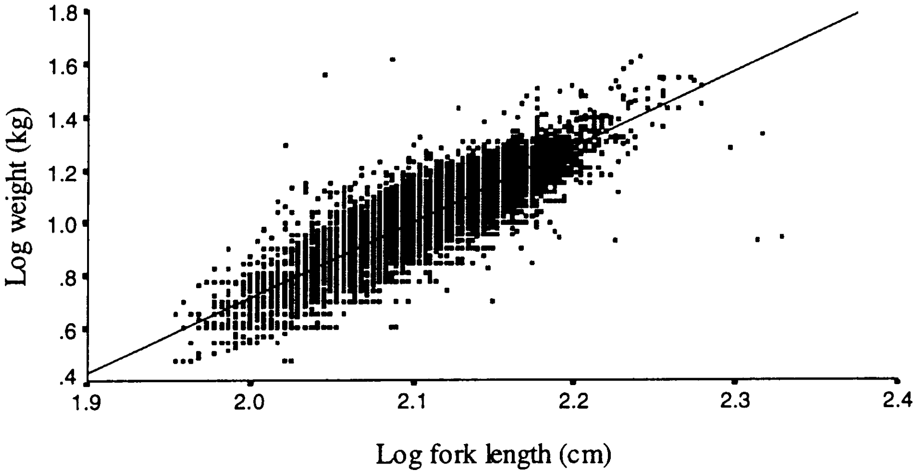


Fig 6.2: Plot of log weight vs log length of the female Stellate Sturgeon 1990-1994.

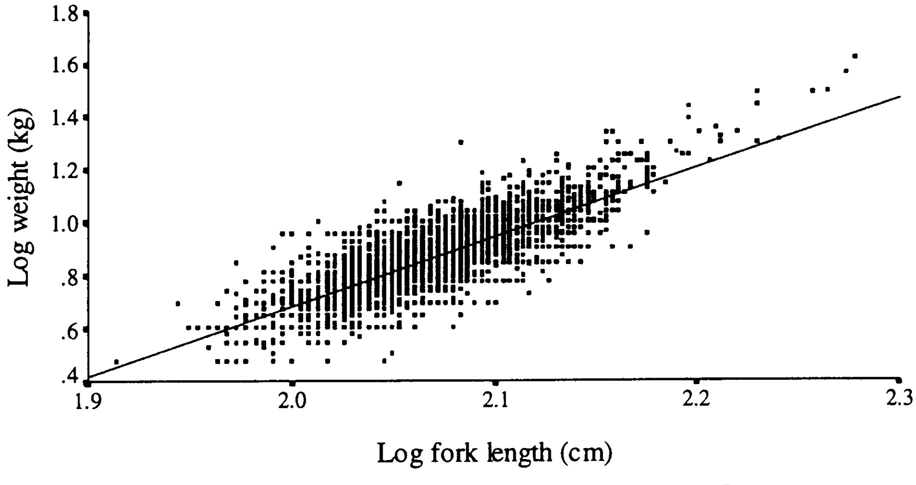


Fig 6.3: Plot of log weight vs log length of the male Stellate Sturgeon 1990-1994.

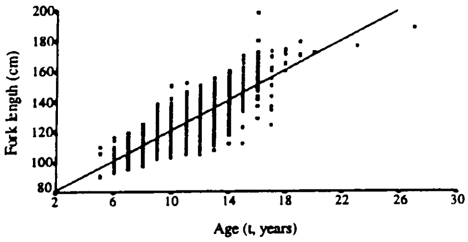


Fig 6.4: Length-age relationship of the female Stellate Sturgeon 1990 (linear plot).

Fig 6.5: Length-age relationship of the female Stellate Sturgeon 1990 (quadratic plot).

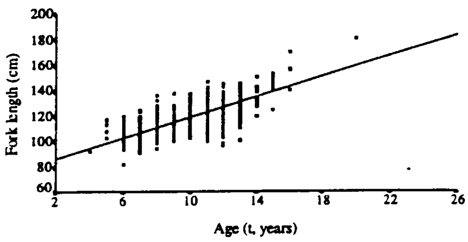


Fig 6.6: Length-age relationship of the male Stellate Sturgeon 1990 (linear plot).

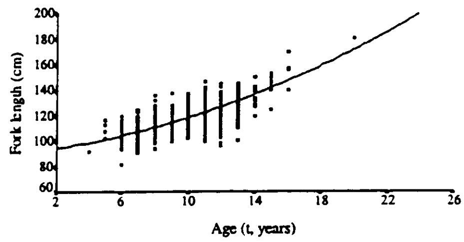


Fig 6.7: Length-age relationship of the male Stellate Sturgeon 1990 (quadratic plot).

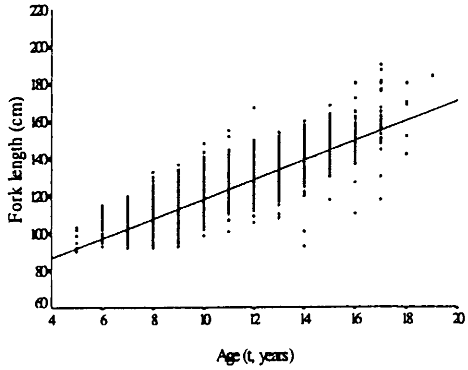


Fig 6.8: Length-age relationship of the female Stellate Sturgeon 1991 (linear plot).

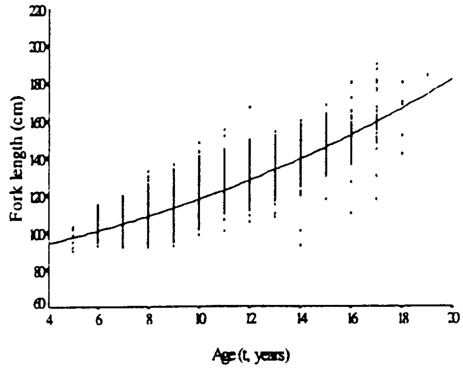


Fig 6.9: Length-age relationship of the female Stellate Sturgeon 1991 (quadratic plot)..

Fig 6.10: Length-age relationship of the male Stellate Sturgeon 1991 (linear plot).

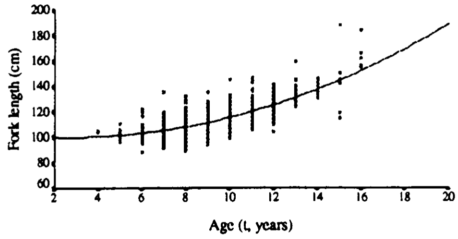


Fig 6.11: Length-age relationship of the male Stellate Sturgeon 1991 (quadratic plot).

Fig 6.12: Length-age relationship of the female Stellate Sturgeon (linear plot).

Fig 6.13: Length-age relationship of the female Stellate Sturgeon 1992 (quadratic plot).

Fig 6.14: Length-age relationship of the male Stellate Sturgeon 1992 (linear plot).

Fig 6.15: Length-age relationship of the male Stellate Sturgeon 1992 (quadratic plot).

Fig 6.16: Length-age relationship of the female Stellate Sturgeon 1993 (linear plot).

Fig 6.17: Length-age relationship of the female Stellate Sturgeon 1993 (quadratic plot).

Fig 6.18: Length-age relationship of the male Stellate Sturgeon 1993 (linear plot).

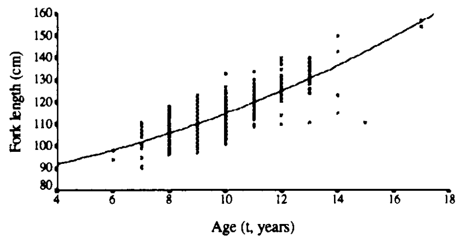


Fig 6.19: Length-age relationship of the male Stellate Sturgeon 1993 (quadratic plot)

Fig 6.20: Length-age relationship of the female Stellate Sturgeon 1994 (linear plot).

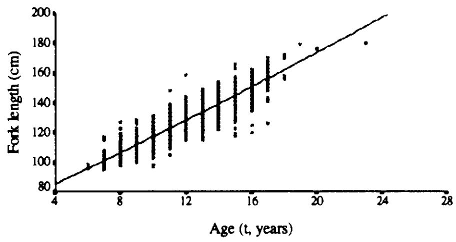


Fig 6.21: Length-age relationship of the female Stellate Sturgeon 1994 (quadratic plot).

Fig 6.22: Length-age relationship of the male Stellate Sturgeon 1994 (linear plot).

Fig 6.23: Length-age relationship of the male Stellate Sturgeon 1994 (quadratic plot).

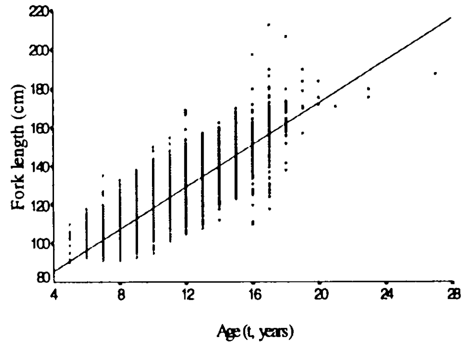


Fig 6.24: Length-age relationship of the female Stellate Sturgeon 1990-1994 (linear plot).

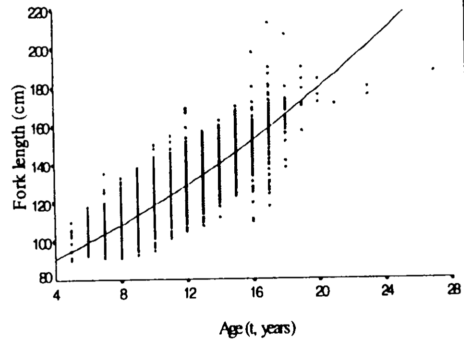


Fig 6. 25: Length-age relationship of the female Stellate Sturgeon 1990-1994 (quadratic plot).

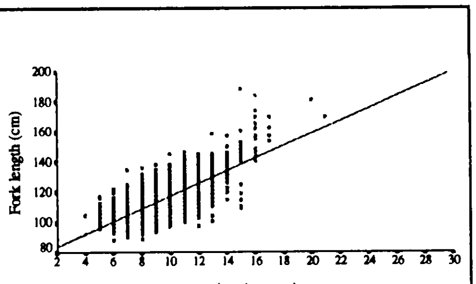


Fig 6.26: Length-age relationship of the male Stellate Sturgeon 1990-1994 (linear plot).

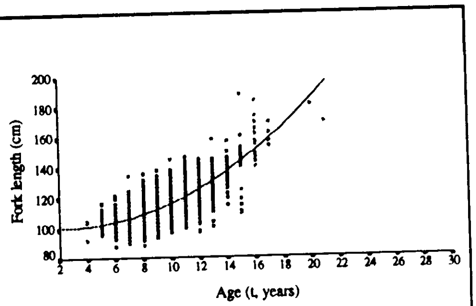


Fig 6.27: Length-age relationship of the male Stellate Sturgeon 1990-1994 (quadratic plot).

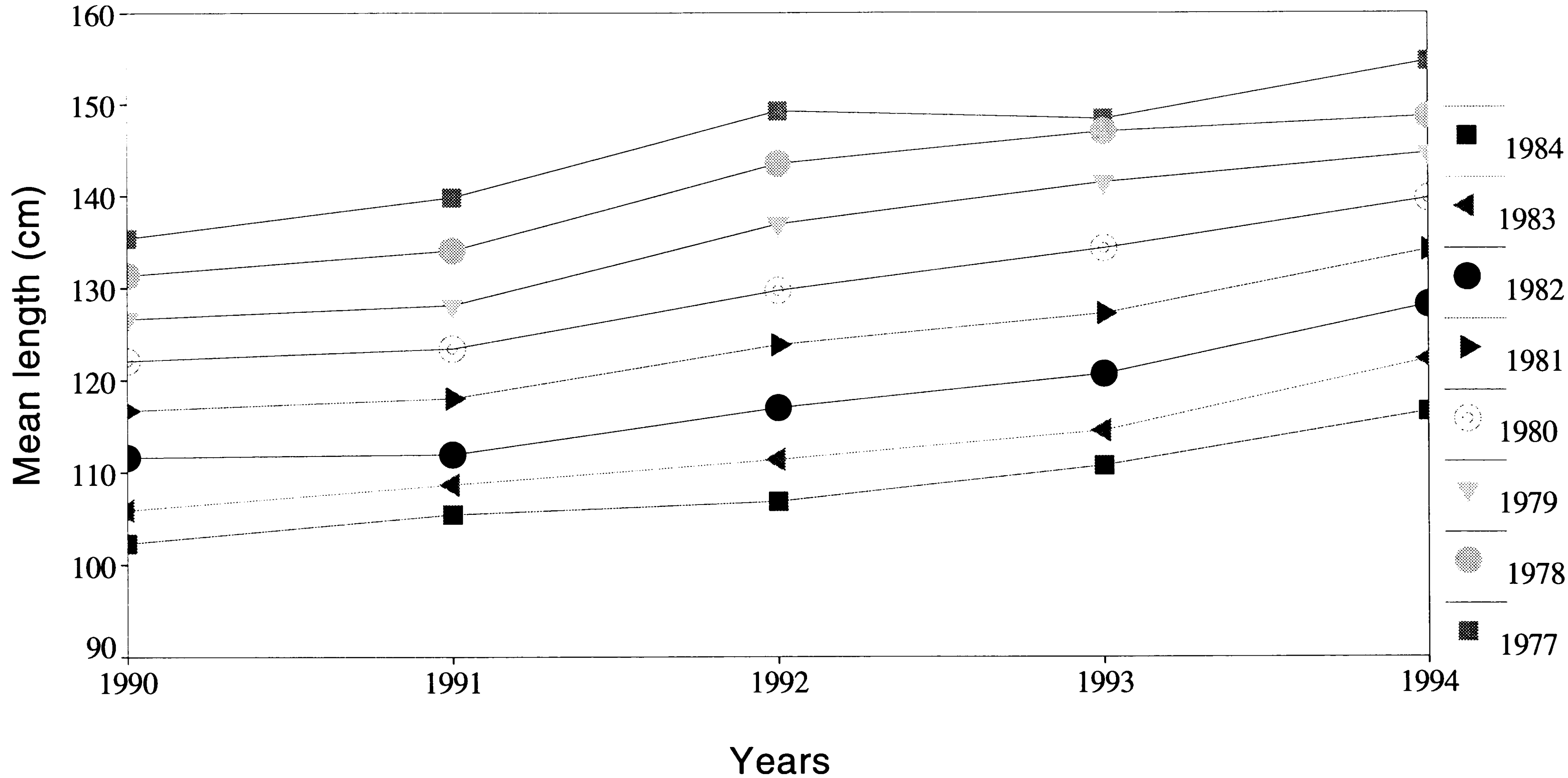


Fig 6.28: Female Stellate Sturgeon mean length at age by cohorts

Fig 6.29: Plot of log weight vs age of the female Stellate Sturgeon 1990.

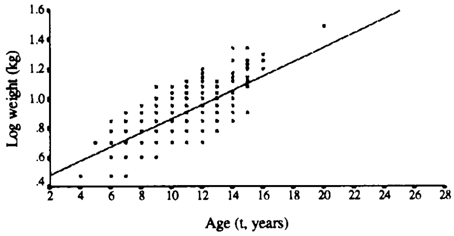


Fig 6.30: Plot of log weight vs age of the male Stellate Sturgeon 1990.

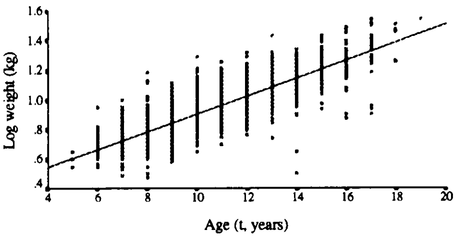


Fig 6.31: Plot of log weight vs age of the female Stellate Sturgeon 1991.

Fig 6.32: Plot of log weight vs age of the male Stellate Sturgeon 1991.

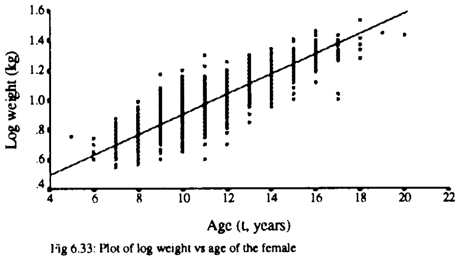


Fig 6.33: Plot of log weight vs age of the female Stellate Sturgeon 1992.

Fig 6.34: Plot of log weight vs age of the male Stellate Sturgeon 1992.

Fig 6.35: Plot of log weight vs age of the female Stellate Sturgeon 1993.

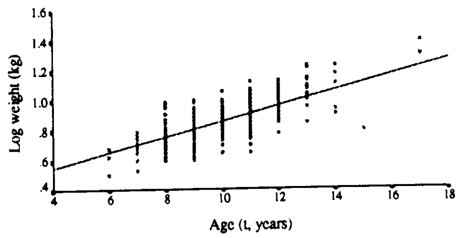


Fig 6.36: Plot of log weight vs age of the male Stellate Sturgeon 1993.

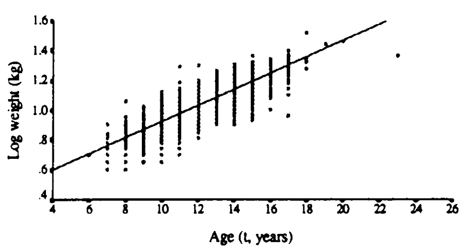


Fig 6.37: Plot of log weight vs age of the female Stellate Sturgeon 1994.

Fig 6.38: Plot of log weight vs age of the male Stellate Sturgeon 1994.

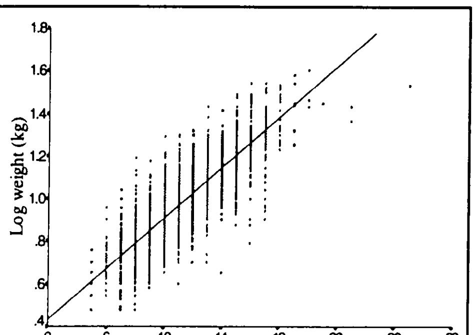


Fig 6.39: Plot of log weight vs age of the female Stellate Sturgeon 1990-1994.

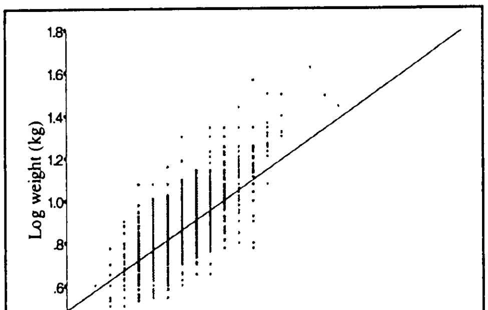


Fig 6. 40: Plot of log weight vs age of the male Stellate Sturgeon 1990-1994.

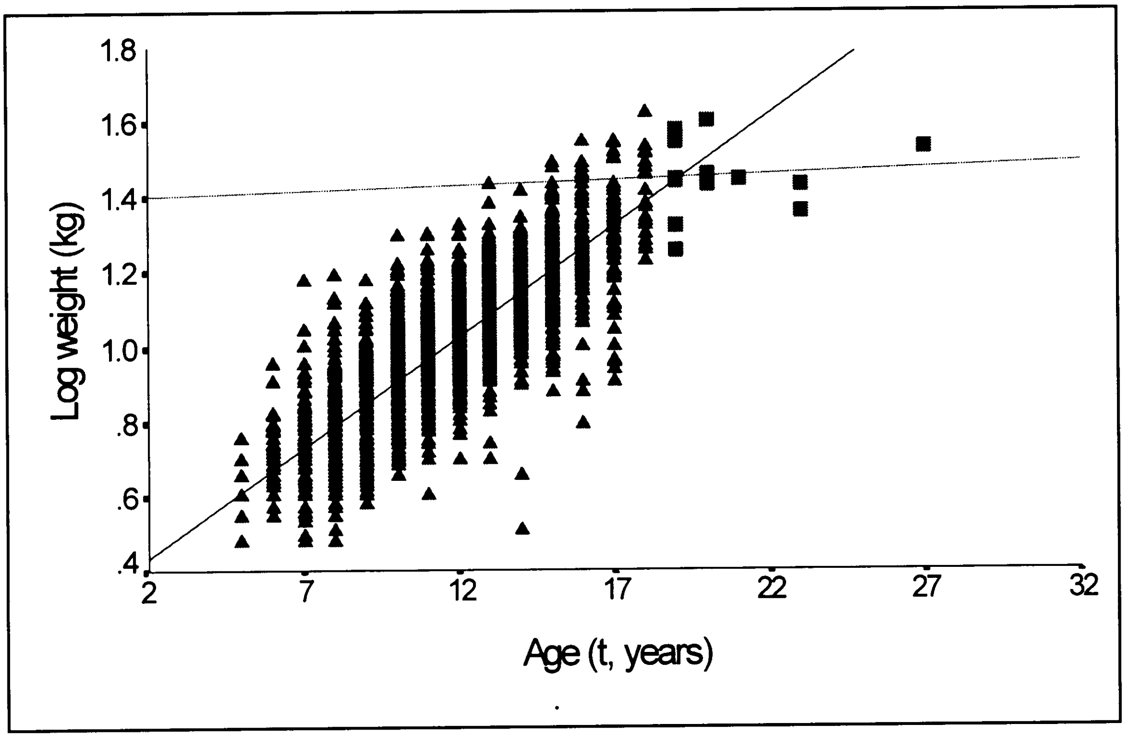


Fig 6.41: Stanzas of growth-in-weight of the female Stellate Sturgeon 1990-1994. Graph showing log growth-in-weight data regarded as stanzas rather than as a decaying exponential. The graph shows the periods from age 5 to 18 with fitted straight line (log W = 0.3163 + 0.0594t) and from 19 to 27 with another (log W = 1.3954 + 0.003t). It should be noted that the sample sizes during the second stanza tend to be very small (Table 6. 31).

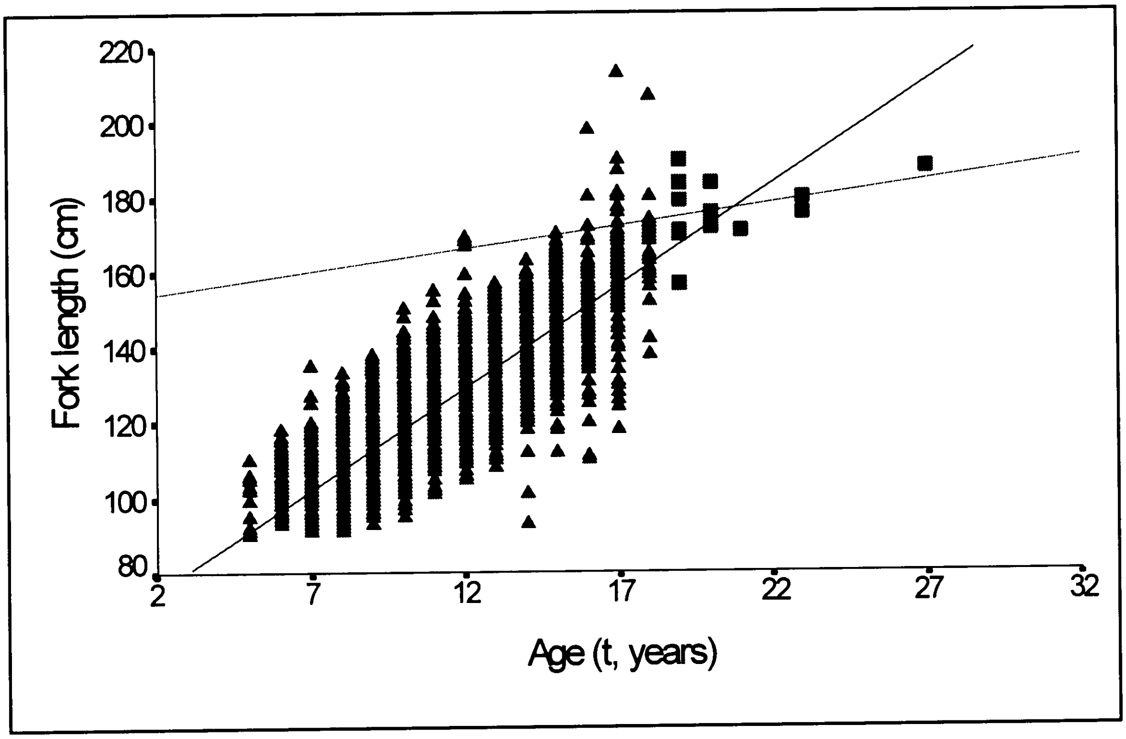


Fig 6.42: Stanzas of growth-in-length of the female Stellate Sturgeon 1990-1994. Graph showing log growth-in-length data regarded as stanzas rather than as a decaying exponential. The graph shows the periods from age 5 to 18 with fitted straight line ($L = 63.8781 + 5.4508t$) and from 19 to 27 with another ($L = 152.128 + 1.2098t$). It should be noted that the sample sizes during the second stanza tend to be very small (Table 6. 23).

CHAPTER 7

Length, weight and age relationships of the Persian Sturgeon, *Acipenser persicus*, in the Caspian Sea

7. 1 Introduction

The Persian Sturgeon is the commonest sturgeon in the catches from the southern part of the Caspian Sea. From 1972 through 1978, the catch of the Persian Sturgeon in the Kura river fluctuated between 90 and 220 tonnes (Kazancheev 1981). At the present, Persian Sturgeon make up about 25% of the annual Iranian sturgeon catches (extracted from the annual reports of the Gilan and Mazandran Province Research Centre, from 1986 to 1992). According to Saheli (1989), while the percentage of the Russian Sturgeon during the recent years in the Iranian catches decreased, the percentage of the Persian Sturgeon increased. For instance in 1972 the percentage of the Persian Sturgeon in the Iranian catches was only about 50 tonnes, which increased to about 426 tonnes in 1987 and 546 tonnes in 1988. From 1991 to 1994 every year Persian and Russian Sturgeon have supplied 38% of Iranian caviar, while Persian Sturgeon caviar comprised about 23% of this (Mr. Laloie, Deputy of Mazadran Fishery Research Centre, Pers. Com.). Now, Persian Sturgeon like Russian Sturgeon, is considered a prime candidate for artificial propagation in the Caspian Sea. The minimum length for catching the Persian Sturgeon in the Caspian Sea is 113 cm total length.

This chapter will present data on sex, age, length and weight composition, weight and age, and length and age relationships of the Persian Sturgeon in the southern part of the Caspian Sea.

7. 2 Results

7. 2. 1 Sex composition

Tables 7.1-7.5 show the mean age, mean fork length, mean total weight and proportion of the different sexes in the catch of Persian Sturgeon in the years 1990-1994, and the combined data are in Table 7.6.

Table 7. 1: Sex composition, mean age, mean length (fork length) and mean weight of the Persian Sturgeon, 1990 (n = 2188).

sex	mean age (years)	mean fork length (± SD) (cm)	mean weight (±SD) (kg)	number	percentage
Immature female	13.0	138.6 ± 23.3	19.5 ± 13.3	93	4.3%
Mature female	17.9	166.1 ± 11.8	31.4 ± 6.0	1235	56.4%
Immature male	11.3	127.8 ± 14.4	13.6 ± 5.2	107	4.9%
Mature male	13.8	140.6 ± 12.5	17.4 ± 5.1	753	34.4%
Total	16.0	154.4 ± 18.8	25.2 ± 9.4	2188	100%

Table 7. 2: Sex composition, mean age, mean fork length and mean weight of Persian Sturgeon, 1991 (n = 6507).

sex	mean age (years)	mean fork length (± SD) (cm)	mean weight (± SD) (kg)	number	percentage
Immature female	14.0	135.9± 16.3	19.0 ± 7.9	448	6.9%
Mature female	17.0	159.5 ± 11.7	32.1 ± 6.7	3275	50.6%
Immature male	12.9	130.3 ± 13.0	16.3 ± 5.6	235	3.6%
Mature male	13.9	138.1 ± 10.9	19.1 ± 4.9	2519	38.9%
Total	15.4	147.9 ± 16.3	25.2 ± 2.5	6507	100%

Table 7. 3: Sex composition, mean age, mean fork length, and mean weight of Persian Sturgeon, 1992 (n = 6041).

sex	mean age (years)	mean fork length (± SD) (cm)	mean weight (± SD) (kg)	number	percentage
Immature female	14.0	137.4 ± 13.1	19.6 ± 6.4	564	9.3%
Mature female	17.1	158.8 ± 11.7	32.4 ± 6.7	3007	49.8%
Immature male	14.2	138.1 ± 9.7	20.6 ± 4.6	632	10.5%
Mature male	14.3	139.5 ± 10.5	20.3 ± 5.0	1838	30.4%
Total	15.6	148.5 ± 15.0	26.2 ± 8.5	6041	100%

Table 7. 4: Sex composition, mean age, mean fork length and mean weight of Persian Sturgeon, 1993 (n = 2019).

sex	mean age (years)	mean fork length (± SD) (cm)	mean weight (± SD) (kg)	number	percentage
Immature female	13.9	138.4 ± 13.6	20.3 ± 6.6	153	7.6%
Mature female	16.6	156.5 ± 11.8	31.0 ± 6.9	1130	56.0%
Immature male	14.2	139.5 ± 10.8	21.3 ± 4.9	281	13.9%
Mature male	13.9	139.1 ± 10.1	19.4 ± 5.0	455	22.5%
Total	15.4	148.9 ± 14.4	26.2 ± 8.3	2019	100%

Table 7. 5: Sex composition, mean age, mean fork length and mean weight of Persian Sturgeon, 1994 (n = 3856).

sex	mean age (years)	mean fork length (± SD) (cm)	mean weight (± SD) (kg)	number	percentage
Immature females	14.4	138.7 ± 16.3	21.10 ± 8.6	238	6.2%
Mature females	16.4	155.2 ± 11.9	30.10 ± 6.9	2454	63.6%
Immature males	13.9	139.2 ± 10.2	19.90 ± 4.8	843	21.9%
Mature males	14.2	140.1 ± 9.0	20.70 ± 4.4	321	8.3%
Total	15.9	149.2 ± 13.8	26.3 ± 8.0	3856	100%

The data of the five years' catches reflect the same patterns as the individual years. Almost 60% of the catches were females. The mean age, mean fork length, and mean weight of females were all significantly higher (t-test, t-value = 83.7, 87 and 104 respectively, $P<0.01$) than of males. Overall 16.4% of the catches were immature.

Most of the mature females were older than 16 years and mature males were younger than 16 years, which suggests that the males mature earlier than females. Mean age, mean fork length and mean weight of mature males were significantly higher than immature females (t-test, t-value = 12.7, 15.1, and 6.2 respectively, $P<0.01$). From 1990 to 1994, the percentage of females shows to increase (60.7% in 1990, 69.8% in 1994) and of males to decrease (39.3% in 1990, 30.2% in 1994) but the trends are not significant (df = 3, r = 0.794, $P>0.05$ for females; df = 3, r = 0.611, $P>0.05$ for males).

Table 7. 6: Sex composition, mean age, mean fork length and mean weight of five year catches of Persian Sturgeon, 1990-1994 (n = 17378)

sex	**mean age (years)**	**mean fork length (± SD) (cm)**	**mean weight (± SD) (kg)**	**number**	**percentage**
Immature female	14.0	137.4 ± 15.7	19.8 ± 8.0	1042	7.0%
Mature female	17.1	160.0 ± 12.2	31.8 ± 6.7	9474	54.0%
Immature male	13.8	136.9 ± 11.3	19.2 ± 5.2	1680	9.5%
Mature male	14.0	139.1 ± 10.9	19.4 ± 5.0	5182	29.5%
Total	15.5	149.2 ± 16.0	25.7 ± 8.7	17378	100%

7. 2. 2 Age composition

Analysis of five years' data (Table 7. 7 below) shows that the range of ages is greater in females than in males, and that the mean age of females is also higher than of males. Usually most of the females were aged 14-19 years, whereas males were

11-16 years. Range of the age of females was seven to 39 years, while that of the males was seven to 23 years. Mean age of females was 16.8 years, and of males 14.0 years. The percentage of males was higher in younger age groups (9-15 years), while females predominated in older age groups. The percentage of older age groups of both sexes decreased year by year, for instance, 17 year old females accounted for 20.2% in 1990 while in 1994 the figure was 16.4%, and 18 year old females accounted for 22.2% in 1990, but in 1994 the total was 7.9%. In males, the percentage of 16 year olds decreased from 10.9% in 1990 to 8.5% in 1994. The mean age of females shows a decreasing trend and males increasing but, none of them were significant (df = 3, r = 0.730, P>0.05 for females; df = 3, r = 0.853, P>0.05 for males).

Table 7. 7: Age composition of Persian Sturgeon, from the south part of the Caspian Sea; 1990-1994 data combined.

	Females			Males		
age	**number**	**percentage**	**mature %**	**number**	**percentage**	**mature %**
7	2	0.0	0.0	3	0.0	0.0
8	6	0.1	16.7	15	0.2	40.0
9	29	0.3	6.9	52	0.9	42.9
10	48	0.5	7.5	124	2.0	68.2
11	67	0.7	17.1	282	4.7	78.9
12	96	1.1	24.6	530	8.8	79.2
13	230	2.6	32.0	843	13.9	73.2
14	769	8.5	61.4	1848	30.5	69.0
15	1274	14.2	86.2	1483	24.5	75.8
16	1804	20.0	94.9	647	10.7	77.6
17	1827	20.3	97.7	176	2.9	80.0
18	1227	13.6	99.1	30	0.5	77.8
19	748	8.3	98.6	10	0.2	60.0
20	344	3.8	98.1	3	0.0	50.0
21	185	2.1	99.0	1	0.0	100.0
22	136	1.5	96.6	3	0.0	0.0
23	90	1.0	98.9	1	0.0	100.0
24	38	0.4	97.7			
25	34	0.4	97.1			
26	14	0.1	92.9			
27	19	0.2	89.5			
28	9	0.1	80.0			
29	2	0.0	100.0			
30	5	0.0	80.0			
31	1	0.0	100.0			
32	2	0.0	100.0			
33	1	0.0	100.0			
34						
35						
36						
37						
38						
39	1	0.0	100.0			
mean age	**16.76**			**13.98**		

Fig 7.1 shows the age distribution of both sexes for 1990-1994. The results of Kolmogorov - Smirnov 2-sample test (Table 7.8) show that the differences between the age distributions for each year of the catch compared to the next is highly

significant in both males and females, except for females between 1991 and 1992.

Table 7.8: The results of Kolmogorov-Smirnov 2. Sample test for age distribution of male and female Persian Sturgeon (1990-1994).

years	**female**		**male**	
	number	**K-S Z**	**number**	**K-S Z**
1990-1991	1327, 2561	6.7 **	860, 2141	3.1 **
1991-1992	2561, 2555	0.6	2141, 1844	3.3 **
1992-1993	2555, 1280	2.7 **	1844, 736	3.1 **
1993-1994	1280, 2261	1.7 **	736, 1025	2.9 **

(* $P \leq 0.05$, ** $P \leq 0.01$)

The differences between mean ages for each year of the catch were examined with Tukey's T (Table 7.9). In females, significant differences were found between 1990 and 1991, 1992, 1993 and 1994; between 1991 and 1993; between 1992 and 1993; and between 1993 and 1994. For males, the mean age in 1990 was significantly different from 1991, 1992, 1993 and 1994; year 1991 different from 1992, 1993 and 1994; and year 1992 was different from 1993.

Table 7.9: Statistical analysis of mean age (Tukey's T), 1990-1994.
Females above the diagonal, males below it.

	1990 (F)	1991 (F)	1992 (F)	1993 (F)	1994 (F)
1990 (M)		n = 1327, 2561 $\bar{x}$ = 17.5, 16.6 MSD = 0.2234 *	n = 1327, 2555 $\bar{x}$ = 17.5, 16.6 MSD = 0.2235 *	n = 1327, 1280 $\bar{x}$ = 17.5, 16.3 MSD = 0.2587 *	n = 1327, 2261 $\bar{x}$ = 17.5, 16.6 MSD = 0.2284 *
1991 (M)	n = 860, 2141 $\bar{x}$ = 13.5, 13.8 MSD = 0.1789 *		n = 2561, 2555 $\bar{x}$ = 16.6, 16.6 MSD = 0.1845	n = 2561, 1280 $\bar{x}$ = 16.6, 16.3 MSD = 0.2259 *	n = 2561, 2261 $\bar{x}$ = 16.6, 16.6 MSD = 0.1905
1992 (M)	n = 860, 1844 $\bar{x}$ = 13.5, 14.2 MSD = 0.1830 *	n = 2141, 1844 $\bar{x}$ = 13.8, 14.2 MSD = 0.1408 *		n = 2555, 1280 $\bar{x}$ = 16.6, 16.3 MSD = 0.2260 *	n = 2555, 2261 $\bar{x}$ = 16.6, 16.6 MSD = 0.1905
1993 (M)	n = 860, 736 $\bar{x}$ = 13.5, 14.0 MSD = 0.2226 *	n = 2141, 736 $\bar{x}$ = 13.8, 14.0 MSD = 0.1844 *	n = 1844, 736 $\bar{x}$ = 14.2, 14.0 MSD = 0.1933 *		n = 1280, 2261 $\bar{x}$ = 16.3, 16.6 MSD = 0.2587 *
1994 (M)	n = 860, 1025 $\bar{x}$ = 13.5, 14.2 MSD = 0.2050 *	n = 2141, 1025 $\bar{x}$ = 13.8, 14.2 MSD = 0.1684 *	n = 1844, 1025 $\bar{x}$ = 14.2, 14.2 MSD = 0.1773	n = 736, 1025 $\bar{x}$ = 14.0, 14.2 MSD = 0.2141	

* $P \leq 0.05$

Note: the difference between two means is significant if

[Mean (I) - Mean (J)] $\geq$ MSD

7. 2. 3 Length composition

Fork length means (±SD) and ranges of Persian Sturgeon caught from 1990-1994 are given in Table 7.10. The range of fork lengths for all the years' data was greater in females than in males. The majority of females were 135 to 175 cm, while males were only 120 to 155 cm.

Table 7. 10: Mean length ±SD of the Persian Sturgeon, from the south part of the Caspian Sea (1990-1994).

years	Females			Males		
	number	**mean length (cm)**	**range (cm)**	**number**	**mean length (cm)**	**range (cm)**
1990	1327	164.3 ± 14.8	98-226	860	139.0 ± 13.4	102-183
1991	2561	156.5 ± 14.7	103-200	2141	137.5 ± 11.2	104-197
1992	2555	155.1 ± 14.1	108-200	1844	139.2 ± 10.4	107-179
1993	1280	154.4 ± 13.4	110-195	736	139.2 ± 10.4	108-180
1994	2261	153.7 ± 13.1	103-271	1025	139.4 ± 9.9	99-175
all years	9984	156.5 ± 14.4	98-271	6623	138.7 ± 11.0	99-197

Mean length of females decreased throughout the study period (df = 3, r = 0.873, P = 0.05), whereas the males showed no change (df = 3, r = 0.499, P>0.05). Table 7.11 shows the results of Tukey's T, for differences between the mean length of males and females for the years under study. Among females, significant differences in mean fork lengths occurred between 1990 and 1991, 1992, 1993 and 1994; between 1991 and 1992, 1993, 1994; and between 1992 and 1994. For males significant differences appeared between 1990 and 1991; and between 1991 and 1992, 1993 and 1994.

Table 7.11: Results of Tukey's T for differences between the mean length 1990-1994.

	1990 (F)	1991 (F)	1992 (F)	1993 (F)	1994 (F)
1990 (M)		n = 1327, 2561 $\bar{x}$ = 164.3, 156.5 MSD = 1.2943 *	n = 1327, 2555 $\bar{x}$ = 164.3, 155.1 MSD = 1.2948 *	n = 1327, 1280 $\bar{x}$ = 164.3, 154.4 MSD = 1.4988 *	n = 1327, 2261 $\bar{x}$ = 164.3, 153.7 MSD = 1.3232 *
1991 (M)	n = 860, 2141 $\bar{x}$ = 139.0, 137.5 MSD =1.2118 *		n = 2561, 2555 $\bar{x}$ = 156.5, 155.1 MSD = 1.0692 *	n = 2561, 1280 $\bar{x}$ = 156.5, 154.4 MSD = 1.3089 *	n = 2561, 2261 $\bar{x}$ = 156.5, 153.7 MSD=1.1034 *
1992 (M)	n = 860, 1844 $\bar{x}$ = 139.0, 139.2 MSD = 1.2395	n = 2141, 1844 $\bar{x}$ = 137.5, 139.2 MSD = 0.9537 *		n = 2555, 1280 $\bar{x}$ = 155.1, 154.4 MSD = 1.3094	n = 2555, 2261 $\bar{x}$ = 155.1, 153.7 MSD = 1.3375 *
1993 (M)	n = 860, 736 $\bar{x}$ = 139.0, 139.2 MSD = 1.5078	n = 2141, 736 $\bar{x}$ = 137.5, 139.2 MSD = 1.2833 *	n = 1844, 736 $\bar{x}$ = 139.2, 139.2 MSD = 1.3094		n = 1280, 2261 $\bar{x}$ = 154.4, 153.7 MSD= 1.3375
1994 (M)	n = 860, 1025 $\bar{x}$ = 139.0, 139.4 MSD = 1.3881	n = 2141, 1025 $\bar{x}$ = 137.5, 139.4 MSD = 1.1401 *	n = 1844, 1025 $\bar{x}$ = 139.2, 139.4 MSD = 1.1695	n = 736, 1025 $\bar{x}$ = 139.2, 139.4 MSD = 1.4508	

* $P \leq 0.05$

Note: the difference between two means is significant if

[Mean (I) - Mean (J)] ≥ MSD

7. 2. 4 Weight composition

Weight composition was calculated for each year of the catches, for each sex separately. Analysis of weight composition (Table 7. 12), shows that most of the catches consisted of fish which weighed 5-45 kg. The range of weights for females was always greater than for males. In all years most of the females weighed 15-45 kg, and the males 5-25 kg. As with mean length, mean weight of females decreased throughout the study period (df = 3, r = 0.931, P<0.05), but the males show no significant trend in mean weight (df = 3, r = 0.839, P>0.05).

Table 7.12: Mean weight (total weight) of the Persian Sturgeon, from the south part of the Caspian Sea (1990 - 1994).

years	Females			Males		
	number	mean weight kg	range kg	number	mean weight kg	range kg
1990	1327	30.6 ± 7.4	6-112	860	16.9 ± 5.2	6-46
1991	2561	30.5 ± 8.1	5.50-80	2141	18.9 ± 5.0	5-43.5
1992	2555	30.4 ± 8.1	6.5-65	1844	20.3 ± 4.9	5.5-52.5
1993	1280	29.8 ± 7.7	8.90-61	736	20.1 ± 5.0	8.70-39
1994	2261	29.2 ± 7.5	5-80	1025	20.1 ± 4.7	5-47
90-94	9984	30.2 ± 7.9	5-112	6623	19.3 ± 5.1	5-5250

The differences between the mean weight of the Persian Sturgeon for each year were examined using Tukey's T (Table 7.13). For females significant differences appeared between years 1990 and 1994; between 1991 and 1994; and 1992 and 1994. For males, the differences were significant between 1990 and 1991, 1992, 1993 and 1994; and between 1991 and 1992, 1993 and 1994.

Table 7.13: Results of Tukey's T for differences between the mean weight of the 1990-1994.

	1990 (F)	**1991 (F)**	**1992 (F)**	**1993 (F)**	**1994 (F)**
1990 (M)		n = 1327, 2561 x̄ = 30.6, 30.5 MSD = 0.7221	n = 1327, 2555 x̄ = 30.6, 30.4 MSD= 0.7224	n = 1327, 1261 x̄ = 30.6, 29.7 MSD = 0.8394	n = 1327, 2261 x̄ = 30.6, 29.1 MSD = 0.7383 *
1991 (M)	n = 860, 2141 x̄ = 16.9, 18.9 MSD = 0.5432 *		n = 2561, 2555 x̄ = 30.5, 30.4 MSD = 0.5965	n = 2561, 1261 x̄ = 30.5, 29.7 MSD = 0.7339	n = 2561, 2261 x̄ = 30.5, 29.1 MSD = 0.6156 *
1992 (M)	n = 860, 1844 x̄ = 16.9, 20.3 MSD = 0.5556 *	n = 2141, 1844 x̄ = 18.9, 20.3 MSD =0.4275 *		n = 2555, 1261 x̄ = 30.4, 29.7 MSD = 0.7342	n = 2555, 2261 x̄ = 30.4, 29.1 MSD = 0.6160 *
1993 (M)	n = 860, 735 x̄ = 16.9, 20.1 MSD = 0.6759 *	n = 2141, 735 x̄ = 18.9, 20.1 MSD = 0.5752 *	n = 1844, 735 x̄ = 20.3, 20.1 MSD = 0.5869		n = 1261, 2261 x̄ = 29.7, 29.1 MSD = 0.7498
1994 (M)	n = 860, 1025 x̄ = 16.9, 20.1 MSD = 0.6222 *	n = 2141, 1025 x̄ = 18.9, 20.1 MSD =0.4275 *	n = 1844, 1025 x̄ = 20.3, 20.1 MSD = 0.5242	n = 735, 1025 x̄ = 20.1, 20.1 MSD = 0.6503	

* P≤0.05

Note: the difference between two means is significant if

[Mean (I) - Mean (J)] ≥ MSD

7. 2. 5 Weight-length relationship

Relationships between weight and length of Persian Sturgeon were calculated for each year for males and females separately (Tables 7.14 and 7.15). Figures 7.2 and 7.3 show the weight-length (logW / logFL) relationships for all years combined. The differences between males and females are significant for both adjusted mean and slope (ANCOVA, $F = 329.9$, $P \approx 0$, $F= 3.7$, $P<0.05$)

Table 7. 14: Weight-length relationship of female Persian Sturgeon, (W = weight (kg), L = fork length (cm)).

years	number	Weight-length relationships & equation	correlation coefficient (r)
1990	1328	LogW = 2.6 (log L) - 4.21	0.89
1991	2561	LogW = 2.8 (log L) - 4.48	0.86
1992	2555	LogW = 2.8 (log L) -4.70	0.88
1993	1283	LogW = 2.8 (log L) - 4.70	0.89
1994	2274	LogW = 2.7 (log L) - 4.44	0.87
90-94	9984	LogW = 2.6 (log L) - 4.24	0.85

Table 7. 15: Weight-length relationships of male Persian Sturgeon (W = weight (kg), L = fork length (cm)).

years	number	Weight-length relationships & equation	correlation coefficient (r)
1990	860	LogW = 2.8 (log L) - 4.73	0.86
1991	2141	LogW = 2.8 (log L) - 4.73	0.83
1992	1844	LogW = 2.6 (log L) - 4.37	0.79
1993	736	LogW = 2.9 (log L) - 4.85	0.84
1994	1025	LogW = 2.8 (log L) - 4.75	0.83
90-94	6623	LogW = 2.64 (log L) - 4.64	0.81

7. 2. 6 Length-age relationship

The length at age data were analysed using linear and quadratic equations (see chapter 5). Analysis of covariance showed significant differences between males and females (e.g. in 1990, $F = 115.2$, $P<0.01$, $F = 7.1$, $P<0.01$; in 1993, $F = 103.2$, $P<0.01$, $F = 19.4$, $P<0.01$ and in 1994 $F = 223$, $P<0.01$, $F = 61.6$, $P<0.01$, for adjusted means and slopes respectively). Therefore, length-age relationships were estimated separately for males and females (Table 7.16 and 7.17).

Table 7. 16: Length-age relationship of female Persian Sturgeon, south part of the Caspian Sea (Y = fork length (cm), X = age (t, years), Fig = Figures).

years	N	quadratic equation	r	Fig	linear equation	r	Fig
1990	1328	$Y = 26.5327 + 11.1330X - 0.1828X^2$	0.85	7.5	$Y = 77.3237 + 4.9671X$	0.84	7.4
1991	2561	$Y = 10.8722 + 12.4506X - 0.2176X^2$	0.84	7.9	$Y = 73.6832 + 4.9800X$	0.81	7.8
1992	2555	$Y = -18.791 + 15.3651X - 0.2890X^2$	0.86	7.13	$Y = 57.3241 + 5.8438X$	0.84	7.12
1993	1283	$Y = -5.8538 + 14.4145X - 0.2750X^2$	0.86	7.17	$Y = 76.7251 + 4.7765X$	0.81	7.16
1994	2274	$Y = 21.2228 + 11.4065X - 0.2015X^2$	0.85	7.21	$Y = 91.7341 + 3.7233X$	0.79	7.20
90-94	9984	$Y = 2.1613 + 13.3290X - 0.2405X^2$	0.84	7.25	$Y = 75.7483 + 4.8209X$	0.81	7.24

Table 7.17: Length-age relationships of male Persian Sturgeon, south part of the Caspian Sea (Y = length (cm), X = age (t, years), Fig = Figures).

years	N	quadratic equation	r	Fig	linear equation	r	Fig
1990	860	$Y = 70.3492 + 4.8041 + 0.0212X^2$	0.85	7.7	$Y = 66.7176 + 5.3661X$	0.85	7.6
1991	2141	$Y = 84.0488 + 2.4748X + 0.0989X^2$	0.78	7.11	$Y = 66.1916 + 5.1544X$	0.78	7.10
1992	1844	$Y = 132.802 - 4.5832X + 0.3499X^2$	0.70	7.15	$Y = 66.2333 + 5.1231X$	0.70	7.14
1993	736	$Y = 58.0274 + 5.9746X - 0.0117X^2$	0.81	7.19	$Y = 60.2759 + 5.6490X$	0.81	7.18
1994	1025	$Y = 68.7444 + 4.7880X + 0.0133X^2$	0.72	7.23	$Y = 66.1468 + 5.1611X$	0.73	7.22
90-94	6623	$Y = 92.4966 + 1.3277X + 0.1389X^2$	0.76	7.27	$Y = 67.2421 + 5.1025X$	0.76	7.26

Figures 7.4 to 7.27 show the length-age relationships of the Persian Sturgeon for each year of the catch, (linear and quadratic equations). In many instances, the equation of best fit (highest r) was found to be the quadratic. However, quadratic curves cannot be extrapolated beyond the data points, as the relationship (as in Fig 7.15) becomes clearly impossible. The correlation coefficients (r) were higher in females than in males for all years.

7. 2. 7 Annual increment in length

The annual increments in length for five years' data was calculated to see if there was a trend in growth. Tables 7.18-7.22 show the annual increments for males and females separately for 1990-1994.

Table 7. 18: Annual increment in length of Persian Sturgeon from the south part of the Caspian Sea 1990.

	Females			Males		
age (years)	**number**	**mean length cm**	**annual increment**	**number**	**mean length cm**	**annual increment**
7	1	105.0		2	105.0	
8	4	107.8	2.8	7	108.9	3.9
9	12	110.6	2.8	27	115.3	6.4
10	14	124.6	14.0	32	120.4	5.1
11	11	127.5	2.9	86	126.2	5.9
12	7	136.9	9.4	124	131.0	4.8
13	16	135.2	-1.7	128	136.3	5.3
14	34	145.2	10.0	168	141.9	5.6
15	81	151.1	5.9	140	146.0	4.0
16	187	157.2	6.1	94	153.5	7.6
17	267	162.9	5.7	38	159.9	6.4
18	294	168.2	5.3	10	164.2	4.3
19	200	173.4	5.2	3	157.0	-7.2
20	86	176.3	2.9	1	183.0	26.0
21	44	179.7	3.4			
22	33	181.0	1.3			
23	20	183.2	2.2			
24	10	184.0	0.8			
25	2	189.0	5.0			
26	3	200.7	11.7			
27	1	190.0	-10.7			

Table 7. 19: Annual increment in length of Persian Sturgeon, catch from the south part of the Caspian Sea (1991).

age (years)	Females number	Females mean length cm	Females annual increment	Males number	Males mean length cm	Males annual increment
7	1	125.0				
8	1	107.0	-18.0	6	115.7	
9	14	116.6	9.6	20	113.3	-2.4
10	23	115.7	-0.9	56	119.3	6.0
11	24	122.6	6.9	123	123.8	4.5
12	30	129.8	7.2	223	128.0	4.2
13	66	131.9	2.1	326	132.0	4.0
14	207	140.4	8.5	627	138.4	6.4
15	323	147.7	7.2	471	143.0	4.7
16	546	154.2	6.6	213	149.4	6.4
17	567	160.2	6.0	62	156.1	6.8
18	353	165.4	5.2	9	165.0	8.9
19	183	171.3	6.0	1	190.0	25.0
20	93	173.1	1.8	2	187.5	-2.5
21	43	176.4	3.2			
22	39	177.5	1.2	1	180.0	-3.7
23	24	179.4	1.8	1	139.0	-41.0
24	9	182.9	3.5			
25	5	169.0	-13.9			
26	3	189.0	20.0			
27	5	168.8	-20.2			
28						
29						
30	1	200.0	10.4			
31						
32						
33						
34						
35	1	200.0	0.0			

Table 7. 20: Annual increment in length (fork length) of Persian Sturgeon, south part of the Caspian 1992.

age (years)	Females			Males		
	number	mean length cm	annual increment	number	mean length cm	annual increment
8				1	104.0	
9	1	121.0		3	121.7	17.7
10	8	115.0	-6.0	27	120.8	-0.9
11	22	125.1	10.1	40	126.6	5.8
12	37	126.5	1.5	124	130.2	3.7
13	90	130.8	4.3	260	131.3	1.1
14	221	138.0	7.2	539	136.9	5.6
15	351	145.9	7.9	561	142.8	5.9
16	515	152.2	6.2	233	149.6	6.8
17	549	159.1	6.9	50	157.2	7.7
18	368	165.5	6.4	5	162.4	5.2
19	212	170.3	4.9			
20	86	173.5	3.2			
21	51	177.9	4.4			
22	25	175.2	-2.7	1	179.0	4.2
23	13	176.5	1.3			
24						
25	2	163.0	-6.7			
26						
28	2	168.0	2.5			
29	1	181.0	13.0			
30	1	183.0	2.0			

Table 7. 21: Annual increment in length (fork length) of Persian Sturgeon from the southern Caspian Sea 1993.

	Females			Males		
age (years)	**number**	**mean length cm**	**annual increment**	**number**	**mean length cm**	**annual increment**
9				4	116.5	
10	6	118.3		5	115.2	-1.3
11	15	122.1	3.7	24	122.3	7.1
12	21	126.9	4.8	77	127.3	5.1
13	47	132.9	6.0	137	134.0	6.7
14	161	141.1	8.2	249	139.1	5.2
15	202	147.7	6.6	139	145.8	6.6
16	290	155.1	7.4	68	150.5	4.7
17	243	160.5	5.4	25	155.8	5.3
18	137	165.0	4.5	6	159.7	3.8
19	86	169.2	4.2	1	165.0	5.3
20	31	169.6	0.4	1	174.0	9.0
21	9	178.6	9.0			
22	14	173.9	-4.6			
23	3	178.0	4.1			
24	5	171.6	-6.4			
25	4	178.5	6.9			
26	1	188.0	9.5			
27	2	182.0	-6.0			
28	1	185.0	3.0			
29						
30	1	180.0	-2.5			
31						
32						
33	1	189.0	3.0			

Table 7. 22: Annual increments in length (fork length) of Persian Sturgeon, south part of the Caspian Sea (1994).

	Females			Males		
age (years)	number	mean length cm	annual increment	number	mean length cm	annual increment
7				1	104.0	
8	1	115.0		1	127.0	23.0
9	2	106.5	-8.5	2	112.0	-15.0
10	3	116.0	9.5	9	116.3	4.3
11	10	123.8	7.8	30	128.2	11.9
12	19	130.9	7.1	54	130.3	2.1
13	47	130.7	-0.2	104	129.2	-1.1
14	290	139.1	8.4	458	137.4	8.1
15	466	147.5	8.5	241	145.5	8.2
16	494	152.9	5.4	87	151.2	5.7
17	371	158.1	5.1	25	155.0	3.8
18	178	162.3	4.3	6	156.2	1.2
19	122	165.4	3.1	5	150.0	-6.2
20	70	168.2	2.8	1	148.0	-2.0
21	45	169.9	1.7			
22	38	172.9	3.0	1	171.0	11.5
23	33	173.0	0.1			
24	19	175.7	2.7			
25	21	176.8	1.1			
26	7	175.9	1.0			
27	11	177.6	1.8			
28	7	185.1	7.5			
29	1	182.0	-3.1			
30	2	175.5	-6.5			
31	1	194.0	18.5			
32	2	195.0	1.0			

For the combined years 1990 to 1994 (Table 7. 23) annual increments differed and fluctuated from year to year. For females the greatest increments can be seen in 11, 14 to 19, 26 and 28 year old fish. In males annual increments were highest in fish of 14 to 18 years, but no male fish above 22 years old were captured. The differences between the annual increments in length of males and females (from 9-19 years old, where the number is high) were tested, using paired samples t-tests, and it was found that the differences were not significant ($t = 1.2$, $P>0.05$).

Table 7. 23: Annual increment in length (fork length) of Persian Sturgeon (1990-1994).

	Females			Males		
age (years)	**number**	**mean length cm**	**annual increment**	**number**	**mean length cm**	**annual increment**
7	2	115.0		3	104.6	
8	6	108.8	-6.2	15	112.4	7.8
9	29	113.6	4.7	52	114.7	2.3
10	48	118.2	4.6	124	119.7	4.9
11	67	124.4	6.2	282	125.4	5.7
12	96	127.7	3.3	530	129.4	4.0
13	230	131.3	3.6	843	132.0	2.6
14	769	139.4	8.1	1847	137.9	5.9
15	1274	147.3	7.9	1482	143.5	5.7
16	1804	153.5	6.2	647	150.3	6.8
17	1827	160.3	6.8	176	157.0	6.7
18	1227	165.6	5.4	30	162.5	5.5
19	748	170.6	5.0	10	157.7	-4.8
20	344	173.0	2.4	3	174.3	16.6
21	185	176.0	3.0	1	183.0	8.7
22	136	176.6	0.6	3	176.6	-6.3
23	90	177.5	0.9	1	139.0	-37.7
24	38	179.6	2.1			
25	31	175.4	-4.2			
26	13	184.6	9.2			
27	18	176.3	-8.3			
28	9	181.3	5.0			
29	2	181.5	0.2			
30	4	183.5	2.0			
31	1	194.0	10.0			
32	2	195.0	1.0			
33						
34						
35	1	200.0	1.3			
36						
37						
38						
39	1	202.0	0.5			

Fig 7.28 shows plots of mean length at age in ten cohorts (1971-1980) followed through the years 1990-1994. The graph shows some variation in growth in

same cohorts but not as much as in the Beluga. The data in Tables 7.16 to 7.23 and graphs 7.4 to 7.27 indicate that the annual increments in length fluctuate rather than decreasing annually in a regular manner, and that a linear plot tends to give a good fit to the data.

There were no significant differences between annual mean lengths (Table 7.23) of males and females from ages 9-14 years (paired samples t-test, t-value = 2.0, $P>0.05$). However from age 15 years the annual means are significantly higher for females than for males (ages 15-19, paired samples t-test, $t = 2.8$, $P<0.05$).

7. 2. 6 Weight - age relationship

The relationships between weight and age (Log w/age) of Persian Sturgeon are given in Tables 7.24 and 7.25. The results of ANCOVA show significant differences between females and males (for means, $F = 576.8$, $P<0.01$; for slopes $F = 187.8$, $P<0.01$), therefore, data for sexes have been analysed separately.

Table 7.24: Weight-age relationship of female Persian Sturgeon (W = weight (kg), X = age (t, years), Fig = figures).

year	number	Weight-age relationships & equation	r	Fig
1990	1328	Log W = 0.7635 + 0.0404X	0.81	7.29
1991	2561	Log W = 0.7184 + 0.0450X	0.81	7.31
1992	2555	Log W = 0.6359 + 0.0501X	0.83	7.32
1993	1283	Log W = 0.7412 + 0.0440X	0.82	7.35
1994	2274	Log W = 0.9026 + 0.0329X	0.78	7.37
90-94	9984	Log W = 0.7746 + 0.0411X	0.80	7.39

Table 7. 25: Weight-age relationships of male Persian Sturgeon (W = weight (kg), X = age (t, years), Fig = Figures).

year	number	Weight-age relationships & equation	r	Fig
1990	860	Log W = 0.5044 + 0.0522X	0.81	7.30
1991	2141	Log W = 0.4584 + 0.580X	0.82	7.32
1992	1844	Log W = 0.5869 + 0.0497X	0.64	7.34
1993	736	Log W = 0.4462 + 0.0603X	0.81	7.36
1994	1025	Log W = 0.4921 + 0.0562X	0.74	7.38
90-94	6623	Log W = 0.4886 + 0.0558X	0.77	7.40

Figs 7.29 to 7.40 show the logarithmic plots of weight at age data for each year of the catch. In most of the years the correlation coefficients were higher in females than in males. The logarithmic plots are of specific growth rate, which should

decline during growth but rarely appear to do so, although such a trend is apparent for the combined years' data for females (Fig 7.41).

7. 2. 8 Annual increment in weight

Annual increments in weight were calculated for male and female Persian Sturgeon separately and are presented in Tables 7.26-7.30.

Table 7. 26: Annual increment in weight of Persian Sturgeon, south part of the Caspian Sea (1990).

	Females			Males		
age (years)	**number**	**mean weight kg**	**annual increment (kg)**	**number**	**mean weight kg**	**annual increment (kg)**
7	1	11.0		2	7.0	
8	4	8.3	-2.8	7	7.7	0.7
9	12	9.1	0.8	27	9.2	1.5
10	14	11.8	2.7	32	10.6	1.4
11	11	12.6	0.9	86	12.3	1.7
12	7	15.4	2.8	124	14.0	1.7
13	16	18.6	3.1	128	15.7	1.7
14	34	23.5	4.9	168	17.6	1.8
15	81	24.5	1.0	140	19.4	1.9
16	187	27.4	2.9	94	21.9	2.5
17	267	29.8	2.4	38	25.1	3.1
18	294	31.8	2.0	10	27.9	2.9
19	200	34.1	2.3	3	27.0	-0.9
20	86	36.5	2.4	0	0.0	0.0
21	44	38.2	1.6	1	46.0	9.5
22	33	40.4	2.2			
23	20	39.5	-0.9			
24	10	41.2	1.7			
25	2	42.5	1.3			
26	3	65.3	22.8			
27	1	44.0	-21.3			

Table 7. 27: Annual increment in weight of the Persian Sturgeon, south part of the Caspian Sea (1991).

age (years)	Females number	Females mean weight kg	Females annual increment (kg)	Males number	Males mean weight kg	Males annual increment (kg)
7	1	10.0				
8	1	9.0	-1.0	6	10.6	
9	14	14.3	5.3	20	8.8	-1.8
10	23	10.8	-3.5	56	11.4	2.5
11	24	13.7	2.9	123	12.9	1.6
12	30	16.2	2.5	223	14.3	1.4
13	66	18.4	2.1	326	16.3	2.1
14	207	22.0	3.6	627	19.0	2.7
15	323	25.2	3.2	471	21.7	2.7
16	546	28.8	3.6	213	24.8	3.1
17	567	31.9	3.1	62	27.5	2.7
18	353	35.4	3.4	9	31.0	3.5
19	183	38.4	3.0	1	40.0	9.0
20	93	41.0	2.6	2	42.8	2.8
21	43	42.3	1.3			
22	39	41.7	-0.1	1	43.0	0.1
23	24	45.0	3.3	1	23.0	-20.0
24	9	43.6	-1.4			
25	5	40.7	-2.9			
26	3	55.7	15.1			
27	5	57.4	1.7			
28						
29						
30	1	66.0	2.9			
31						
32						
33						
34						
35	1	80.0	2.8			

Table 7. 28: Annual increment in weight of Persian Sturgeon, south part of the Caspian Sea (1992).

	Females			Males		
age (years)	**number**	**mean weight kg**	**annual increment (kg)**	**number**	**mean weight kg**	**annual increment (kg)**
8				1	8.0	
9	1	12.4		3	10.2	2.2
10	8	10.5	-1.9	27	13.1	2.9
11	22	14.2	3.7	40	14.4	1.3
12	37	15.2	1.0	124	16.7	2.3
13	90	17.1	1.9	260	17.0	0.3
14	221	20.5	3.4	539	19.3	2.3
15	351	25.1	4.6	561	21.8	2.5
16	515	28.9	3.8	233	25.0	3.2
17	549	32.6	3.7	50	28.0	3.0
18	368	35.9	3.3	5	29.6	1.6
19	212	38.8	2.9			
20	86	41.4	2.6			
21	51	43.3	1.9			
22	25	43.9	6.0	1	41.0	2.9
23	13	44.9	1.0			
24						
25	2	37.5	-3.7			
28	2	52.0	14.5			
29	1	52.2	0.2			
30	1	50.8	-1.4			

Table 7. 29 Annual increment in weight of Persian Sturgeon, south part of the Caspian Sea 1993.

	Females			Males		
age (years)	number	mean weight kg	annual increment kg	number	mean weight kg	annual increment kg
9				4	10.6	
10	6	11.8		5	10.7	0.2
11	15	12.6	0.9	24	12.8	2.1
12	21	15.0	2.3	77	14.6	1.9
13	47	18.0	3.1	137	17.4	2.8
14	161	22.2	4.2	249	19.9	2.5
15	202	25.7	3.5	139	22.7	2.8
16	290	29.5	3.8	68	25.6	2.9
17	243	32.9	3.4	25	29.0	3.4
18	137	36.4	3.5	6	35.3	6.3
19	86	38.7	2.3	1	33.8	-1.5
20	31	39.3	0.6	1	35.0	1.2
21	9	44.7	5.4			
22	14	43.9	-0.8			
23	3	41.8	-2.2			
24	5	41.3	-0.5			
25	4	44.1	2.8			
26	1	52.0	7.9			
27	2	51.5	-0.5			
28	1	59.0	7.5			
29						
30	1	50.0	-4.5			
31						
32						
33	1	52.0	0.7			

Table 7. 30: Annual increment in weight of Persian Sturgeon, south part of the Caspian Sea (1994).

	Females			Males		
age (years)	number	mean weight kg	annual increment kg	number	mean weight kg	annual increment kg
7				1	5.0	
8	1	8.2		1	11.5	6.5
9	2	5.5	-2.7	2	8.6	-2.9
10	3	12.2	6.7	9	11.2	2.6
11	10	13.1	0.8	30	14.1	2.9
12	19	16.3	3.3	54	15.2	1.1
13	47	17.4	1.0	104	15.5	0.3
14	290	21.3	3.9	458	19.2	3.7
15	466	25.2	4.0	241	22.7	3.5
16	494	28.5	3.3	87	25.6	2.9
17	371	31.2	2.7	25	28.9	3.3
18	178	33.8	2.5	6	26.0	-2.9
19	122	35.9	2.2	5	23.8	-2.2
20	70	37.1	1.1	1	27.5	3.7
21	45	39.6	2.5			
22	38	41.4	1.8	1	43.0	7.8
23	33	42.1	0.7			
24	19	41.5	-0.6			
25	21	41.2	-0.4			
26	7	41.6	0.4			
27	11	48.3	6.7			
28	7	58.8	10.5			
29	1	54.0	-4.8			
30	2	41.0	-13.0			
31	1	54.0	13.0			
32	2	55.5	1.5			

Five years' data were combined for estimating and comparing the annual increments in weight. The data (Table 7. 31) show variation in both males and females. In 26 (n=13) and 28 year females (n=9) the increments were high, averaging 9.2 and 6.6 kg. For males the greatest increments were in 14-17 years old fish. In most of the age groups (in which the number of fish is high) the annual increment in weight is higher in females than in males. The differences for age groups 9-19 (where

$n \geq 10$) were found to be significant (paired samples t-test, $t = 3.5$, $P<0.01$). However in some younger age groups the increments of males were higher than of females. In females the greatest increments were found mostly in 14 and 15-year-old fish. The trend of annual increments in weight of males generally stabilized between 14 and 17 years. The older age groups (above 21 years) occurred only in small numbers, therefore estimating and making judgments on these was difficult.

Table 7. 31: Annual increment in weight of Persian Sturgeon, Caspian Sea (1990-1994).

	Females			Males		
age (years)	**number**	**mean weight kg**	**annual increment kg**	**number**	**mean weight kg**	**annual increment kg**
7	2	10.5		3	6.3	
8	6	8.4	-2.1	15	9.1	2.8
9	29	11.5	3.1	52	9.1	-0.1
10	48	11.1	-0.3	124	11.5	2.4
11	67	13.6	2.5	282	13.1	1.5
12	96	15.7	2.0	530	14.9	1.8
13	230	17.5	1.9	843	16.3	1.5
14	769	21.3	3.8	1847	19.0	2.7
15	1274	25.1	3.8	1482	21.7	2.7
16	1804	28.6	3.5	647	24.5	2.9
17	1827	31.7	3.1	176	27.3	2.8
18	1227	34.7	3.0	30	28.7	1.4
19	748	37.0	2.3	10	27.0	-1.7
20	344	39.2	2.2	3	37.7	10.7
21	185	41.0	1.8	1	46.0	8.3
22	136	41.7	0.7	3	42.3	-3.7
23	90	42.7	1.0	1	23.0	-19.3
24	38	41.9	-0.8			
25	31	41.1	-0.8			
26	13	50.3	9.2			
27	18	50.7	0.4			
28	9	57.3	6.6			
29	2	53.1	-4.2			
30	4	49.7	-3.4			
31	1	54.0	4.3			
32	2	55.5	1.5			
33						
34						
35	1	80.0	8.2			
36						
37						
38						
39	1	69.5	2.6			

Examination of the growth in weight graphs of the Persian Sturgeon (Figs 7.29-7.40) suggests a rather sudden, rather than gradual decline in rate, or that there are two different growth rates after recruitment to the fishery. A single von

Bertalanffy equation, derived by standard methods (see Chapter 9) does not fit the data well. Figures 7.41 illustrates these two stanzas (with the regression equations), which can be seen, through less clearly, in the graphs of growth in length (Fig 7.42). Inspection indicates that the inflection between two stanzas occurs at about t = 22 years, which is about the age of second maturity in females. The correlation coefficients for the first stanzas of weight and length were 0.986 and 0.987 respectively. However the values tended to be lower for the second stanza (0.867 and 0.901 for weight and length respectively) where sample sizes were small. The first stanza indicates the growth of the female in the largely immature stage, which as expected is very high, and the second stanza, which shows a lower growth, accords with higher incidence of maturity.

7. 3 Discussion

7. 3. 1 Sex composition

Five years catches of the Persian Sturgeon (*Acipenser persicus*) from the southern part of the Caspian Sea show a predominance of females. An increasing proportion of females was recorded in the catches of 1962 to 1989 in the southern part of the Caspian Sea (Emadi 1989) no percentage were given. The proportion of female Persian Sturgeon in the catches of 1987-1988 of the southern Caspian was 66% (Saheli, 1989). In the present study the proportion of females increased from 60.6% in 1990 to 68.5 % in 1994. Persian Sturgeon in the Kura River mature for the first time between 8 and 13 years old (Markarova and Alekperov, 1988). According to

Saheli (1989), Persian Sturgeon in the southern Caspian Sea mature at 10 to 15 years, males earlier than females. In the Volga and Ural Rivers, maturity is reached a little later; at 15 for the males and 18 for the females. In the Black Sea watershed, the males in the Rioni River become sexually ripe between 8 and 12 years, while the females mature between the ages of 13 and 15 years (Marti, 1940). The mean age of the immature females in the present study (1990-1994) varied between 13.0 and 14.4. For the males these figures were from 11.3 to 14.2 years, confirming that the males mature earlier than females but before 10 years old. The percentages of mature fish are shown in Table 7.7. The mean age of mature females varied between 16.4 and 17.1 but the earliest age recorded in the present study is 8 years.

7. 3. 2 Age composition

In this study, the Persian Sturgeon is represented by fish 7 to 39 years old, but the majority (85.7%) are 13 -19 years old. Maximum age was 39 years. The maximum recorded age of a Persian Sturgeon in the Kura is 48 years (Babushkin and Borzenko, 1951), and for the Volga 38 years (Putilina 1981). Sturgeon 20-25 years old account for only 5.3%, of the catch and older ones were rarely found. The different years, show nearly the same age range, but the distribution of ages was significantly different (see Table 7.8, Kolmogorov-Smirnov 2-sample test, and Fig 7.1) and a slight tendency was noted for the population to become younger (1990-1994); for example, the percentage of 18 year old Persian Sturgeon in 1990 was 13.9%, which decreased to 5.6% in 1994, and the percentage of 19 year olds was 9.3%

in 1990, which decreased to 3.8% in 1994. The same changes were observed in the older age groups, which probably indicates overfishing.

Markarova and Alekperov (1988) studied the age composition of Acipenseridae along the western shores of the south Caspian from 1982-1985. They observed nearly the same age range as now, from 8 to 33 years old, but the percentage of older (18-23) age group was higher in 1983. In the present study no appreciable changes were observed in the percentage of age groups younger than 12 years. An appreciable change was noted in the percentage of 14-year old fish, up from 9.2% in 1990 to 22.7% by 1994. Mean age of both females and females showed no significant change during the present study. According to Babushkin and Borzenko (1951), the ages of Persian Sturgeon captured in the main southern Caspian fishing sites were 7 to 48 years. Over 70% of the males in the catch were 13 to 24 years old, and 66% of the females were 19 to 30 years.

Expeditions from 1932 to 1938 obtained specimens of Persian Sturgeon from Iranian waters. The spawning migrations in the Sefid-Rud River included individuals from 7 to 48 years old. Among these, 75% of the males were 13 to 24 years old, while 61% of the females were in the 14 to 38 year age groups (Rostami 1961). Comparison between this period and the present demonstrates that the population of Persian Sturgeon in the southern part of the Caspian Sea is becoming younger, with most of the catch now comprising fish less than 18 years old.

Persian Sturgeon caught in the Volga River in 1980, were 19 through 38 years old Putilina (1981). The average age of the females was 26.6, and of males 23.3

years, both higher than in the present study. Comparing Persian Sturgeon and Russian Sturgeon, a similar age structure can be detected for both species in the south part of the Caspian Sea, but according to Putilina (1981) Persian Sturgeon in the Volga are represented by groups of older fishes than Russian Sturgeon.

7. 3. 3 Length composition

The maximum length recorded for Persian Sturgeon in the Caspian region is 231 to 242 cm (Rostami, 1961), but the present study includes one female of 271 cm. The mean length of the entire catch was 149.3 cm. The length of the females varied from 98 to 271 cm, and of males from 99 to 197 cm. Mean fork length decreased throughout the study period for females ($P = 0.05$), while for the males means are more or less constant ($P>0.05$). The mean lengths of females, but not males, in the present study are higher than calculated by Markarova and Alekperov (1988) along the western shores of the Caspian Sea and in the Kura River. For example, the mean total lengths of the Persian Sturgeon for 1990 were 182.4 cm (females) and 154.3 cm (males), whereas in the Kura River for 1984, these were 167.2 and 154.2 cm and for the western shores 170.8 and 153.6 cm. A comparison of the five years' catches in the southern Caspian Sea shows that most of the catches consist of females of 135 to 175 cm, whereas the males range from 120 to 155 cm. The minimum length for catching the Persian Sturgeon in the southern Caspian is 113 cm (total length) but most of the mature females (82.6%) and males (70%) in the present study were larger than 130 cm, this suggests that to avoid capturing immature fish the mesh size should be increased.

7. 3. 4 Weight composition

Weight of Persian Sturgeon in the southern part of the Caspian Sea for the period 1990 to 1994 ranged between five and 112 kg in females and five to 52.5 kg in males. Annual mean weight of females varied between 29.2 and 30.6 kg, and of males from 16.9 to 20.1 kg. Average weight of the Persian Sturgeon for the catches between 1962 and 1987, for different districts in the southern part of the Caspian Sea combined, was 15.3 kg to 18.5 kg (Emadi, 1989). Comparing the present study with 1962 - 1987, the average weight of Persian Sturgeon in the catches has increased. Mean weighs of females decreased during the present study ($P<0.05$) but, the mean weighs of males showed no significant change. Most of the females were concentrated in a group weighing 15 to 45 kg, whereas the males were concentrated between five and 25 kg.

7. 3. 5 Annual increment in length and weight

In a particular water body during different years, the growth rate of Persian Sturgeon may vary considerably depending upon the basic food supply and the number of other benthos-feeding fishes (Legeza and Voinova 1966). Growth rate is highly dependent upon the environment (water temperature, food and competition) and may differ greatly in different stocks of one species (Chugunov and Chugunova 1964; Sokolov and Akimova 1976). In the present study annual increment in length and weight of the Persian Sturgeon, though dependent on age and sex of the fish, varied considerably. Often, fishes of the same age are substantially different in length and body weight. This is observed among both males and females. As the figures (7.4 to 7.27) show, the graph of length-at-age in the Persian Sturgeon is not of the decaying exponential type usual for most fish. This seems likely because the Persian Sturgeon is a long-lived fish (probably over 45 years old). After initial rapid growth (until 7 years old) its annual increments are relatively small. Sampling error, compounded by the fact that the fish mature only at intervals of several years (Pavlov and Elizarov 1970), results in variations in mean length. The data suggest three distinct growth stanzas. Initially, before entering the fishery, it is high; from about 7 to 22, in the classes that dominate in the fishery, growth rate is intermediate; and from about 22 onwards the rate appears slower. It is clear from the graph 7.41 that growth changed from 22 onwards which might, as in some other fishes (Cushing, 1981), accord with a high occurrence of maturity . One single von Bertalanffy equation, derived by standard methods, does not describe growth of the Persian Sturgeon throughout the entire span of life. In this case it is necessary to find equations that best fit the middle stage.

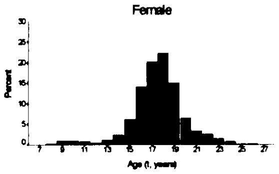
A comparison between annual length of males and females (Table 7.23), shows that there were no significant differences between annual means from 8 to 14 years ($P>0.05$), which suggests a similar growth rate for both sexes in this stage, but that growth rate is noticeably higher for females than for males after 14 years, $P<0.05$). Holci'k (1989) used the data collected by other authors, such as Putilina

(1981, 1983a) and Babushkin and Borzenko (1951), to conclude that the length and weight of Persian Sturgeon are strongly dependent on the age, sex, and feeding conditions in the habitat. He also noted that females are always larger than males of the same age, especially after reaching sexual maturity. Putilina (1981, 1983a) presented growth in length data for Persian Sturgeon caught in Volga and Kura Rivers. Comparison between the populations of the southern Caspian and of the Volga and Kura shows more rapid growth in the south. For example, the mean total length of 18 year old males in the Volga and Kura Rivers respectively was 149.2 and 153 cm, and of females 162.5 and 170 cm, whereas for the southern Caspian these figures were 173.4 cm for males and 180.2 cm for females. In 15 year old fish, the mean total length of males and females combined in the Volga and the Kura was 152.5 cm and 153 cm, while in the southern region it was 163 cm.

Comparison of the weights of Persian Sturgeon from the Volga River obtained by Putilina (1981, 1983a) with data from the present study shows that the mean weight of the southern fish was much higher. Thus, the mean weight of 18 year old females in the southern Caspian was 33.8 kg (Table 7.31), while mean weight of the Volga fish was obtained as 19 kg; for 23 year old females, average weight was 42.7 kg in the south Caspian (Table 7.31) and 26.5 kg in the Volga. In general the comparison of data shows that the annual mean weight and length of the Persian Sturgeon in the southern Caspian is higher than in other areas of the Sea.

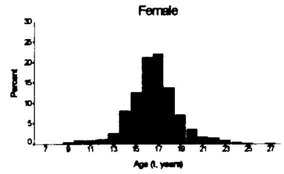
Fig 7.1: Age distribution of female and male Persian Sturgeon 1990-1994.

1990

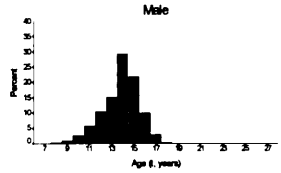


1990

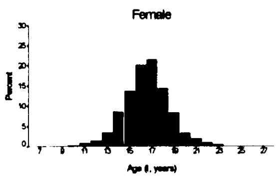
1991



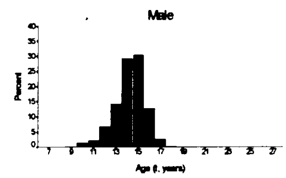
1991



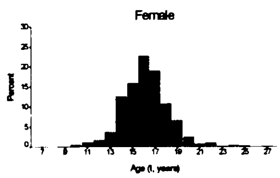
1992



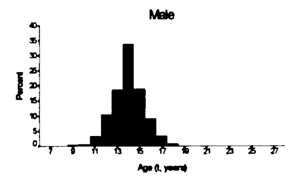
1992



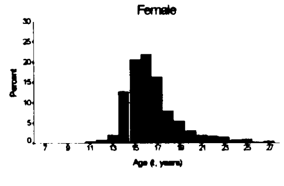
1993



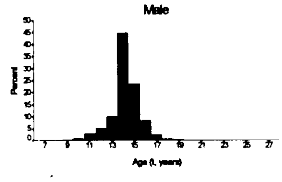
1993



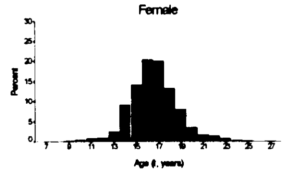
1994



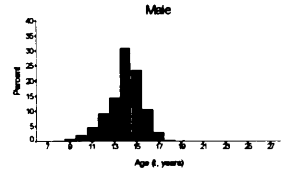
1994



1990-1994



1990-1994



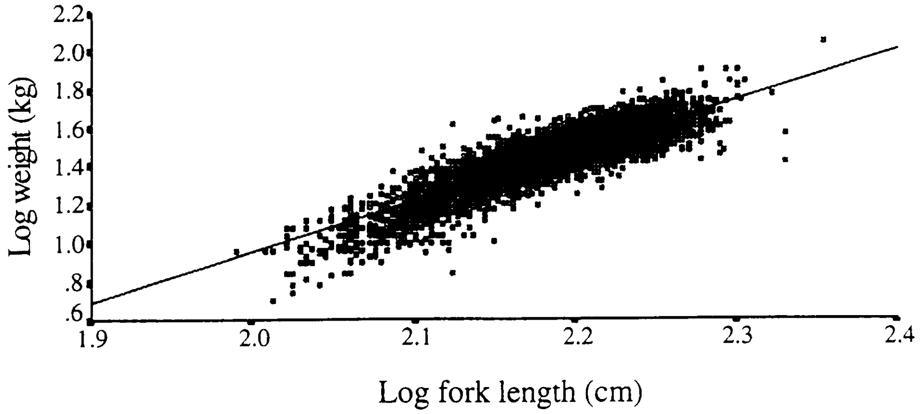


Fig 7.2: Plot of log weight vs log length of the female Persian Sturgeon 1990-1994.

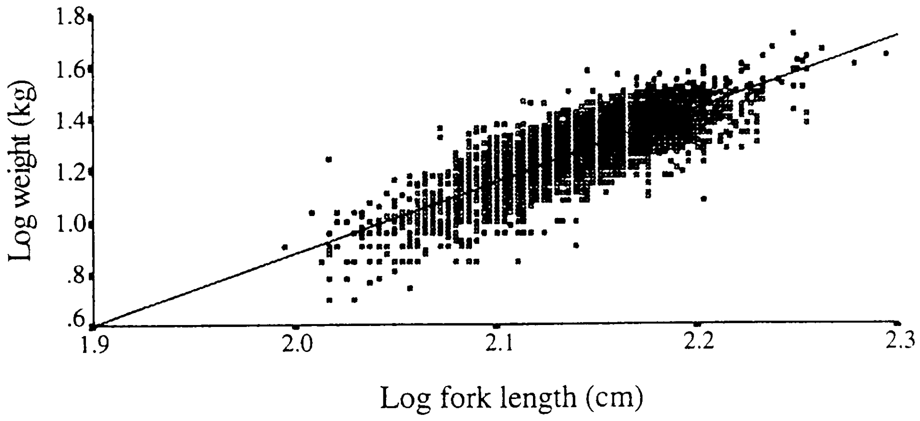


Fig 7.3: Plot of log weight vs log length of the male Persian sturgeon 1990-1994.

Fig 7.4: Length-age relationship of the female Persian Sturgeon 1990 (linear plot).

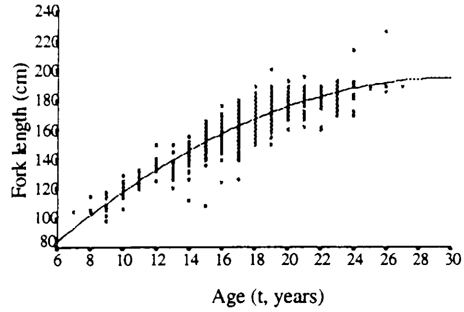


Fig 7.5: Length-age relationship of the female Persian Sturgeon 1990 (quadratic plot).

Fig 7.6: Length-age relationship of the male Persian Sturgeon 1990 (linear plot).

Fig 7.7: Length-age relationship of the male Persian Sturgeon 1990 (quadratic plot).

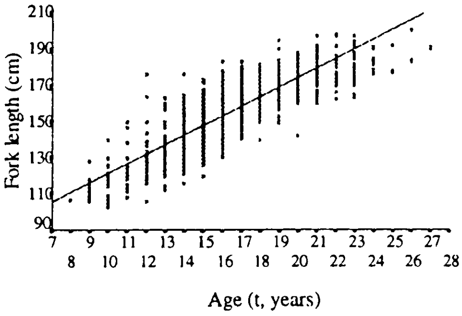


Fig 7.8: Length-age relationship of the female Persian Sturgeon 1991 (linear plot).

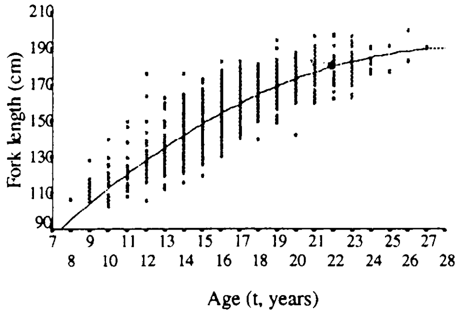


Fig 7.9: Length-age relationship of the female Persian Sturgeon 1991 (quadratic plot).

Fig 7.10: Length-age relationship of the male Persian Sturgeon 1991 (linear plot).

Fig 7.11: Length-age relationship of the male Persian Sturgeon 1991 (quadratic plot).

Fig 7.12: Length-age relationship of the female Persian Sturgeon 1992 (linear plot).

Fig 7.13: Length-age relationship of the female Persian Sturgeon 1992 (quadratic plot).

Fig 7.14: Length-age relationship of the male Persian Sturgeon 1992 (linear plot).

Fig 7.15: Length-age relationship of the male Persian Sturgeon 1992 (quadratic plot).

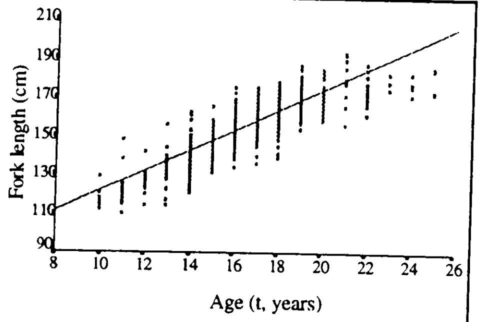


Fig 7.16: Length-age relationship of the female Persian Sturgeon 1993 (linear plot).

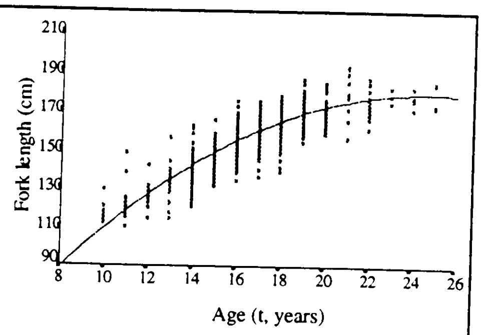


Fig 7.17: Length-age relationship of the female Persian Sturgeon 1993 (quadratic plot).

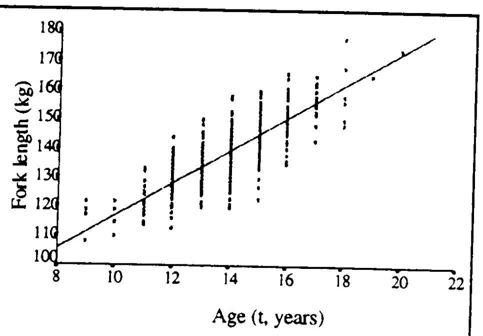


Fig 7.18: Length-age relationship of the male Persian Sturgeon 1993 (linear plot).

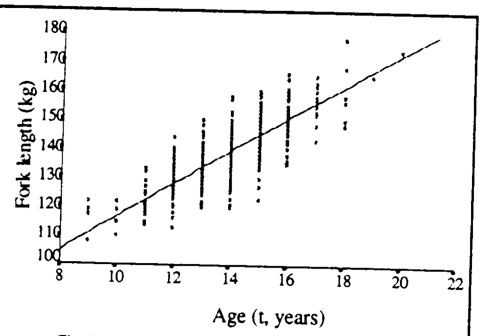


Fig 7.19: Length-age relationship of the male Persian Sturgeon 1993 (quadratic plot).

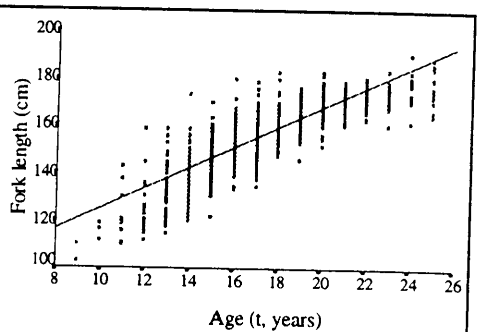


Fig 7.20: Length-age relationship of the female Persian Sturgeon 1994 (linear plot).

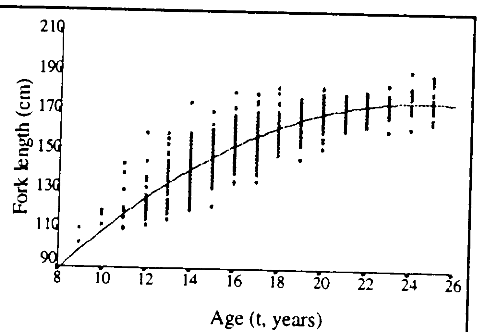


Fig 7.21: Length-age relationship of the female Persian Sturgeon 1994 (quadratic plot).

Fig 7.22: Length-age relationship of the male Persian Sturgeon 1994 (linear plot).

Fig 7.23: Length-age relationship of the male Persian Sturgeon 1994 (quadratic plot).

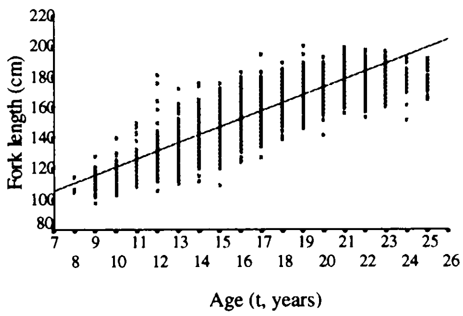


Fig 7.24: Length-age relationship of the female Persian Sturgeon 1990-1994 (linear plot).

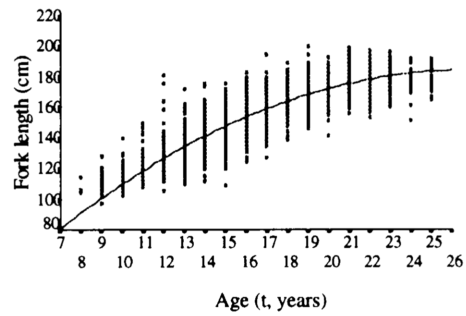


Fig 7.25: Length-age relationship of the female Persian Sturgeon 1990-1994 (quadratic plot).

Fig 7.26: Length-age relationship of the male Persian Sturgeon 1990-1994 (linear plot).

Fig 7.27: Length-age relationship of the male Persian Sturgeon 1990-1994 (quadratic plot).

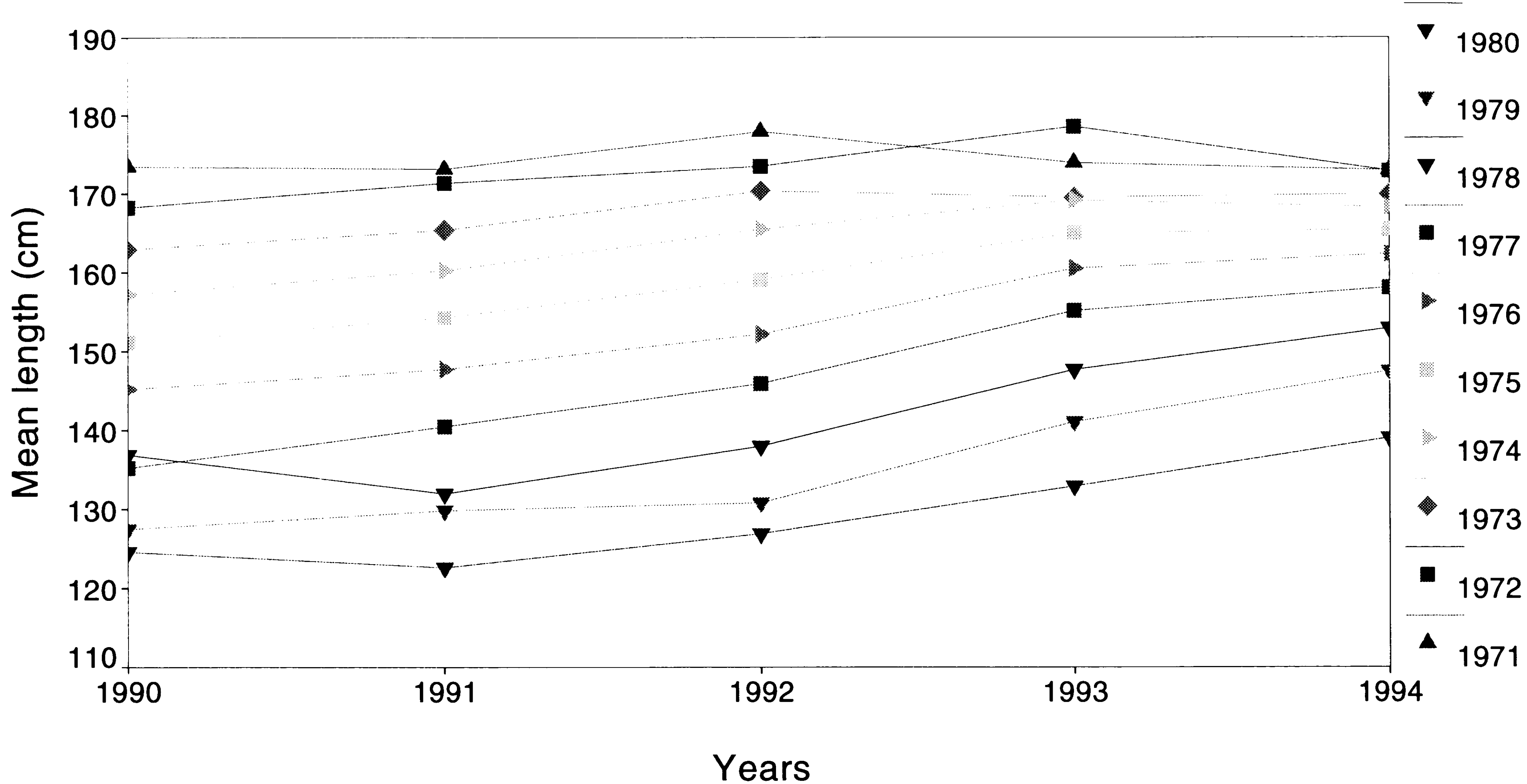


Fig 7.28: Female Persian Sturgeon: Mean length at age by cohorts

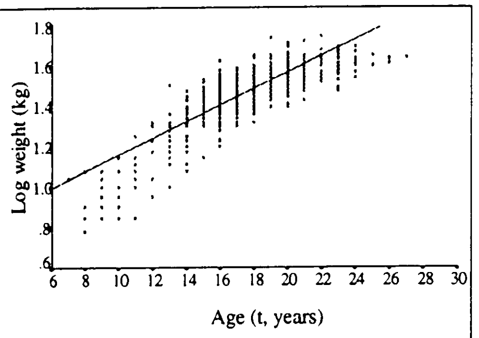


Fig 7.29: Plot of log weight vs age of the female Persian Sturgeon 1990.

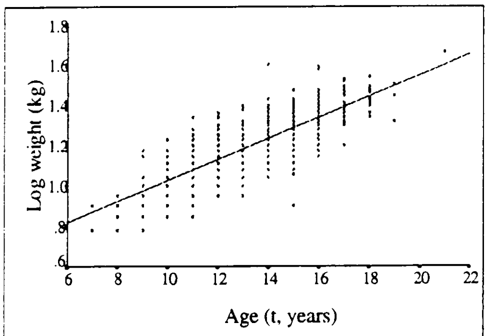


Fig 7.30: Plot of log weight vs age of the male Persian Sturgeon 1990.

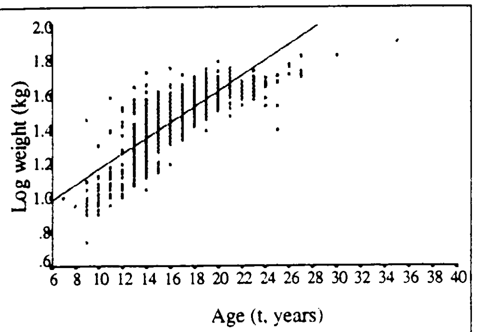


Fig 7.31: Plot of log weight vs age of the female Persian Sturgeon 1991.

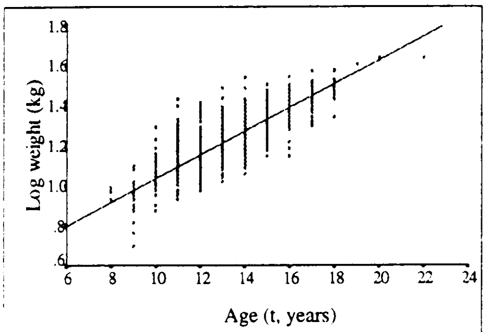


Fig 7.32: Plot of log weight vs age of the male Persian Sturgeon 1991.

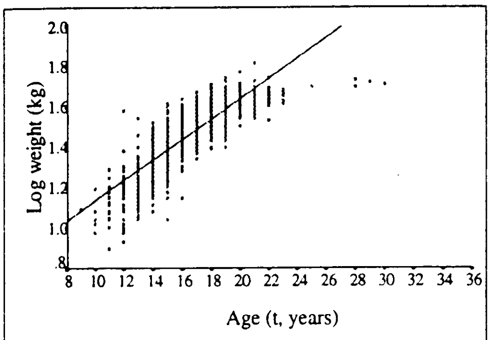


Fig 7.33: Plot of log weight vs age of the female Persian Sturgeon 1992.

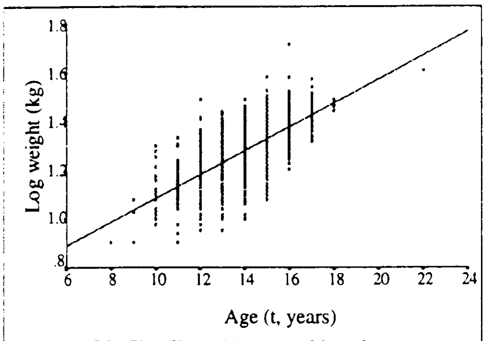


Fig 7.34: Plot of log weight vs age of the male Persian Sturgeon 1992.

Fig 7.35: Plot of log weight vs age of the female Persian Sturgeon 1993.

Fig 7.36: Plot of log weight vs age of the male Persian Sturgeon 1993.

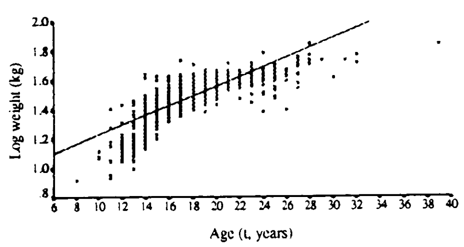


Fig 7.37: Plot of log weight vs age of the female Persian Sturgeon 1994.

Fig 7.38: Plot of log weight vs age of the male Persian Sturgeon 1994.

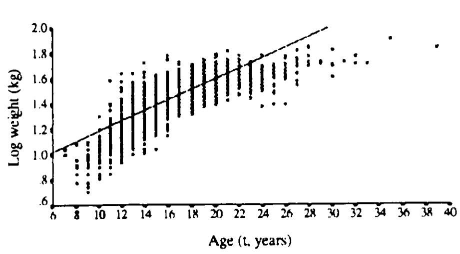


Fig 7.39: Plot of log weight vs age of the female Persian Sturgeon 1990-1994.

Fig 7.40: Plot of log weight vs age of the male Persian Sturgeon 1990-1994

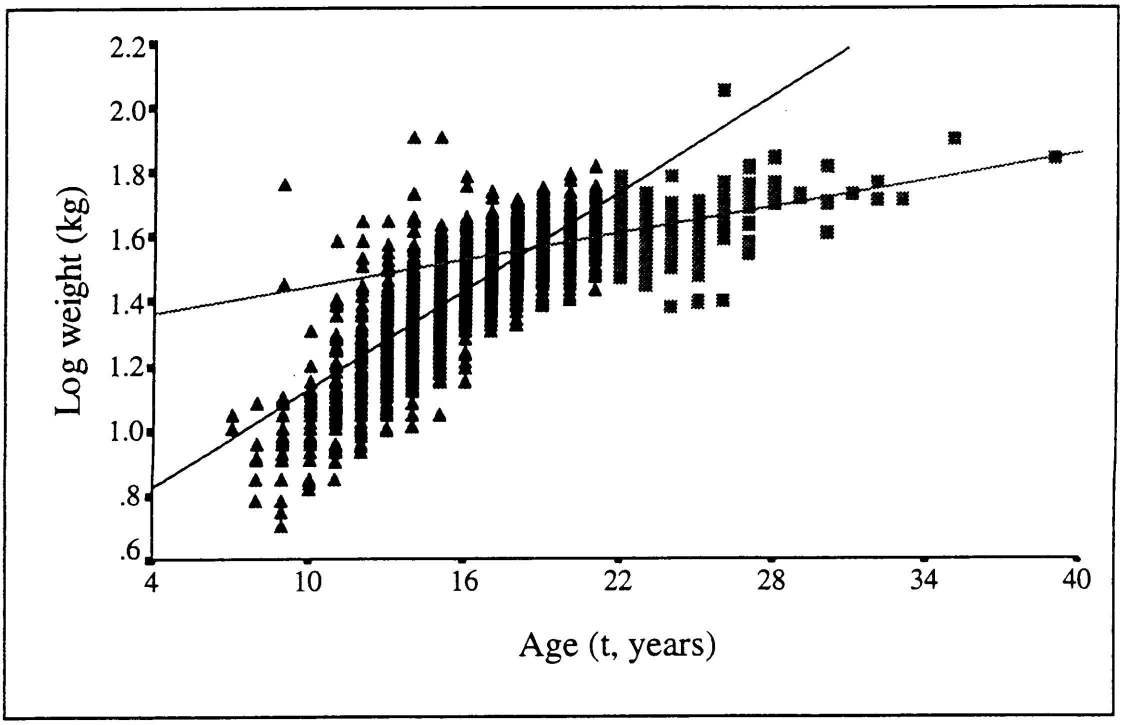


Fig 7.41: Female Persian Sturgeon: Stanzas of growth-in-weight 1990-1994. Although the data indicate a declining rate of growth, they are not fitted closely by a single von Bertalanffy curve. Rather, there appear to be two stanzas: the first between ages 6 and 22, the second from 22 onwards. It should be noted that the sample sizes during the second stanza tend to be small (Table 7.31). Theregression equations for the stanzas are as follows:

First stanza: Low W = 0.6618 + 0.0481t

Second stanza: Log W = 1.2350 + 0.0165t

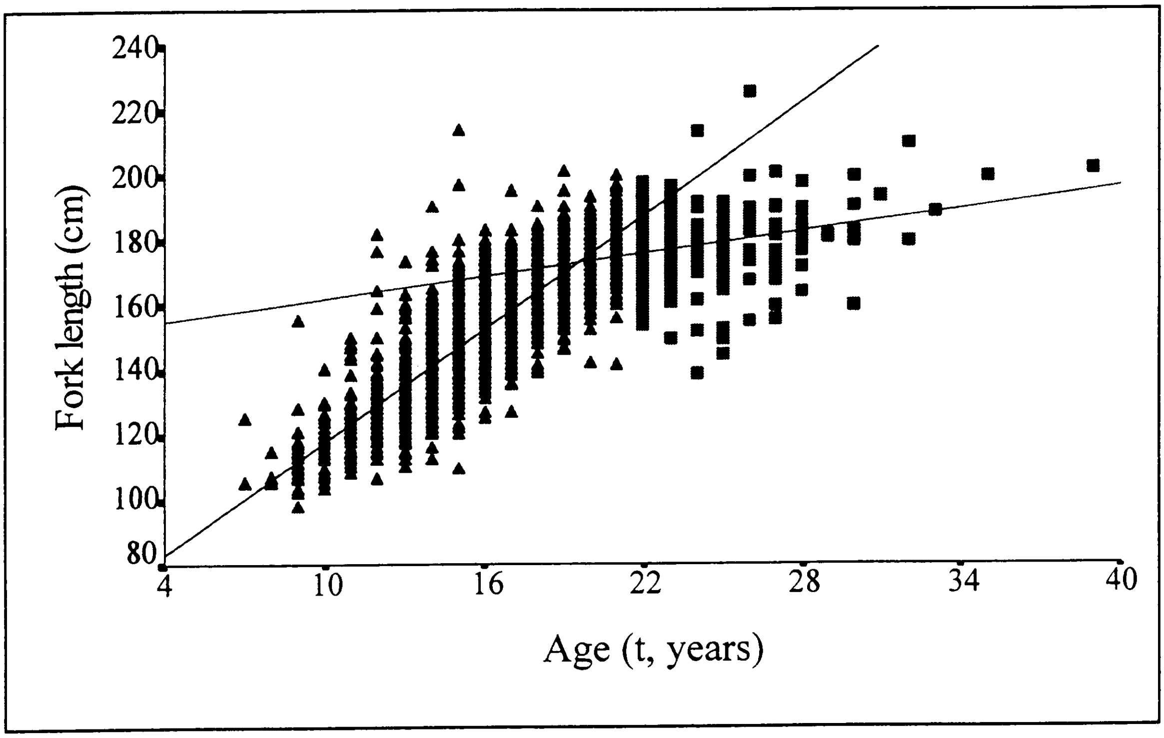


Fig 7.42: Female Persian Sturgeon: Stanzas of growth-in-length 1990-1994. Although the data indicate a declining rate of growth, they are not fitted closely by a single von Bertalanffy curve. Rather, there appear to be two stanzas: the first between ages 6 and 22, the second from 22 onwards. It should be noted that the sample sizes during the second stanza tend to be small (Table 7.24). Theregression equations for the stanzas are as follows:

First stanza: $L = 62.8634 + 5.6223t$

Second stanza: $L = 151.263 + 1.1115t$

CHAPTER 8

Length, weight and age relationships of the Russian Sturgeon, *Acipenser guldenstadti,* in the Caspian Sea

8. 1 Introduction

According to Holci'k (1989) the Russian Sturgeon is considered to be a valuable and delicious fish; and occupies the first prize among the catch of acipenserids.

Most of the sturgeon catch, from 40 to 50%, in the past as well as nowadays, is made up of the Russian Sturgeon (Kosarev and Yablonskaya 1994). Most of them are caught in the Caspian Sea watershed, and considerably fewer come from the Black Sea and Azov watersheds. The Russian Sturgeon fishery in the Caspian Sea is primarily concentrated in the north, whereas in the southern part of the sea, the Persian Sturgeon (*Acipenser persicus*) is caught. The northern Caspian population of the Russian Sturgeon was exposed to intensive exploitation at the end of the nineteenth century and, recently, its spawning grounds have been considerably reduced in size, and their migration routes blocked by dams built along almost all the European rivers. During the period from 1898 to 1913, the catch of this species in the northern Caspian ranged from 4,600 to 10,000 tonnes per year and averaged 6,700 tonnes (Korobochkina 1964b). The catch during the period from 1925 through 1939 ranged from 2,800 to 6,600 tonnes. By 1941, such a high proportion of the catch was being taken in the sea, that it had damaged the structure of the population and the capture of all acipenserids in the Caspian Sea was forbidden, and the fishing transferred primarily to the rivers. From 1947 through 1962, the Russian Sturgeon catch in the northern Caspian ranged from 3,050 to 7,700 tonnes (Korobochkina 1964b). Thereafter, the annual catch more than doubled and reached a record amount of 11,980 tonnes in 1977 (Kazancheev 1981). The minimum length for catching the Russian Sturgeon in southern Caspian is 113 cm total length.

8. 2 Results

8. 2. 1 Sex composition

Sex composition for years 1990-1994 are shown in Tables 8.1-8.5, with the mean age, mean weight, mean length and proportion of each sex.

Table 8.1: Mean age, mean length, mean weight, and proportion of each sex of the catch of 1990 (Russian Sturgeon, south part of the Caspian Sea).

sex	mean age (years)	mean fork length (± SD) (cm)	mean weight (± SD) (kg)	number	percentage %
Immature female	11.6	123.1 ± 15.2	15.7 ± 7.4	616	45.1
Mature female	14.4	138.5 ± 12.0	24.6 ± 6.8	605	44.3
Immature male	11.1	116.6 ± 12.3	12.9 ± 5.5	53	3.9
Mature male	12.9	128.8 ± 12.6	15.8 ± 5.5	91	6.7
Total	13.0	130.0 ± 15.7	19.6 ± 8.4	1365	100.0

Table 8.2: Mean age, mean fork length, mean weight and proportion of each sex group of the Russian Sturgeon,1991.

sex	mean age (years)	mean fork length (± SD) (cm)	mean weight (± SD) (kg)	number	percentage %
Immature female	12.7	122.2 ± 13.3	17.3 ± 6.8	1171	32.6
Mature female	14.6	136.0 ± 11.0	25.1 ± 6.2	1713	47.6
Immature male	12.0	115.3 ± 9.8	14.2 ± 3.8	264	7.3
Mature male	12.5	120.2 ± 10.1	15.8 ± 4.0	448	12.5
Total	13.5	128.0 ± 14.0	20.6 ± 7.4	3596	100.0

Table 8.3: Mean age, mean length, mean weight and proportion of each sex group of the Russian Sturgeon, 1992.

sex	mean age (years)	mean fork length (± SD) (cm)	mean weight (± SD) (kg)	number	percentage %
Immature female	13.7	126.0 ± 12.4	19.1 ± 6.2	653	25.5
Mature female	15.2	137.5 ± 10.6	26.2 ± 6.6	1530	59.7
Immature male	12.6	120.4 ± 9.2	16.1 ± 4.3	145	5.7
Mature male	13.1	124.0 ± 10.6	17.5 ± 5.0	233	9.1
Total	14.5	132.4 ± 12.7	23.0 ± 7.4	2561	100

Table 8.4: Mean age, mean length, mean weight and proportion of each sex group of the Russian Sturgeon, 1993.

sex	mean age (years)	mean fork length (± SD) (cm)	mean weight (± SD) (kg)	number	percentage %
Immature female	13.6	128.0 ± 13.2	19.7 ± 7.2	356	23.8
Mature female	14.4	135.6 ± 11.6	24.2 ± 6.5	949	63.5
Immature male	12.7	126.1 ± 14.3	17.7 ± 6.8	107	7.2
Mature male	12.5	125.9 ± 12.2	17.1 ± 5.1	82	5.5
Total	14.0	132.8 ± 12.8	22.4 ± 7.1	1494	100.0

Table 8.5: Mean age, mean length, mean weight and ratio of each sex group of the Russian Sturgeon, 1994.

sex	mean age (years)	mean fork length (± SD) (cm)	mean weight (± SD) (kg)	number	percentage %
Immature female	14.1	126.6 ± 12.4	19.7 ± 7.0	275	21.5
Mature female	15.0	135.0 ± 10.9	24.0 ± 5.9	808	63.3
Immature male	13.3	122.3 ± 9.8	16.60 ± 3.8	142	11.3
Mature male	13.1	126.1 ± 9.8	17.10 ± 4.1	50	3.9
Total	14.6	131.6 ± 12.1	22.0 ± 6.6	1277	100.0

Five years' data are combined in Table 8. 6. For the years under study, the sex ratio was characterized by a predominance of females (>84%) over males. The mean age, mean fork length, and mean weight of mature females were significantly greater than of males (t-test, t-values = 28.7, 34.1 and 45.3 respectively, $P<0.01$) as they were for all the years separately. Mean age, mean length and mean weight of immature females were also significantly higher than of mature males (t-test, t-values = 2.4, $P<0.05$; 2.9 and 6.8 respectively, $P<0.01$), implying earlier maturation for a males and higher growth rate for females.

Table 8.6: Mean age, mean length, mean weight and ratio of each sex group of the Russian Sturgeon,1990-1994.

sex	mean age (years)	mean fork length (± SD) (cm)	mean weight (± SD) (kg)	number	percentage %
Immature female	12.9	124.1 ± 13.6	17.8 ± 7.0	2960	29.7
Mature female	14.8	136.5 ± 11.2	25.1 ± 6.5	5422	54.5
Immature male	12.4	119.3 ± 1.2	15.4 ± 4.7	689	6.9
Mature male	12.7	122.8 ± 11.1	16.4 ± 4.6	883	8.9
Total	13.9	130.4 ± 13.7	21.5 ± 7.5	9954	100.0

8. 2 .2 Age composition

From 1990 to 1994 (Table 8.7), the majority of the catch (92.9%) of Russian Sturgeon consisted of fish aged 10 to 17. The age of females varied between 5 and 37 years, of males between 8 and 31 years old. The mean ages of females and males were 14.0 and 12.5 respectively. The majority of the catch of females (92.7%) consisted of fish aged 10 to 17 years, and males (95.3%) aged 9 to 15 years old. The maximum age of females and males in the southern part of Caspian Sea was 37 and 31 years respectively. Comparing females and males, the age ranges of females were higher than of males and the percentage of females was higher in both younger and older age groups. For both sexes the proportion of fish older than 19 was low, only 1.8% of the total catches, and the percentage of immature fish in each year's catch high (Table 8.7).

Table 8. 7: Age composition of the Russian Sturgeon, 1990-1994.

age (years)	**Females**			**Males**		
	number	**percentage**	**mature %**	**number**	**mature %**	**percentage**
5	1	0.0	0.0			
6						
7	13	0.2	23.1	11	36.4	0.7
8	54	0.6	0.0	59	49.2	3.8
9	129	1.5	1.6	129	47.3	8.2
10	335	4.0	9.0	230	49.1	14.0
11	438	5.2	25.3	324	57.1	20.6
12	734	8.8	46.7	351	56.7	22.3
13	1237	14.8	57.3	292	59.6	18.6
14	1917	22.9	70.6	110	66.4	7.0
15	1545	18.4	77.5	31	74.2	2.0
16	1010	12.1	83.6	21	61.9	1.3
17	555	6.6	87.9	7	71.4	0.4
18	213	2.5	85.9	3	66.7	0.2
19	88	1.0	84.1			
20	44	0.5	79.5			
21	23	0.3	78.3	1	100.0	0.1
22	13	0.2	69.2	1	100.0	0.1
23	6	0.1	100.0			
24	4	0.0	50.0			
25	10	0.1	60.0			
26	5	0.1	60.0			
27	3	0.0	66.7	1	0.0	0.1
30	3	0.0	66.7			
31				1	0.0	0.1
32						
33						
34						
35						
36						
37	1	0.0				

Figure 8.1 shows the age distribution of females and males in the catches of 1990 to 1994. The Kolmogorov - Smirnov 2-sample test (Table 8.8) shows significant differences between age distribution of males and females in successive pair of years.

Table 8.8: Kolmogorov-Smirnov 2-sample test for age distribution of male and female Russian Sturgeon (1990-1994).

year	**female**		**male**	
	number	**K-S Z**	**number**	**K-S Z**
1990-1991	12221, 2884	5.3**	144, 712	1.6*
1991-1992	2884, 2183	6.6**	712, 378	2.9**
1992-1993	2183, 1011	4.7**	378, 146	1.6*
1993-1994	1011, 1082	4.4**	88-168	2.4**

(* $P<0.05$, ** $P<0.01$)

The differences between mean ages of the Russian Sturgeon for each year of the catch were examined using Tukey's T. The mean age of female in 1990 was significantly different from 1991,1992,1993 and 1994; 1991 from 1992, 1993 and 1994; 1992 was different from 1993 and 1994, and 1993 from 1994. The mean age of males in 1990 was significantly different from 1992 and 1994; 1991 from 1992 and 1994; 1992 from 1994; and 1993 from 1994 (Table 8.9). A slight increase was observed in the mean age of the population from 1990 through 1994 (df = 3, r = 0.879, $P<0.05$ for females, df = 3, r = 0.881, $P<0.05$ for males).

Table 8.9: Statistical analysis of mean age of the Russian Sturgeon (1990-1994). Females above the diagonal, males below it.

	1990 (F)	1991 (F)	1992 (F)	1993 (F)	1994 (F)
1990 (M)		n= 1221, 2884 x̄ = 13.00, 13.9 MSD =0.2050 *	n = 1221, 2183 x̄ = 13.0, 14.7 MSD = 0.2146 *	n = 1221, 1011 x̄ = 13.0, 14.2 MSD = 0.2554 *	n = 1221, 1082 x̄ = 13.0, 14.8 MSD = 0.2507 *
1991 (M)	n = 144, 712 x̄ = 12.2, 12.3 MSD = 0.4657		n = 2884, 2183 x̄ = 13.9, 14.7 MSD = 0.1704 *	n = 2884, 1011 x̄ = 13.9, 14.2 MSD = 0.2195 *	n = 2884, 1082 x̄ = 13.9, 14.8 MSD = 0.2141 *
1992 (M)	n = 144, 378 x̄ = 12.2, 12.9 MSD = 0.4991 *	n = 712, 378 x̄ = 12.3, 12.9 MSD = 0.3243 *		n = 2183, 1011 x̄ = 14.7, 14.2 MSD = 0.2283 *	n = 2183, 1082 x̄ = 14.7, 14.8 MSD = 0.2233
1993 (M)	n = 144, 146 x̄ = 12.2, 12.6 MSD = 0.5986	n = 712, 146 x̄ = 12.3, 12.6 MSD = 0.4630	n = 378, 146 x̄ = 12.9, 12.6 MSD = 0.4966		n = 1011, 1082 x̄ = 14.2, 14.8 MSD = 0.2627 *
1994 (M)	n= 144, 192 x̄ = 12.2, 13.2 MSD = 0.5618 *	n = 712, 192 x̄ = 12.3, 13.2 MSD = 0.4144 *	n = 378, 192 x̄ = 12.9, 13.2 MSD = 0.4517 *	n = 146, 192 x̄ = 12.6, 13.2 MSD = 0.5596 *	

* $P \leq 0.05$

The difference between two means is significant if

[Mean (I) - Mean (j)] ≥ MSD

8. 2. 3 Length composition

Analysis of the fork length composition of the Russian Sturgeon in the south part of the Caspian Sea for the combined years' 1990-1994 shows (Table 8.10) that most of the female catches (around 92%) consisted of fish 110-150 cm, of males (88%) 105-135 cm. The range of the lengths for females was always greater than for males. Mean fork length of the entire population was 130.4 cm; for females 132.1 cm and for males 121.3 cm. The range was 90 to 204 cm for females, and 95 to 189 cm for males. There was no trend in mean length of either sex (df = 3, r = 0.726, P>0.05 for females; df = 3, r = 0.312, P>0.05 for males).

Table 8.10: Mean fork length ±SD of the Russian Sturgeon, from the south part of Caspian Sea (1990-1994).

years	**female**			**male**		
	number	**mean length (cm)**	**range (cm)**	**number**	**mean length (cm)**	**range (cm)**
1990	1221	130.7 ±15.7	94-198	192	124.3 ±13.8	100-171
1991	2884	130.4 ±13.8	90-204	144	118.4 ±10.3	95-156
1992	2183	134.1 ±12.4	96-194	712	122.7 ±100.3	97-163
1993	1011	133.7 ±12.4	101-201	378	126.0 ±13.4	105-189
1994	1082	133.0 ±11.9	96-176	146	123.3 ±9.9	103-163
all years	8381	132.1 ±13.4	90-204	1572	121.3 ±11.2	95-189

The differences between mean lengths of the Russian Sturgeon for each year of the catch were examined using Tukey's T (Table 8.11). Mean length of the females in year 1990 was significantly different from 1992, 1993 and 1994; 1991 was different from 1992, 1993 and 1994; and 1992 from 1994. For males the differences were significant between 1990 and 1991; between 1991 and 1992, 1993 and 1994; and between 1992 and 1993.

Table 8.11: Statistical analysis of female and male mean length of the Russian Sturgeon (1990-1994).

	1990 (F)	1991 (F)	1992 (F)	1993 (F)	1994 (F)
1990 (M)		n = 1221, 2884 x̄ = 130.7, 130.4 MSD = 1.2427	n = 1221, 2183 x̄ = 130.7, 134.1 MSD = 1.3007 *	n = 1221, 1011 x̄ = 130.7, 133.7 MSD = 1.5477 *	n = 1221, 1082 x̄ = 130, 7, 133.0 MSD = 1.5197 *
1991 (M)	n = 144, 712 x̄ = 124.3, 118.4 MSD = 2.7223 *		n = 2884, 2183 x̄ = 130.4, 134.1 MSD = 1.0326 *	n = 2884, 1011 x̄ = 130.4, 133.7 MSD = 1.3303 *	n = 2884, 1082 x̄ = 130.4, 133.0 MSD = 1.2976 *
1992 (M)	n = 144, 378 x̄ = 124.3, 122.6 MSD = 2.9177	n = 712, 378 x̄ = 118.4, 122.6 MSD = 1.8961 *		n = 2183, 1011 x̄ = 134.1, 133.7 MSD = 1.3846	n = 2183, 1082 x̄ = 134.1, 133.0 MSD = 1.3532 *
1993 (M)	n = 144, 146 x̄ = 124.3, 126.0 MSD = 3.4992	n = 712, 146 x̄ = 118.4, 126. MSD = 2.7068 *	n = 378, 146 x̄ = 122.6, 126.0 MSD = 2.9031 *		n = 1011, 1082 x̄ = 133.7, 133.0 MSD = 1.5921
1994 (M)	n = 144, 192 x̄ = 124.3, 123.3 MSD = 3.2845	n = 712, 192 x̄ = 118.4, 123.3 MSD = 2.4228 *	n = 378, 192 x̄ = 122.6, 123.3 MSD = 2.6404	n = 146, 192 x̄ = 126.0, 123.3 MSD = 3.2716	

*P≤0.05

The difference between two means is significant if

[Mean (I) - Mean (j)] ≥ MSD

8. 2. 4 Weight composition

Weight composition of the Russian Sturgeon in five years' catches, 1990 to 1994, were analysed (Table 8.12). The range of weight of females is appreciably greater than that of the males; females varied between 3.3 and 96 (mean 22.5) kg; males between 5 and 50 (mean 16.0) kg. Most of the combined yearly catches (>93%)

consisted of females weighing 10-35 kg and males weighing 10 - 25 kg. The highest mean weight of females was in 1992 at 24.1 kg, of males in 1993 at 17.4 kg. Mean weight of females and males changed from to year, but no trends are apparent (df = 3, r = 0.710, P>0.05 for females; df = 3, r = 0.839, P> 0.05 for males).

Table 8.12: Mean total weight ±SD of the Russian Sturgeon, from the south part of the Caspian Sea (1990-1994).

years	female			male		
	number	mean weight (kg)	range kg	number	mean weight (kg)	range kg
1990	1221	20.1 ± 8.4	5-96	192	14.7 ±5.7	5-38
1991	2884	21.9 ±7.5	3.3-92	144	15.2 ±4.0	6.7-40
1992	2183	24.1 ±7.3	5.5-66.7	712	17.0 ±4.8	5.5-45.2
1993	1011	23.1 ±7.0	8.2-72.5	378	17.4 ±6.1	8.6-50
1994	1082	22.9 ±6.5	7.8-59	146	16.7 ±4.0	10-31.5
all years	8381	22.5 ± 7.5	3.3-96	1572	16.0 ±4.7	5-50

The differences between mean weight for each year of the catch were examined using Tukey's T (Table 8.13). For females significant differences appeared between years 1990 and 1991, 1992, 1993, and 1994; between 1991 and 1992, 1993 and 1994; and between 1992 and years 1993 and 1994. For males the differences are significant between 1990 and 1992, 1993 and 1994; and between 1991 and 1992, 1993 and 1994.

Table 8.13: Tukey's T for female and male mean weight of the Russian Sturgeon (1990-1994).

	1990 (F)	**1991 (F)**	**1992 (F)**	**1993 (F)**	**1994 (F)**
1990 (M)		n = 1221, 2884 $\bar{x}$ = 20.1, 22.0 MSD = 0.6887 *	n = 1221, 2183 $\bar{x}$ = 20.1, 24.1 MSD = 0.7209 *	n = 1221, 994 $\bar{x}$ = 20.1, 23.1 MSD = 0.8618 *	n = 1221, 1082 $\bar{x}$ = 20.1, 22.9 MSD = 0.8422 *
1991 (M)	n = 144, 712 $\bar{x}$ = 14.7, 15.2 MSD = 1.1451		n = 2884, 2183 $\bar{x}$ = 21.9, 24.1 MSD = 0.5723 *	n =2884, 994 $\bar{x}$ = 21.9, 23.1 MSD = 0.7419 *	n = 2884, 1082 $\bar{x}$ = 21.9, 22.9 MSD = 0.7191 *
1992 (M)	n = 144, 378 $\bar{x}$ = 14.7, 17.0 MSD = 1.2273 *	n = 712, 378 $\bar{x}$ = 15.2, 17.0 MSD = 0.7976 *		n = 2183, 994 $\bar{x}$ = 24.1, 23.1 MSD = 0.7719 *	n = 2183. 1082 $\bar{x}$ = 24.1, 22.9 MSD = 0.7500 *
1993 (M)	n = 144, 145 $\bar{x}$ = 14.7, 17.4 MSD = 1.4744 *	n = 712, 145 $\bar{x}$ = 15.2, 17.4 MSD = 1.1418 *	n = 378, 145 $\bar{x}$ = 17.0, 17.4 MSD = 1.2242		n = 994, 1082 $\bar{x}$ = 23.1, 22.9 MSD = 0.8863
1994 (M)	n = 144, 192 $\bar{x}$ = 14.7, 16.7 MSD = 1.3816 *	n = 712, 192 $\bar{x}$ = 15.2, 16.7 MSD = 1.0191 *	n = 378, 192 $\bar{x}$ = 17.0, 16.7 MSD = 1.1107	n = 145, 192 $\bar{x}$ = 17.4, 16.7 MSD = 1.3789	

* $P \leq 0.05$

The difference between two means is significant if

[Mean (I) - Mean (j)] $\geq$ MSD

8. 2. 5 Weight-length relationships

Relationships between weight and length were calculated for each year of the catches. The differences between females and males (log W/ log L) were tested using ANCOVA. There were significant differences (e.g., in 1990, F= 62.2, P≈0 for adjusted means; F= 8.3, P<0.01 for slopes; in 1992, F=103.2, P≈0 for adjusted means; F=15.7, P<0.01 for slopes; and nearly the same results for other years), therefore, the weight-length relationship was calculated separately for each sex and is shown in Tables 8.14 and 8.15. The relationship was calculated from the regression of log W / log FL (log W = log a + b log FL) model.

Table 8.14: Weight-length relationship of female Russian Sturgeon 1990-1994, (W = total weight (kg), L = fork length (cm).

year	number	Weight - length relationship & equation	correlation coefficient (r)
1990	1221	LogW = 3.2 (log L) - 5.23	0.90
1991	2884	LogW = 2.98 (log L) - 4.99	0.91
1992	2183	LogW = 2.9 (log L) - 4.94	0.90
1993	1011	LogW = 2.7 (log L) - 4.50	0.90
1994	1082	LogW = 2.7 (logL) - 4.48	0.90
all years	8381	LogW = 3 (log L) - 5.03	0.90

Table 8.15: Weight-length relationship of male Russian Sturgeon 1990-1994 (W = total weight (kg), L = fork length (cm).

year	number	Weight - length relationships & equation	correlation coefficient (r)
1990	192	LogW = 2.8 (log L) - 4.65	0.83
1991	144	LogW = 2.4 (log L) - 3.80	0.84
1992	712	LogW = 2.6 (log L) - 4.23	0.83
1993	378	LogW = 2.5 (log L) - 3.9	0.85
1994	146	LogW = 2.3 (log L) - 3.62	0.82
all years	1572	LogW = 2.4 (log L) - 3.88	0.82

There is a high correlation between weight and length in both male and female Russian Sturgeon particulary for females. Figs 8.2 and 8.3 shows the weight-length relationship of males and females for combined years. There is no indication of growth stanzas in the relationship. The value of b was close to 3 for all the years' data.

8. 2. 6 Length-age relationship

The results of ANCOVA for length at age data show significant differences between males and females (e.g. for adjusted means and slopes for 1990, $F= 14.4$, $P<0.01$, $F= 36.1$, $P\approx0$, respectively; of 1991, $F= 150.7$, $P\approx0$, $F = 18.8$, $P\approx0$ respectively; and nearly the same results for other years). Therefore, the relation between length and age of Russian Sturgeon was estimated for males and females separately (Table 8.16-8.17). Quadratic and linear equations were applied (Figs 8.4 to 8.27).

Table 8.16: Length-age relationship of female Russian Sturgeon 1990-1994, (Y= fork length (cm), X= age (t, years), Fig = Figures).

year	N	equation (quadratic)	r	Fig	equation (linear)	r	Fig
1990	1221	$Y = 49.4457 + 7.1465X - 0.0658X^2$	0.90	8.5	$Y = 61.1454 + 5.3554X$	0.90	8.4
1991	2884	$Y = 51.1710 + 6.3001X - 0.0411 X^2$	0.83	8.9	$Y = 59.0036 + 5.1504X$	0.83	8.8
1992	2183	$Y = 83.0346 + 1.7954X + 0.1119X^2$	0.78	8.13	$Y = 58.8306 + 5.1129X$	0.77	8.12
1993	1011	$Y = 43.2286 + 8.3016X - 0.1324X^2$	0.77	8.17	$Y = 78.9315 + 3.8551X$	0.74	8.16
1994	1082	$Y = 15.6571 + 11.0613X - 0.2074X^2$	0.76	8.21	$Y = 70.9779 + 4.1933X$	0.73	8.20
90-94	8381	$Y = 47.7896 + 7.2192X - 0.086X^2$	0.80	8.25	$Y = 65.7517+4.7016X$	0.80	8.24

Table 8.17: Length-age relationship of male Russian Sturgeon 1990-1994 (Y= length (cm), X= age (t, years), Fig = Figures).

year	N	equation (quadratic)	r	Fig	equation (linear)	r	Fig
1990	192	$Y = 30.4265 + 11.4051X - 0.2938X^2$	0.70	8.7	$Y = 78.4388 + 3.7452X$	0.66	8.6
1991	144	$Y = 68.0069 + 4.1155X - 0.0016X^2$	0.70	8.11	$Y = 68.2501+ 4.0763X$	0.68	8 10
1992	712	$Y = 136.608 - 6.1885X + 0.3898X^2$	0.7	8.15	$Y = 71.2528 + 3.9900X$	0.65	8.14
1993	378	$Y = 62.4903 + 5.7984X - 0.0582X^2$	0.75	8.19	$Y = 77.9134 + 3.8104X$	0.75	8.18
1994	146	$Y = 165.389 - 11.490X + 0.6192X^2$	0.76	8.23	$Y = 65.5751 + 4.3663X$	0.71	8.22
90-94	1572	$Y = 73.2288 + 3.6477X+ 0.0133X^2$	0.68	8.27	$Y = 70.8356 + 4.0094X$	0.68	8.26

Data in the above Tables show that length of both female and male Russian Sturgeon, especially females, is highly correlated with age. Using curve-fitting procedures, the equation of best fit (higher r) was in most of the cases found to be quadratic. However, the quadratic curves cannot describe this relationship in some of the samples (as in Fig 8.15) as the relationship becomes clearly impossible. There is little sign of the decaying exponential curve usually found in fish growth in most years (Fig 8.17, 8.21)

8. 2. 7 Annual increment in length

The annual increment in length was calculated for each year of the catch for males and females separately (Tables 8.18-8.22).

Table 8.18: Annual increments in length of male and female Russian Sturgeon, 1990.

age (years)	Females			Males		
	number	mean length (cm)	annual increment (cm)	number	mean length (cm)	annual increment (cm)
5	1	96.0				
6						
7	5	100.2	2.1	2	106.0	
8	27	103.6	3.4	13	112.2	6.2
9	65	109.5	5.9	25	113.1	0.9
10	154	113.6	4.1	25	118.8	5.7
11	121	119.9	6.3	22	126.6	7.8
12	132	125.7	5.8	15	128.6	2.1
13	182	130.2	4.5	14	133.9	5.3
14	202	136.4	6.2	13	136.9	2.9
15	150	142.9	6.5	7	137.3	0.4
16	91	147.6	4.7	4	130.5	-6.8
17	43	154.5	6.9	1	171.0	40.5
18	27	155.3	0.9	3	137.0	-34.0
19	9	161.6	6.2			
20	3	144.3	-17.2			
21	1	187.0	42.7			
22	4	176.8	-10.3			
23						
24	1	195.0	9.2			
25	1	184.0	-11.0			
26	1	170.0	-14.0			
27	1	193.0	23.0			

Table 8.19: Annual increments in length of male and female Russian Sturgeon, 1991.

age (years)	Females			Males		
	number	mean length (cm)	annual increment (cm)	number	mean length (cm)	annual increment (cm)
7	6	102.8				
8	24	105.8	3.0	5	105.0	
9	56	106.8	1.0	28	107.8	2.8
10	131	109.8	3.0	66	110.2	2.4
11	176	114.3	4.5	120	112.3	2.1
12	277	119.4	5.1	180	116.1	3.9
13	497	125.9	6.5	154	120.3	4.1
14	647	131.5	5.6	105	125.9	5.6
15	479	136.3	4.8	35	133.5	7.7
16	303	142.2	5.9	8	140.5	7.0
17	181	146.7	4.4	7	145.6	5.1
18	62	153.9	7.3	3	137.0	-8.6
19	23	153.2	-0.7			
20	10	163.8	10.6			
21	6	177.0	13.2			
22	2	156.5	-20.5	1	113.0	-6.0
23	1	154.0	-2.5			
24						
25	2	156.0	1.0			
26						
27						
28						
29						
30	1	185.0	5.8.0			

Table 8.20: Annual increments in length of male and female Russian Sturgeon, 1992.

age (years)	Females			Males		
	number	mean length (cm)	annual increment (cm)	number	mean length (cm)	annual increment (cm)
7	2	110.0				
8	2	111.0	1.0	2	105.5	
9	5	109.4	-1.6	6	112.3	6.8
10	16	115.6	6.2	19	114.7	2.4
11	65	118.2	2.5	49	115.6	0.9
12	148	120.7	2.6	65	120.7	5.1
13	271	123.7	3.0	106	120.7	0.1
14	456	130.0	6.3	81	125.0	4.3
15	517	134.8	4.8	35	133.4	8.5
16	392	141.1	6.3	8	139.0	5.6
17	184	147.5	6.5	4	151.0	12.0
18	72	152.3	4.8	2	160.5	9.5
19	28	156.6	4.2			
20	11	157.6	1.0			
21	11	165.8	8.3	1	161.0	0.2
22	2	178.0	12.2			
23						
24	1	168.0	5.0			

Table 8.21: Annual increments in length of male and female Russian Sturgeon, 1993.

age (years)	Females			Males		
	number	mean length (cm)	annual increment (cm)	number	mean length (cm)	annual increment (cm)
9	3	111.3		8	110.9	
10	23	111.4	0.1	13	113.9	3.1
11	54	117.6	6.3	25	119.6	5.6
12	125	124.1	6.5	30	126.1	6.6
13	174	129.2	5.1	27	124.4	-1.7
14	247	132.3	3.1	26	129.9	5.4
15	183	138.6	6.3	9	142.0	12.2
16	82	144.8	6.2	4	147.8	5.8
17	63	145.9	1.1	2	147.0	-0.8
18	21	150.8	4.9			
19	9	158.8	8.0			
20	9	149.3	-9.4			
21	4	165.0	15.7			
22	3	164.0	-1.0			
23	1	162.0	-2.0			
24	1	167.0	5.0			
25	5	146.4	-20.6			
26	2	170.5	24.1			
27						
28						
29						
30	1	153.0	-4.4			
31						
32						
33						
34						
35						
36						
37	1	201.0	6.9			

Table 8.22: Annual increments in length of male and female Russian Sturgeon 1994.

age (years)	Females			Males		
	number	mean length (cm)	annual increment (cm)	number	mean length (cm)	annual increment (cm)
8	1	103.0		2	109.0	
9				4	111.3	2.3
10	11	112.7	4.9	6	115.2	3.9
11	22	114.4	1.6	11	115.6	0.4
12	52	118.8	4.4	27	116.6	1.1
13	113	121.8	3.1	49	119.8	3.1
14	365	128.9	7.0	66	126.2	6.4
15	216	136.6	7.7	18	132.5	6.4
16	142	140.7	4.1	4	142.8	10.3
17	84	145.2	4.6	4	146.3	3.5
18	31	146.2	1.0	1	163.0	16.8
19	19	149.8	3.7			
20	11	154.3	4.4			
21	1	114.0	-40.3			
22	2	150.5	36.5			
23	4	157.8	7.3			
24	1	154.0	-3.8			
25	2	162.0	8.0			
26	2	156.0	-6.0			
27	2	163.5	7.5			
28						
29						
30	1	176.0	4.2			

Annual increments were also estimated from five years' data (Table 8.23). Annual mean lengths are nearly similar in females and males from 8 to 10 years (paired samples t-test, t-value = 1.9, $P>0.05$); thereafter annual mean lengths are significantly higher in females than in males (paired samples t-test, t-value = 4.6, $P<0.01$). The annual increments in length from 1990 to 1994 of both males and females fluctuate (Tables 8.18-8.23). In females the greatest increments were observed in 21-year-old fish, averaging 11.7 cm per year (number of specimens 23).

In 26 year old females the length increment was also high, averaging 9.4 cm (n = 5) annually. In males the annual increments were greatest in 14 to 16-year-olds, averaging 5.4, 8.8 and 6.2 cm respectively and high also in 18 year olds, averaging 8.3 (n = 7). The differences in increments in length between males and females (from 8 to 18 year old where n high) were not significant (paired samples t-test, t-value = 0.89, $P>0.05$).

Fig 8.28 shows plots of mean length at age in six cohorts of female Russian Sturgeon (1974-1979) followed through the years 1990-1994. The graph shows less variation in growth rate when the data are cohort based rather than year based.

Table 8.23: Annual increments in length of male and female Russian Sturgeon, (1990 -1994).

age (years)	Females			Males		
	number	mean length (cm)	annual increment (cm)	number	mean length (cm)	annual increment (cm)
5	1	96.0				
6						
7	13	102.9	6.9	11	106.0	
8	54	104.8	1.9	59	109.9	3.9
9	129	108.4	3.5	129	112.0	2.2
10	335	112.0	3.7	230	114.6	2.6
11	438	116.8	4.8	324	118.7	4.1
12	734	121.5	4.7	351	121.0	2.3
13	1237	126.1	4.6	292	126.4	5.4
14	1917	131.3	5.1	110	134.4	8.0
15	1545	136.7	5.4	31	140.6	6.2
16	1010	142.3	5.6	21	144.0	3.4
17	555	147.3	5.0	7	152.3	8.3
18	213	152.1	4.9	3	137.0	-15.3
19	88	155.0	2.8			
20	44	155.6	0.6	1	161.0	12.0
21	23	167.3	11.7	1	113.0	-48.0
22	13	166.9	-0.4			
23	6	157.8	-9.0			
24	4	171.0	13.2			
25	10	155.2	-15.8			
26	5	164.6	9.4	1	169.0	11.2
27	3	173.3	8.7			
28						
29						
30	3	171.3	-0.7	1	189.0	5.0
31						
32						
33						
34						
35						
36						
37	1	201.0	4.2			

8. 2. 8 Weight-age relationships

LogW was plotted against age. There were significant differences between males and females (ANCOVA). For instance, for adjusted means and slope, the values were F= 89.1, P≈0; F= 44.3, P≈0 respectively for 1990; F=93.8, P≈0; F=29.8, P≈0, respectively for 1992, and nearly same results for other years. Therefore weight-age relationships were determined for males and females separately (Tables 8.24-8.25).

Table 8.24: Weight-age relationship of female Russian Sturgeon 1990-1994, W=weight (kg), t = age (years), Fig = Figures.

year	**number**	**Weight - age relationship & equation**	**correlation coefficient (r)**	**Fig**
1990	1221	Log W = 0.4580 + 0.0622t	0.87	8.29
1991	2884	Log W = 0.5215 + 0.0573t	0.83	8.31
1992	2183	Log W = 0.5355 + 0.0561t	0.80	8.32
1993	1011	Log W = 0.8004 + 0.0384t	0.74	8.35
1994	1082	Log W = 0.6877 + 0.0443t	0.76	8.37
all years	8381	Log W = 0.5702 + 0.0536t	0.82	8.39

Table 8.25: Weight-age relationship of male Russian Sturgeon 1990-1994 (W=weight (kg), t = age (years), Fif = Figures).

year	number	Weight - age relationship & equation	correlation coefficient (r)	Fig
1990	192	Log W = 0.6615 + 0.039t	0.60	8.30
1991	144	Log W = 0.6575 + 0.0417t	0.67	8.32
1992	712	Log W = 0.6817 + 0.0414t	0.62	8.34
1993	378	Log W = 0.7545 + 0.0369t	0.77	8.36
1994	146	Log W = 0.6341 + 0.0437t	0.74	8.38
all years	1572	Log W = 0.6678 + 0.0413t	0.67	8.40

Figures 8.29 to 8.40 show the plots of log weight vs age for each year of the catch, separately for females and males. The logarithmic plots are of specific growth rate, which should decline during growth but rarely appear to do so, although such a trend is apparent in some graphs such as 8.30 (males, 1990) and 8.35 (females, 1993). The data show high correlation between weight and age of both sexes, but in most years the correlation coefficients for females were higher than for males.

8. 2. 9 Annual increments in weight

Annual increments in weight were calculated to establish the trend of growth in fish from the south part of the Caspian Sea. As with the analysis of annual increments in length, increments were estimated for each years' data separately (Tables 8. 26 to 8. 30).

Table 8.26: Annual increments in weight of male and female Russian Sturgeon, 1990.

age (years)	Females			Males		
	number	mean weight (kg)	annual increment (kg)	number	mean weight (kg)	annual increment (kg)
5	1	6.0				
6						
7	5	6.8	0.4	2	6.5	
8	27	7.6	0.8	13	10.8	4.3
9	65	10.1	2.6	25	10.9	0.2
10	154	11.8	1.7	25	13.0	2.1
11	121	14.6	2.8	22	15.7	2.7
12	132	16.9	2.3	15	15.7	-0.0
13	182	19.4	2.5	14	18.0	2.3
14	202	22.6	3.2	13	18.5	0.5
15	150	26.2	3.6	7	20.4	1.9
16	91	28.6	2.4	4	15.3	-5.2
17	43	33.2	4.7	1	30.0	14.8
18	27	33.7	0.5	3	20.3	-9.7
19	9	39.9	6.2			
20	3	26.7	-13.2			
21	1	35.0	8.3			
22	4	50.0	15.0			
23						
24	1	48.0	-2.0			
25	1	48.0	0.0			
26	1	50.0	2.0			
27	1	96.0	46.0			

Table 8.27: Annual increments in weight of male and female Russian Sturgeon, 1991.

age (years)	Females			Males		
	number	**mean weight (kg)**	**annual increment (kg)**	**number**	**mean weight (kg)**	**annual increment (kg)**
7	6	11.6				
8	24	10.0	-1.6	5	10.5	
9	56	11.0	1.1	28	11.3	0.8
10	131	11.9	0.9	66	12.5	1.2
11	176	14.1	2.2	120	13.2	0.7
12	277	16.4	2.2	180	14.4	1.2
13	497	19.1	2.7	154	15.8	1.4
14	647	21.8	2.8	105	17.4	1.6
15	479	24.6	2.8	35	21.3	3.9
16	303	28.2	3.5	8	23.1	1.8
17	181	31.5	3.4	7	27.5	4.3
18	62	36.3	4.8	3	32.0	4.5
19	23	37.2	0.8			
20	10	40.0	2.9			
21	6	48.5	8.5			
22	2	41.3	-7.2	1	15.0	-4.3
23	1	33.0	-8.3			
24						
25	2	49.0	16.0			
26						
27						
28						
29						
30	1	92.0	8.6			

Table 8.28: Annual increments in weight of male and female Russian Sturgeon, 1992.

age (years)	Females			Males		
	number	mean weight (kg)	annual increment (kg)	number	mean weight (kg)	annual increment (kg)
7	2	10.4				
8	2	10.5	0.1	2	7.8	
9	5	12.3	1.8	6	14.6	6.8
10	16	13.9	1.5	19	14.0	-0.6
11	65	15.1	1.2	49	13.7	-0.2
12	148	16.6	1.5	65	16.0	2.3
13	271	18.2	1.6	106	16.0	-0.1
14	456	21.1	2.9	81	17.6	1.7
15	517	24.1	3.0	35	22.4	4.8
16	392	28.0	3.8	8	23.6	1.2
17	184	32.4	4.5	4	31.4	7.7
18	72	36.7	4.2	2	36.5	5.2
19	28	39.2	2.6			
20	11	40.5	1.3			
21	11	45.6	5.1	1	34.6	-0.6
22	2	48.7	3.1			
23						
24	1	47.0	-0.9			

Table 8.29: Annual increment in weight of male and female Russian Sturgeon, 1993.

age (years)	Females			Males		
	number	mean weight (kg)	annual increment (kg)	number	mean weight (kg)	annual increment (kg)
9	3	12.6		8	11.2	
10	23	14.0	1.5	13	13.3	2.1
11	54	14.8	0.7	25	14.0	0.7
12	125	18.1	3.3	30	16.9	2.9
13	174	20.4	2.3	27	17.4	0.5
14	247	21.8	1.4	26	17.9	0.5
15	183	25.1	3.3	9	24.0	6.1
16	82	29.1	4.1	4	29.2	5.1
17	63	30.5	1.4	2	28.5	-0.7
18	21	34.6	4.1			
19	9	39.8	5.3			
20	9	36.1	-3.7			
21	4	44.8	8.7			
22	3	41.7	-3.1			
23	1	40.0	-1.7			
24	1	50.0	10.0			
25	5	31.6	-18.4			
26	2	43.0	11.4			
27						
28				1	49.0	2.3
29						
30	1	33.0	-2.5			
31						
32				1	50.0	0.3
33						
34						
35						
36						
37	1	65.0	4.6			

Table 8.30: Annual increment in weight of male and female Russian Sturgeon, 1994.

age (years)	Females			Males		
	number	mean weight (kg)	annual increment (kg)	number	mean weight (kg)	annual increment (kg)
8	1	11.5		2	11.3	
9				4	12.1	0.9
10	11	12.3	0.8	6	12.9	0.9
11	22	14.9	2.6	11	13.2	0.3
12	52	16.5	1.7	27	14.1	0.9
13	113	17.5	0.9	49	15.8	1.7
14	365	20.1	2.6	66	17.6	1.8
15	216	24.1	4.0	18	20.3	2.7
16	142	26.9	2.8	4	24.1	3.8
17	84	29.0	2.1	4	28.0	3.9
18	31	31.5	2.5	1	29.1	1.1
19	19	34.9	3.4			
20	11	38.6	3.6			
21	1	12.6	-26.0			
22	2	39.5	26.9			
23	4	40.9	1.4			
24	1	46.0	5.1			
25	2	44.5	-1.5			
26	2	40.0	-4.5			
27	2	44.5	4.5			
28						
29						
30	1	59.0	4.8			

The annual increments over five years are combined in Table 8.31. Annual increments fluctuated from year to year and do not follow a regular trend. The weight increments were highest in females 21 years old, averaging 6.2 kg per year (n = 23). In males the greatest increment was observed in 18-year-old fish, averaging 6.5 (n = 7). Huge weight gains in some single males and females confirm that increments continue in the older age-groups and no regular trend can be seen. Comparison shows that most of the female age groups have a higher increment than the males. There were significant differences in annual weight increments of males and females (ages 8-18, paired samples t-test, t-value = 2.9, P<0.01).

Table 8.31: Annual increments in weight of male and female Russian Sturgeon, (1990-1994).

age (years)	Females			Males		
	number	mean weight (kg)	annual increment (kg)	number	mean weight (kg)	annual increment (kg)
5	1	6.0				
7	13	9.6	3.6			
8	54	8.8	-0.7	11	9.4	
9	129	10.7	1.8	59	11.5	2.1
10	335	12.1	1.5	129	12.5	1.0
11	438	14.5	2.4	230	13.4	0.9
12	734	16.8	2.3	324	15.0	1.6
13	1237	19.0	2.2	351	15.9	0.9
14	1917	21.4	2.4	292	17.6	1.6
15	1545	24.6	3.2	110	21.4	3.8
16	1010	28.0	3.4	31	23.5	2.2
17	555	31.5	3.5	21	26.1	2.5
18	213	35.2	3.8	7	32.6	6.5
19	88	37.9	2.7	3	20.3	-12.3
20	44	38.1	0.2			
21	23	44.3	6.2	1	34.6	7.2
22	13	44.9	0.6	1	15.0	-19.6
23	6	39.4	-5.5			
24	4	47.8	8.3			
25	10	39.3	-8.5			
26	5	43.2	3.9			
27	3	61.7	18.5	1	49.0	6.8
28						
29						
30	3	61.3	-0.1			
31				1	50.0	0.3
32						
33						
34						
35						
36						
37	1	65.0	0.5			

Growth in weight graphs suggest that, rather than specific growth rate declining steadily, two different growth stanzas occur during the sampling period, the younger fish having the higher rate. Figures 8.41 illustrate these two growth stanzas, which can also be seen, through less clearly, in the graphs of length (8.42). Inspection of these graphs indicates that the inflexion between the two stanzas may be at about age = 21. The correlation coefficients (r) for the first stanza are 0.984 for weight and 0.995 for fork length. However, the values are lower (0.798 and 0.862) for the second stanza where the means are unreliable because of the small sample sizes. The first stanza indicates the growth of the female Russian Sturgeon in the immature stage; the second stanza, which shows a lower growth rate, accords with higher incidence of maturity.

8. 3 Discussion

8. 3. 1 Sex composition

For all the years under study, the sex ratio in the catches of southern Caspian Russian Sturgeon was characterized by a predominance of females over males. An earlier trawling survey in the Caspian Sea, in 1981 and 1984, also showed that females were more numerous than males, accounting for 73.3% and 58.5% respectively (Krasikov and Krasavtsev 1986). In contrast to this, males were predominant at the time of spawning runs in the Volga during 1960 (Pavlov 1964, 1972). Pavlov and Slivka (1972) found that males accounted for 80% of Russian Sturgeon during their observations in 1968 and 1969 on the upstream and downstream migration in the Volga. Veshchev (1978), obtained the same result for the Volga River population in 1968 to 1974. However, according to Pavlov and Zhuravleva

(1984, 1986), the proportion of females in the spawning population of the Volga began steadily to increase in 1973 and, in recent years, they accounted for 55% to 60% of the spawners. According to Emadi (1989) in the fishing years 1962 to 1987 an increasing ratio of females is noticeable in both Russian and Persian Sturgeon, which agrees with the result of the present study. The proportion of females in the catches of Russian Sturgeon during 1987-1988 was more than 55% (Saheli 1989).

8. 3. 2 Age composition

The age of the Russian Sturgeon in catches from Caspian region, particularly in the Volga River, was not exceeded 38 years in recent years (Pavlov and Zhuravleva 1984) but, in the past, individuals were encountered at ages up 48 years or even older (Petrov 1927; Lukin 1949; Babushkin and Borzenko 1951; Chugunov and Chugunova 1964). Analysis of archaeological material has shown that the life span of Russian Sturgeon from the Sea of Azov (Don River) and the Caspian Sea (Volga River) could exceed 50 years (Tsepkin and Sokolov 1970).

Analysis of data reveals a multi-aged population in southern part of the Caspian Sea where, for the five years 1990 to 1994, the catches consisted of age groups from 5 through 37 years. Most of the males (95.1%) were between 9 and 15 years old, while 95.3% of the females were between 10 and 18 years old. Average age for both sexes varied from one year to the next, and the range of the age for the females was from 5 to 37 years, and of males from 8 to 31 years. A slight increase was observed in the mean age of the population from 1990 through 1994 (df = 3, r =

0.879, P<0.05 for females, df = 3, r = 0.881, P<0.05 for males). The proportion of fish older than 16 years in catches of 1987-1989 of the south Caspian exceeded 34% (Saheli 1989), while the proportion of the fish older than 16 years in the catches of 1990-1994 was only about 11.5%. In the catches 1990-1994 most of the population are young (9 to 16). Comparing the catches for the two periods 1987-1989 and 1990-1994, the percentage of older fish has decreased which is a sign of overfishing.

The maximum ages of females and males in the Volga River during 1968 through 1974 were34 and 29 years respectively, and the average ages were 22.3 and 16.9 years (Veshchev 1978). From 1981 through 1985, the spawning populations consisted of 32 age groups, from 7 through 38 years. A large proportion of the males (48%) were 15 to 18 years old, and 53.2% of the females were 19 through 23 years old (Pavlov and Zhuravleva 1986a). The higher mean age for the population of the Volga, is probably because most of the fish entering the Volga for spawning are mature; the catch of the southern Caspian contains many immature fish while most of the mature fish are in their first maturity. According to different authors (Berg 1948; Ambroz 1964; Chuguvov and Chugunova 1964; Kozhin 1964; and Makarov 1964) Russian Sturgeon is in third place among the acipenserid species, behind *Acipenser ruthenus* and *A. stellatus*, for earliness in reaching sexual maturity. Individuals may rarely become sexually ripe at an age 7 to 9 years and a length (*TL*) not less than 100 to 110 cm. The majority of the males being to reproduce at an age of 11 to 13 years, while the equivalent age of the females is 12 to 16 years. In the present study more than 80% of mature females were older than 14 years and 77% of mature males were older than 12 years (Table 8.7).

8. 3. 3 Length composition

According to Nikols'kii (1961) the Russian Sturgeon reaches a maximum length of 235 cm. The fork length of females in the southern Caspian, 1990-1994, ranged between 90 and 204 cm and of males between 95 and 189 cm. The means varied between 130.4 and 134.2 cm in females and, from 118.7 to 127.3 cm in males. There are no comparative data for the southern Caspian.

In the years 1979 to 1985, migrating females in the Volga River ranged between 145 and 171 cm total length and males between 116 and 141 cm; the averages were 154.5 cm for females, and 128.8 cm for males (Raspopov and Putilina 1989). Comparing the two populations, the ranges of lengths in the southern Caspian were higher than in the Volga River, and the average length of the females in the Volga was slightly greater than in the southern part; in contrast the average length of males in the southern part was greater than in the Volga. However, according to Veshchev (1972), the mean total length of Russian Sturgeon females in the Volga was 145.2 cm and of males 128.3 cm, both less than in the present study.

Comparing the Russian with the Persian Sturgeon, in all years the mean lengths of females and males were smaller in the former. Thus, the mean length of the female Persian Sturgeon varied between 153.7 and 164.3 cm, and of males from 137.5 to 139.4 cm, while the figures for the Russian Sturgeon were 130.4 to 134.1 cm for females, and 118.4 to 127.3 cm for males (see, Table 7. 10 and Table 8. 10). The

Persian Sturgeon evidently has the higher growth rate.

The minimum length for catching the Russian Sturgeon in the southern Caspian is 113 cm total length. The present (1990-1994) catches comprised 80% of fish larger than 125 cm, which still contained many immature fish, this suggests that the minimum length of capture for this species should be increased.

8. 3. 4 Weight composition

In 1969, the average weight of female Russian Sturgeon migrating in the Volga was 19.8 kg, while the males averaged 10.7 kg (Pavlov 1972). In 1983, the corresponding weights were 24.4 kg and 14.0 kg, respectively (Pavlov and Zhuravleva 1984). Individual weights for the period 1990-1994 varied between 3.3 kg and 96 kg. Females ranged from 3.3 to 96 kg and males from 5 to 50 kg. The mean individual weight for females ranged between 20.1 to 24.1 kg, of males 14.7 to 17.4 kg. According to Emadi (1989) total average weight of the Russian, Persian Sturgeon for fishing years 1962 to 1987 in the southern Caspian varied between 15.3 and 18.5 kg, but because the result is for two species together it is difficult to be compare with the present study.

The mean weight of migrating sturgeon in the Volga between 1979 and 1985 was 24 kg for females and 11 kg for males (Raspopov and Putilina 1989). Comparing with the present study, the mean weight of females is similar but the mean weight of the males in the southern Caspian is much higher. In the present study, within most age groups, the females usually have a greater weight than the males. Differences in the weights of older fish (18 years or more) are much higher than in younger age groups. Comparing the mean weights of Persian and Russian Sturgeon, (29.2 to 30.6 kg for females and 16.9 to 20.1 kg for males, versus 20.1 to 24.1 kg for females and 14.7 to 17.4 kg for males, (Tables 7. 11 and 8.11) Persian Sturgeon of both sexes were heavier in all years.

8. 3. 5 Annual increment in length and weight

The Russian Sturgeon, like the other three species under study, is characterized by a variable annual increment in length and weight. The great diversity in weight and length has been noted by Altuf'ev and Romanov (1988), who examined the regional differences in growth of juvenile sturgeon (0+ to 7+) in a hatchery pond and in the north and middle of the Caspian Sea.

The graph of length-at-age in the Russian Sturgeon is clearly not of the decaying exponential type usual for most fish (Figs 8.4 to 8.27), most likely because it is a long-lived species (probably over 48 years). After initial rapid growth (Chugunova, 1940; Nikols'kii, 1961), its annual increments are relatively small. Sampling error, compounded by the fact that fish mature only at intervals of several years, about 3 years for males and 5 years for females (Krasikov, 1981), results in apparently erratic variations in length at age. The present data cover only half of the potential life span, with sample sizes of ages >21 years being small, undoubtedly because of the high fishing mortality.

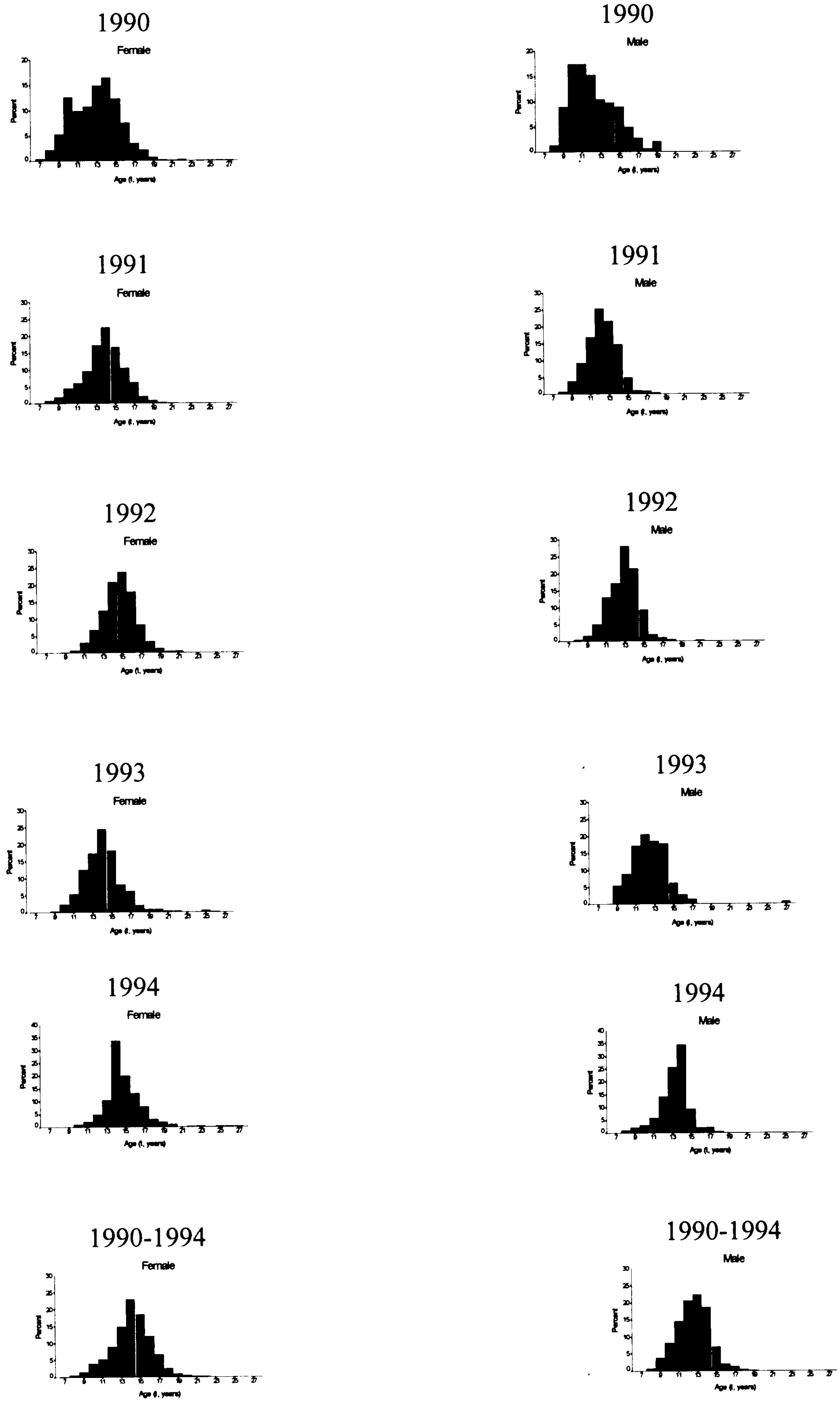
The data suggest three distinct growth stanzas during the Russian Sturgeon's life. Initially, before it enters the fishery, it is high; from about 7 to 21, in the classes that dominate the fishery, growth rate is intermediate; and from about 22 onwards it appears slower. One single equation does not describe growth throughout the entire span of life. Under this circumstances it is necessary to find an equation that best fits the middle stanza.

Holci'k (1989) used data collected by other authors (Ambroz 1964; Chugunov and Chugunova 1964; Tsepkin and Sokolov 1970) and concluded that, within any age group, the females usually are larger and heavier than males. The results of the present study show (Table 8.23) that the annual mean lengths are nearly similar at 8 and 10 years; after that annual mean lengths are significantly higher in females than in males (paired samples t-test, t-value = 4.6, $P<0.01$).

This and earlier studies also demonstrate that Persian Sturgeon grow faster than Russian Sturgeon in the southern Caspian. Comparing the mean lengths from 8 to 18 years old, both male and female Persian Sturgeon were significantly (paired sample t-test, $t = 8.3$ and 13.2 for females and males respectively, $P<0.01$) larger than Russian sturgeon of the same age (Tables 7.23and 8.21). For instance, the mean lengths of 15 year old female and male Persian Sturgeon were 147.5 and 145.5 cm respectively, while the Russian sturgeon were 137.0 and 132.5 cm. For 17 year old fish these figures were 160 and 156 cm for female and male Persian Sturgeon and 146 and 147 cm for female and male Russian sturgeon. Babushkin and Borzenko (1951) noted the slightly higher growth rate for the Persian Sturgeon in this area but the result of the present study confirms it.

Comparison of the annual mean weight of Persian and Russian Sturgeon in the southern Caspian showed no significant differences between them (paired samples t-test, t-values = 1.3 and 0.7 for females and males respectively, $P>0.05$). But, according to Artyukhin (1979) the body weight of Persian Sturgeon is greater than that of Russian Sturgeon in the Volga population.

Fig 8.1: Age distribution of female and male Russian Sturgeon 1990-1994.



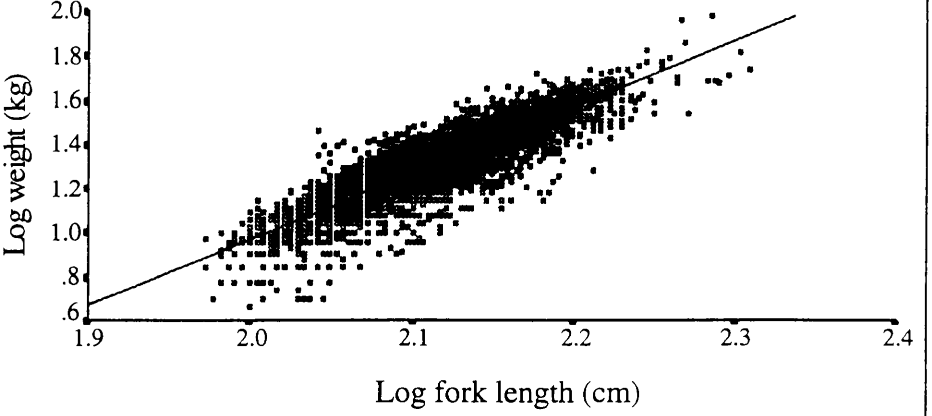


Fig 8.2: Plot of log weight vs log length of the female Russian Sturgeon (1990-1994).

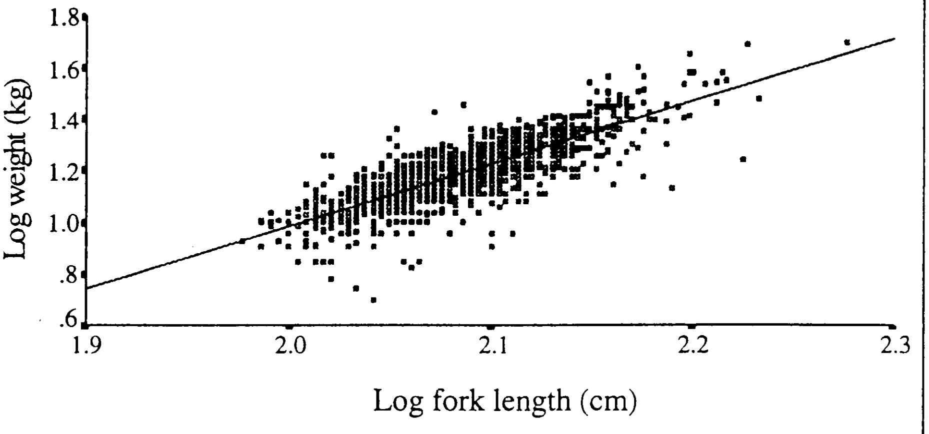


Fig 8.3: Plot of log weight vs log length of the male Russian Sturgeon 1990-1994.

Fig 8.4: Length-age relationship of the female Russian Sturgeon 1990 (linear plot).

Fig 8.5: Length-age relationship of the female Russian Sturgeon 1990 (quadratic plot).

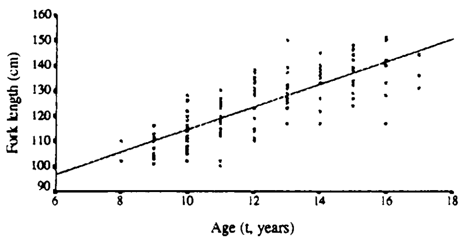


Fig 8.6: Length-age relationship of the male Russian Sturgeon 1990 (linear plot).

Fig 8.7: Length-age relationship of the male Russian Sturgeon 1990 (quadratic plot).

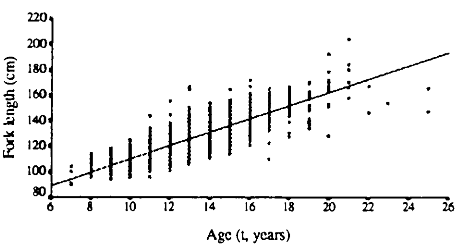


Fig 8.8: Length-age relationship of the female Russian Sturgeon 1991 (linear plot).

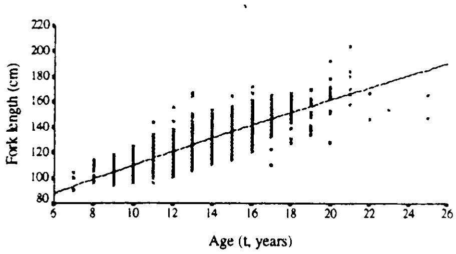


Fig 8.9: Length-age relationship of the female Russian Sturgeon 1991 (quadratic plot).

Fig 8.10: Length-age relationship of the male Russian Sturgeon 1991 (linear plot).

Fig 8.11: Length-age relationship of the male Russian Sturgeon 1991 (quadratic plot).

Fig 8.12: Length-age relationship of the female Russian Sturgeon 1992 (linear plot).

Fig 8.13: Length-age relationship of the female Russian Sturgeon 1992 (quadratic plot).

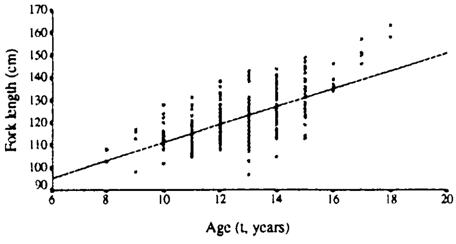


Fig 8.14: Length-age relationship of the male Russian Sturgeon 1992 (linear plot).

Fig 8.15: Length-age relationship of the male Russian Sturgeon 1992 (quadratic plot).

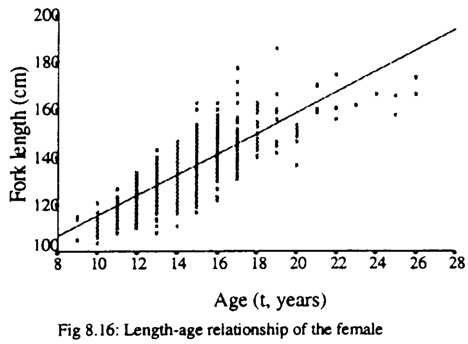


Fig 8.16: Length-age relationship of the female Russian Sturgeon 1993 (linear plot).

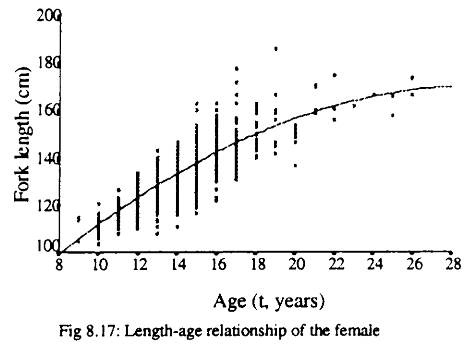


Fig 8.17: Length-age relationship of the female Russian Sturgeon 1993 (quadratic plot).

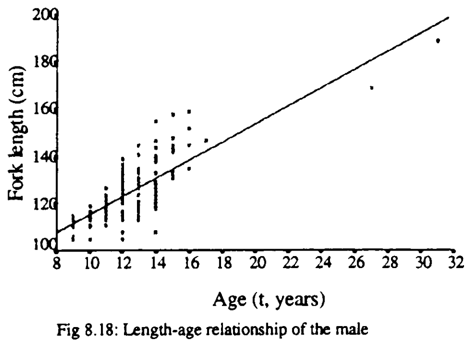


Fig 8.18: Length-age relationship of the male Russian Sturgeon 1993 (linear plot).

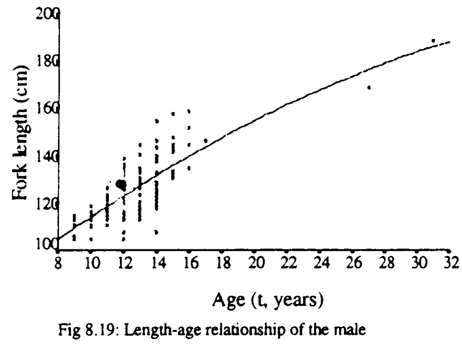


Fig 8.19: Length-age relationship of the male Russian Sturgeon 1993 (quadratic plot).

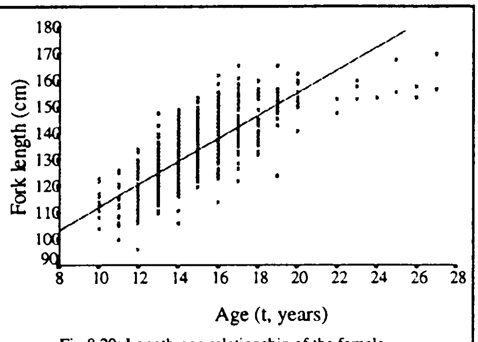


Fig 8.20: Length-age relationship of the female Russian Sturgeon 1994 (linear plot).

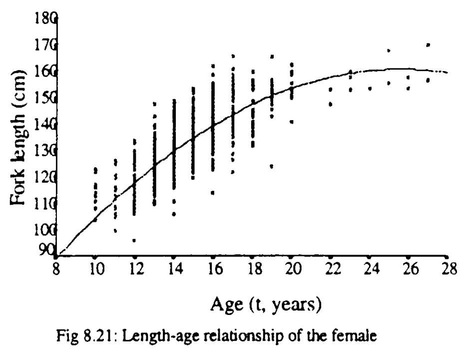


Fig 8.21: Length-age relationship of the female Russian Sturgeon 1994 (quadratic plot).

Fig 8.22: Length-age relationship of the male Russian Sturgeon 1994 (linear plot).

Fig 8.23: Length-age relationship of the male Russian Sturgeon 1994 (quadratic plot).

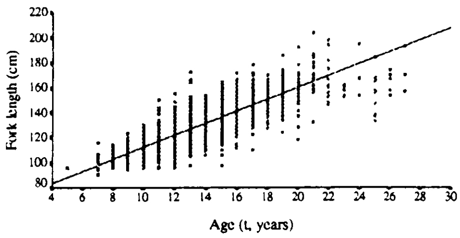


Fig 8.24: Length-age relationship of the female Russian Sturgeon 1990-1994 (linear plot).

Fig 8.25: Length-age relationship of the female Russian Sturgeon 1990-1994 (quadratic plot).

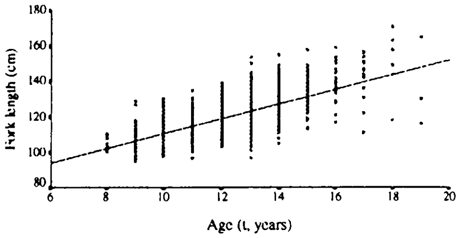


Fig 8.26: Length-age relationship of the male Russian Sturgeon 1990-1994 (linear plot).

Fig 8.27: Length-age relationship of the male Russian Sturgeon 1990-1994 (quadratic plot).

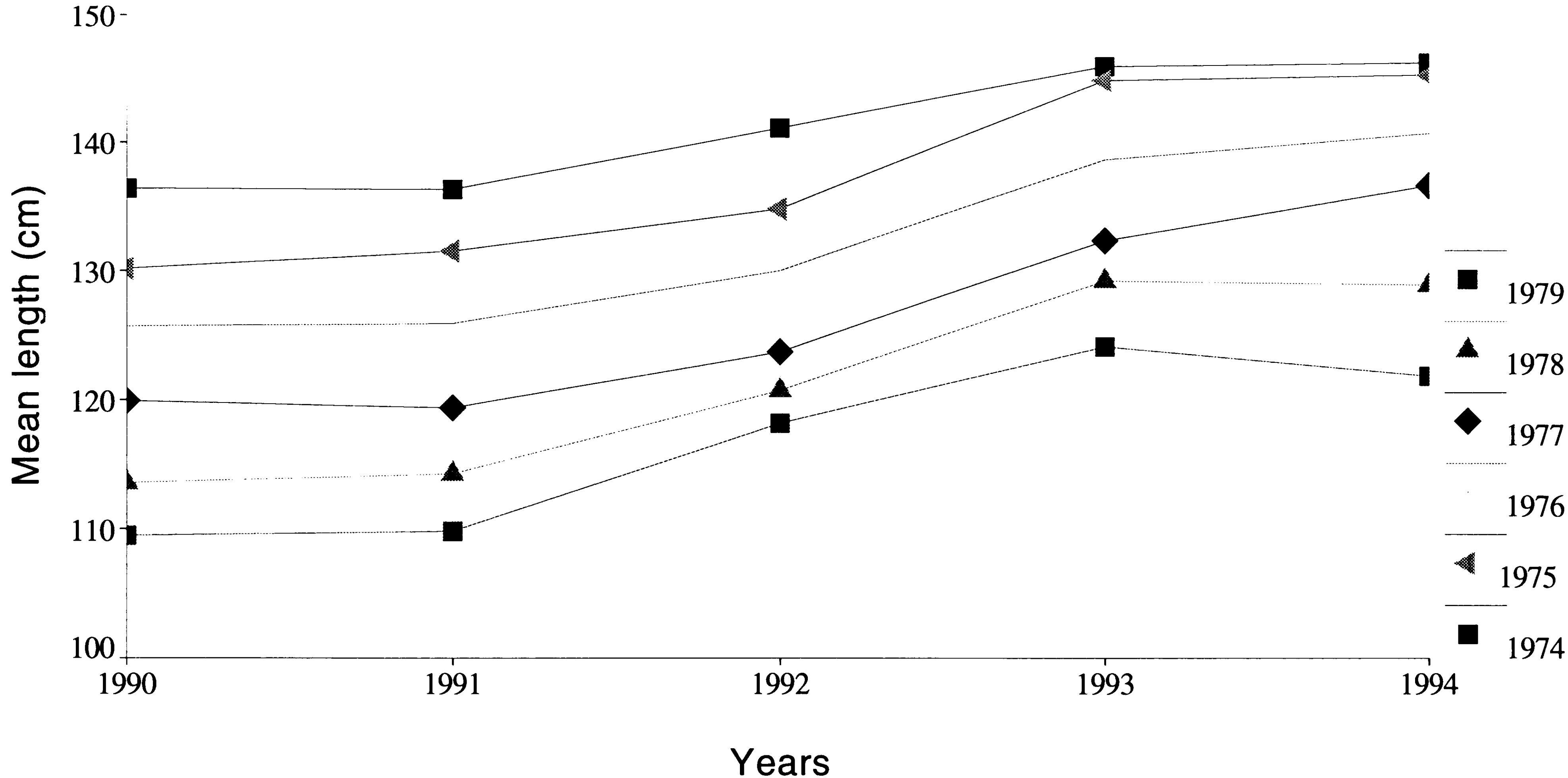


Fig 8.28: Female Russian Sturgeon: mean length at age by cohorts.

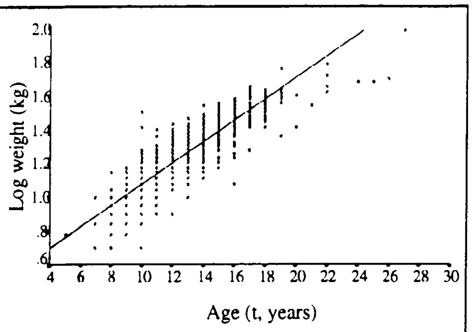


Fig 8.29: Plot of log weight vs age of the female Russian Sturgeon 1990.

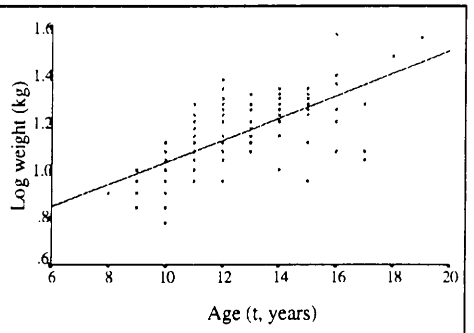


Fig 8.30: Plot of log weight vs age of the male Russian Sturgeon 1990.

Fig 8.31: Plot of log weight vs age of the female Russian Sturgeon 1991.

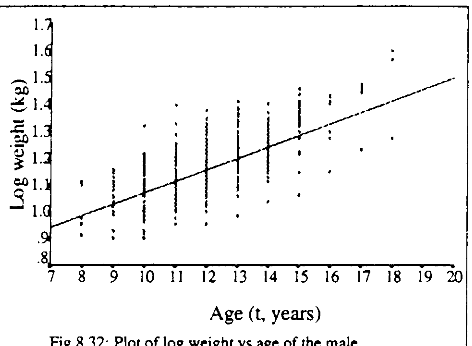


Fig 8.32: Plot of log weight vs age of the male Russian Sturgeon 1991.

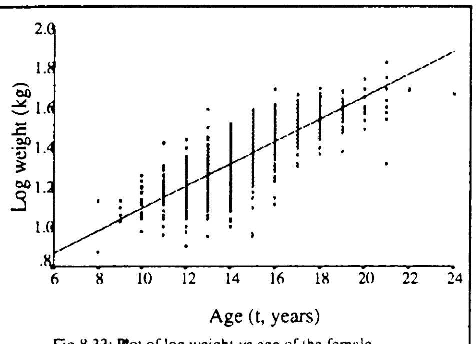


Fig 8.33: Plot of log weight vs age of the female Russian Sturgeon 1992.

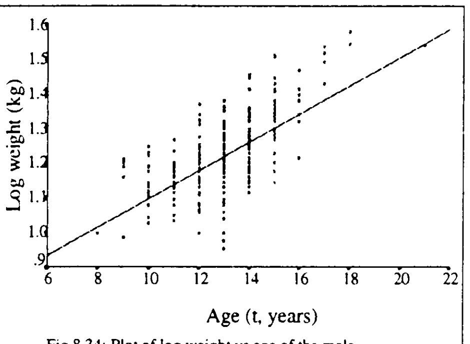


Fig 8.34: Plot of log weight vs age of the male Russian Sturgeon 1992.

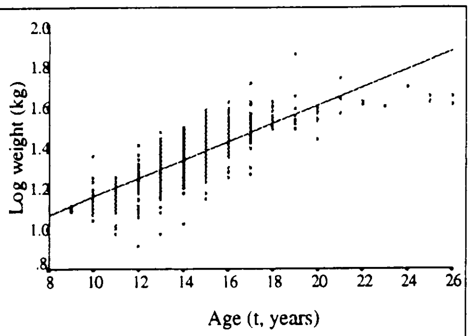


Fig 8.35: Plot of log weight vs age of the female Russian Sturgeon 1993.

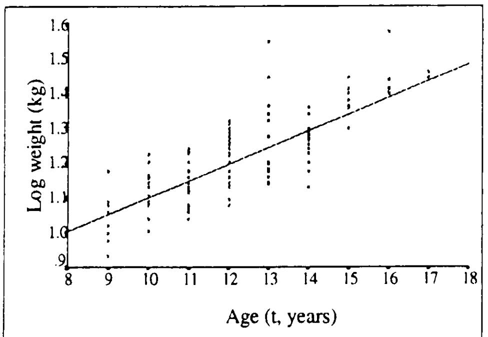


Fig 8.36: Plot of log weight vs age of the male Russian Sturgeon 1993.

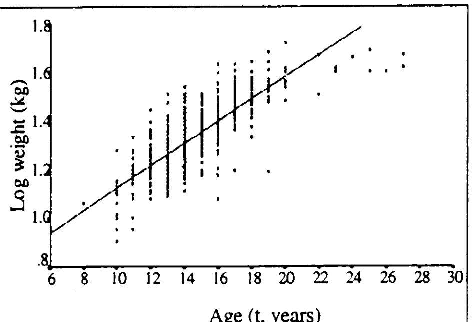


Fig 8.37: Plot of log weight vs age of the female Russian Sturgeon 1994.

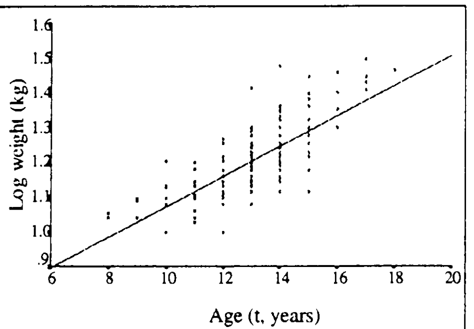


Fig 8.38: Plot of log weight vs age of the male Russian Sturgeon 1994.

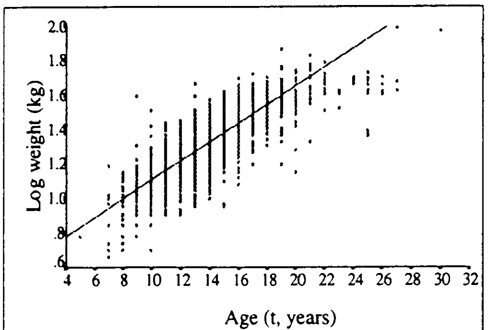


Fig 8.39: Plot of log weight vs age of the female Russian Sturgeon 1990-1994.

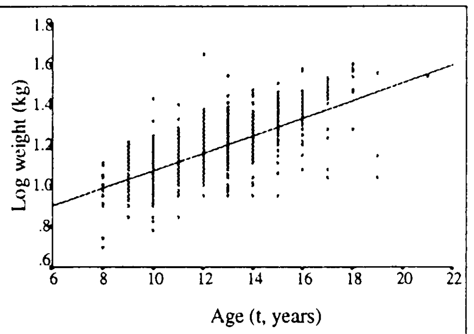


Fig 8.40: Plot of log weight vs age of the male Russian Sturgeon 1990-1994.

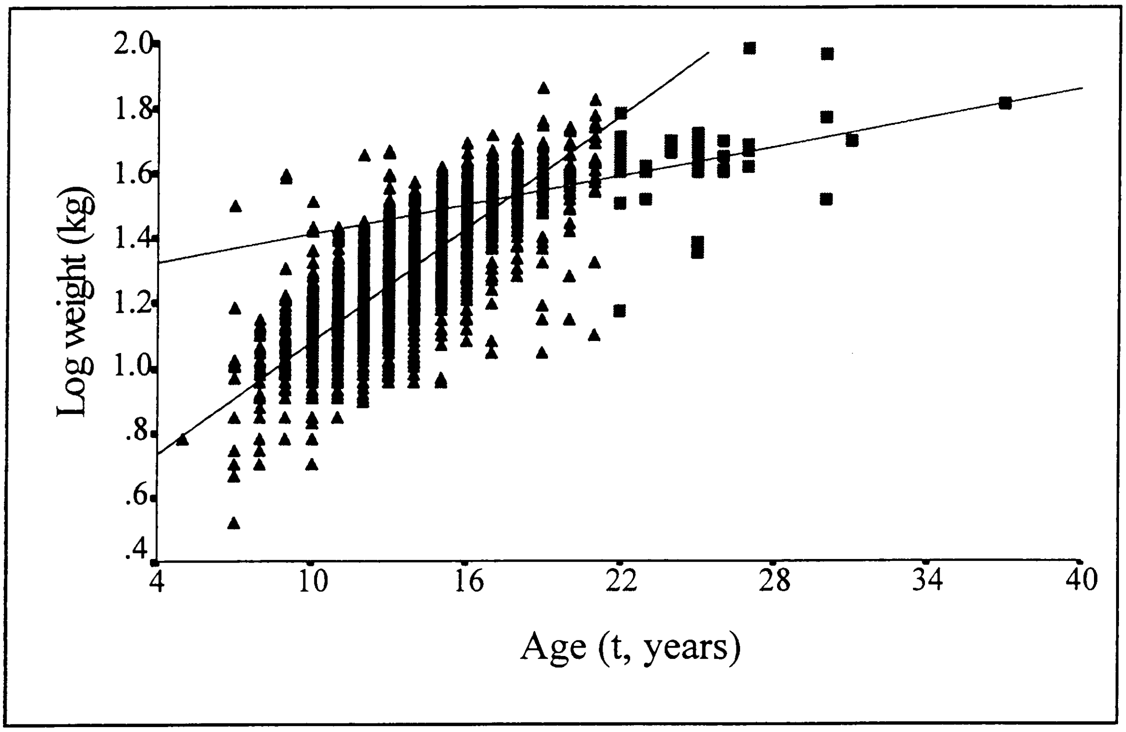


Fig 8.41: Female Russian Sturgeon: Stanzas of growth-in-weight 1990-1994. Graph of growth using log weight regarded as stanzas rather than as a decaying exponential. The graph shows the periods from age 5 to 21 with fitted straight line (log W = 0.5226 + 0.0571t) and from 24 onwards with another (log W = 1.3426 + 0.0122t). It should be noted that the sample sizes during the second stanza tend to be very small (Table 8.31).

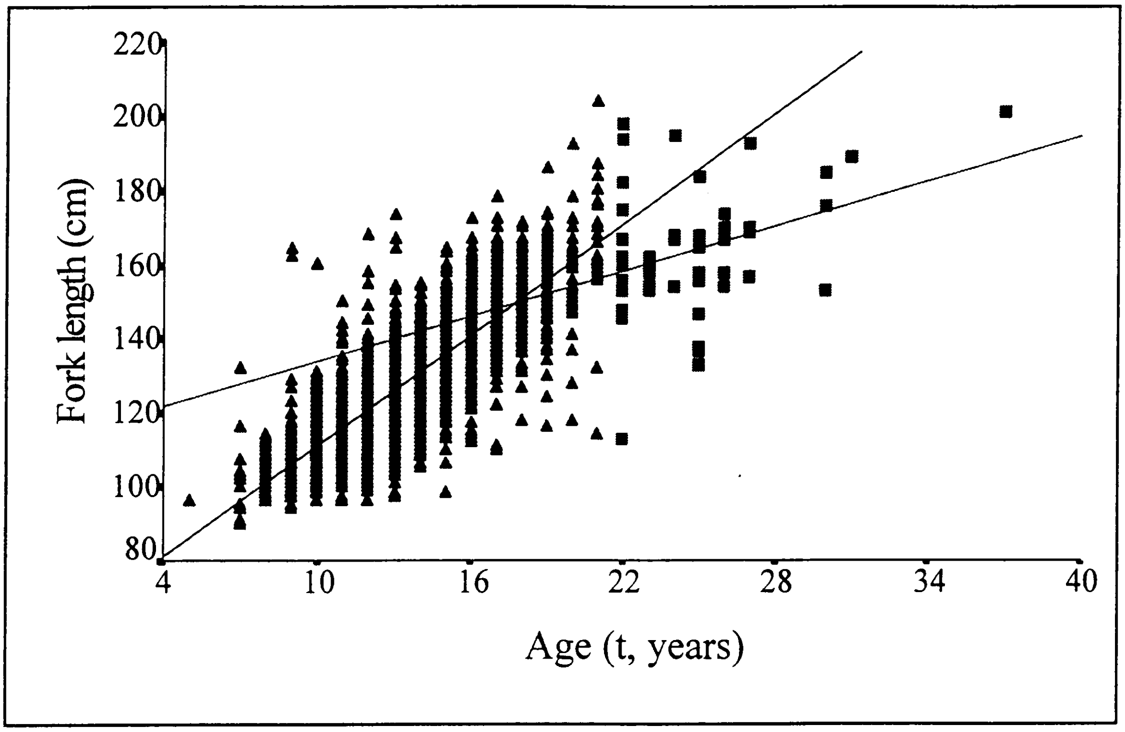


Fig 8.42: Female Russian Sturgeon: Stanzas of growth-in-length 1990-1994. Graph showing growth-in-length data regarded as stanzas rather than as decaying exponential. The graph shows the periods from age 5 to 21 with curve fitted straight line ($L = 62.481 + 4.9429t$) and from 21 onwards with another ($L = 127.9 + 1.4932t$). It should be noted that the sample sizes during the second stanza tend to be very small (Table 8.24).

The regression equations for both stanzas are as follows:

First stanza: $L = 62.241 + 4.9429t$

second stanza: $L = 127.9 + 1.4932t$

CHAPTER 9

Estimation of von Bertalanffy growth parameters

9. 1 Introduction

Growth is the change of size of a living organism with age. Fish differ from the higher animals such as mammals and birds in that they appear to continue growing throughout the whole of their lives (Jones, 1976). Growth may be defined as the change over time of body weight, and was regarded by von Bertalanffy (1938) as being the net result of two processes with opposite tendencies, one building-up body substances (anabolism) and the other breaking these substances down (catabolism). Growth can be recorded by making measurements of the length or weight of an individual and relating it to age. Since growth in fish (and some other organisms including certain crustaceans and molluscs) never quite ceases, the relationship between size and age tends towards an asymptote. The growth rate at any age, corresponds to the slope of the curve at that age.

The study of growth effectively means the determination of body size or weight as a function of age. Therefore, all stock assessment methods work essentially with age composition data. In temperate waters, such data can usually be obtained by the counting annual rings on hard parts such as scales and otoliths; in sturgeons, fin rays are used. Such rings are formed by strong, regular fluctuations in environmental conditions from summer to winter and vice versa.

A number of expressions have been fitted to age/length (and age/weight) data (see Jones 1976). One of the most important and widely used was suggested by von Bertalanffy (1934). The process of anabolism, which leads to the increase in body weight of the organism, has been described as being proportional to the body area

(Bertalanffy, 1938), i.e. to L^2 or $W^{2/3}$, where L, W are the length and weight of the organism, respectively. Likewise, the process of catabolism, which leads to a decrease in the organism's body weight, is proportional to weight itself, i.e. to L^3 or W. This led to growth being mathematically represented as

$$dW/dt = aW^{2/3} - cW \qquad (1)$$

where dW/dt is the change in body weight per unit time (t), a is the anabolic coefficient and c is the catabolic coefficient. The integration for length growth gives the equation

$$L_t = L_\infty [1\text{-}\exp(-K(t\text{-}t_0))] \qquad (2)$$

or since in general, $W = L^3$, equation for growth in weight become

$$W_t = W_\infty [1 - \exp(-K(t - t_0))]^3 \qquad (3)$$

Equation (2) is the most important and widely used, known as the von Bertalanffy Growth Function (VBGF), a mathematical model for individual growth developed by von Bertalanffy (1934), which has been shown to correspond to the observed growth model of most fish and a number of invertebrate species. It expresses growth in length, for example, in terms of three parameters: L_∞, the asymptotic length, K, which describes growth rate, and an extrapolated constant t_0 at which length would have been zero, where L_t is the length at time t.

The von Bertalanffy growth equation describes the decaying exponential curve of length; in its cubic form it describes the sigmoid curve of weight. The constants have been extensively employed to characterize fish species, or stocks within species, and can be incorporated readily into stock assessment models (Beverton and Holt

1957, Ricker 1975, Pauly 1980b, Cushing 1981, Pauly and Morgan 1987). The simplest derivation of parameters values is that of Gulland (1969). The plot of increment against length, introduced by Gulland and Holt (1959) and later more accurately formulated by Gulland (1969), gives a line of negative slope, exp (-k)-1, and x-axis intercept L_∞.

The basic concepts underlying the von Bertalanffy growth equation have often been challenged (see Pauly 1981) but, despite that, the model has received wide support and various works have been carried out to substantialise and improve its performance. Such works led to the development of other mathematical models, some of the most significant being the graphical plots by Walford (1946) and Gulland and Holt (1959).

Gaschutz *et al.* (1980) and Pauly (1981), however, contended the equation (1) may in fact be generalised as

$$DW/dt = aW^d - cW \qquad (4)$$

where a, c and d are constants. By setting the value of d at 2/3, equation (2), which they called the *special* VGBF, is obtained. By allowing d to take a certain range of values, including 2/3, and considering the general length-weight relationship of the animal to be the form $W = q\,L^b$, where q and b are constants, a *generalised* VBGF is obtained which gives the form

$$L_t = L_\infty\,[1 - \exp(-KD\,(t - t_0))]^{1/D} \qquad (5)$$

where D is a "surface factor" defined as D = b (1-d). The advantage of the generalised VBGF is that this form of the growth equation allows smaller deviations when fitting growth data, and a biological interpretation of the equation parameters as intended by Bertalanffy (Pauly, 1984).

Parkin and Larkin (1959) questioned whether, in fact, a single expression, or a single set of parameters, does accurately describe the growth of fish. They considered in particular the growth of diadromous species, such as salmonoids, in which the growth environment totally changes one or more during the life of the fish. These authors concluded that "Many species may change their ecological niche as they grow larger, thus revising the "ultimate size" to which they are growing. Many species of salmonids undergo marked physiological transformations at different periods of their life history and these transformations may also be related to a size "threshold". Growth of fish may thus be visualized as a series of growth stanzas, which are entered by ecological and physiological size thresholds, and with in which size is the basic determinant of both ecological and physiological opportunity for growth. The question of mathematical technique for describing growth is highly controversial. Arbitrary curve fitting may result in growth equations which combine dissimilar growth stanzas, thus "smooth out" important aspects of growth processes".
They suggested that for prediction of growth increments in the population it thus requires to separation into life history stages, each characterized by particular growth rates.

The discussion of growth in previous chapters suggests that stanzas of the type demonstrated by Parkin and Larkin (1959) also occur in sturgeons. Thus while fitting a single von Bertalanffy curve to the data has useful management implications, and is therefore a valuable objective; it may obscure the effects of environmental and/or physiological changes in the life of the growing fish.

The growth of any animal is influenced by many factors, which Royce (1984) categorised them as endogenous and exogenous. The endogenous factors will include events in the animal's schedule of development, from the embryo through maturation to senility. Maturity is a factor likely to influence fish growth. After the onset of maturity, energy that might have been used for growth will be required for developing the maturing gonad and for making spawning migrations. Thus, growth can be expected to be lower after the onset of maturity than it otherwise would have been.

The exogenous factors, on the other hand, are environmental factors which may cause different stocks to grow at different rates. These include environmental conditions and temperatures, quality and abundance of food supply and population density. Investigations have shown that both of the von Bertalanffy parameters, K and L_∞, are influenced by temperature (Jones 1976). Holt (1959) suggested that K ought to increase logarithmically with temperature, and that L_∞ should decrease slowly with temperature.

Growth varies between species. Beverton and Holt (1959), Ursin (1967) and Pauly (1978) have tabulated growth parameters for many of species. For example, of the lager fish species, in the blue-fin tuna, *Thynnus thynnus* (Linnaeus), $L_\infty = 270$ cm and K = 0.6. Acipenser, the sturgeon (*Acipenser fulvescens*), also grows to a large size (178 cm) but it grows relatively slowly, with K = 0.05. The largest value of K is found in the female *Labidesthes* (K = 3.7), which reaches its maximum size in little more than a year.

There is a negative correlation between the values of K and L_∞ in different species. Jones (1976) concluded that the rate of decline in K with increasing value of L_∞ in not uniform, but is most rapid for small values of L_∞. In the length range up to 40 cm, values of K decline from as high as 3.7 to between 0.15 and 0.4. For fish with much larger values of L_∞, more than 100 cm, values of K mainly range from 0.05 to about 0.4 and showed no detectable trend.

The purpose of this chapter is to estimate growth parameters of *Huso huso* (Beluga), *Acipenser stellatus* (Stellate Sturgeon), *A. persicus* (Persian Sturgeon) and *A. guldenstadti* (Russian Sturgeon), taking into consideration the occurrence of stanzas as noted in chapters 5-8.

9. 2 Methods

The length at age data sets of the four species have already been presented in chapters 5 to 8. The method of estimating K and L_∞ from growth increments (Gulland and Holt 1959, Gulland 1969) depends on the increment declining with age, as von Bertalanffy's (1934) model assumes. As the sample sizes for the older age classes tended to be very small and, it became apparent, well off the growth curve predicted by the von Bertalanffy equation, parameter estimates initially utilized only the age classes (8-20) for which lengths were based on large samples. In circumstances in which the increments fluctuated greatly between years, the von Bertalanffy parameters were estimated using smoothed values of length and increment derived from the quadratic equation that best fitted the data. Where, as in the length at age sets for males, the increment did not decrease over the ages covered by adequately sized samples, L_∞ was estimated from maximum observed length, L_{max}. The criterion for choosing the best L_∞ near to L_{max} was that the generated von Bertalanffy curve should pass with ±1SD of all the annual mean lengths.

Since, $\ln [(L_\infty - L_t) / L_\infty] = - K (t - t_0)$, the initial estimates of K and L_∞ were refined by plotting $- \ln [(L_\infty - L_t) / L_\infty]$ against age, t (Gulland 1969), which relationship should be linear, with slope K and x-axis intercept t_0. However, as t increases, the values of $\ln [(L_\infty - L_t) / L_\infty]$ are increasingly sensitive to inaccuracy in the initial estimate of L_∞, so that the line becomes curved. The correct values of K and t_0 are obtained when, by iteration, the exact value of L_∞ is found that produces a straight line. Goodness of fit is assessed by the product-moment correlation coefficient (r). The correct L_∞ is that which produces the highest value of r (for highest correlation r = 1).

It was found that, even for female fish, the parameter estimates produced curves that fitted only the earlier age groups in the data sets which, being based on large sample sizes, had been used in the Gulland plots. To find values that approximated to the entire length at age data sets it was necessary, by iteration, to alter the values of K and L_∞, even though this meant accepting much lower values of r for the most reliable part of the curve. Such derived curves tended to have unrealistic values for t_0. The procedures are fully described using the Beluga data set. As pointed-out earlier (Chapters 4-8), the initial, pre-recruit growth of sturgeon is relatively high, and an appropriate, steeper line had to be fitted by eye.

The growth parameters were also estimated by the program called Fishery Science Application System (FSAS) by S. B. Saila, C. W. Recksiek and, M. H. Prager). To obtain the von Bertalanffy growth parameters of the sturgeon (present data) from this program, it was necessary to force the curve through zero (i.e, put zero for the first row of the data sets (age, mean length)).

9. 3 Results

9. 3. 1 The Beluga

Two growth stanzas (second and third) were recognized during the sampling period for the female Beluga (chapter 5), with a separation at age about $t = 24$. Table 9. 1 shows the input data for estimation of female Beluga growth parameters. For female Beluga the following procedures were employed;

(1) The line of best fit was determined (Chapter 5). This is shown in Fig 9. 1 with actual means (±1SD) superimposed.

(2) Increments were plotted against mean length (Gulland and Holt 1959), ignoring 'rogue' points, to derive first estimates of L_∞ and K. There is great scatter (Fig 9. 2).

(3) A further plot was made using the estimated increment and mean length from (1) above. Since the line of best fit was not a von Bertalanffy curve, the points do not fall as a straight line (Fig 9.3). This confirms that the data sets cannot be fitted by a simply derived von Bertalanffy model.

(4) Plot (3) was repeated, using only points for the middle stanza, which contained the

largest samples. This provided estimates of $L_\infty = 666$ cm and K = 0.016, with r = 0.999. However, an L_∞ of 666 cm is manifestly too high (literature estimates of L_{max} are 490-600 cm total length), and the projected curve is far above the data points for the older year classes. However, these values were used in the von Bertalanffy plot of $- \ln [(L_\infty - Lt) / L_\infty]$ vs age, t (Fig 9. 4), substituting a series of values for L_∞ which are closer to the L_{max}, thus:

$L_\infty = 666$ cm, K = 0.016, $t_0 = -7.0747$, r = 1.000 (Fig 9.5)

$L_\infty = 550$ cm, K = 0.021, $t_0 = - 6.1452$, r = 0.9993 (Fig 9.6)

$L_\infty = 450$ cm, K = 0.029, $t_0 = - 4.8705$, r = 0.9991 (Fig 9. 7)

From the above estimations, three growth curves of female Beluga for the middle stanza were drawn (Figure 9.8). Even though the more realistic curves are obtained with lower (though still high) values of r, the curves remain well within ±1SD.

(5) At this stage, the Gulland plot was repeated for only the older fish, again using estimates from the line of best fit (final stanza, Fig 9. 9).

(6) The estimates of L_∞ and K from (5) were then used in the von Bertalanffy plot (Fig 9. 10),

$L_\infty = 533$ cm, K = 0.023 and $t_0 = - 4.033$, r = 0.9981

Figure 9.11 shows the growth of female Beluga showing annual means ±1SD (where $n \geq 2$) and the calculated von Bertalanffy curve for $L_\infty = 533$ cm, which is regarded as realistic for females. The fit to annual means is not as close in the middle stanza but the line is still almost invariably within ±1SD.

(7) Assuming that the Beluga larva measured about 10 mm at hatching (11 mm,

hatching length, Ghazel 1987), by trial and error, von Bertalanffy parameters were calculated for the juvenile stanza so that a curve from 10 mm at $t = 0$ joined the main curve at about $t = 10$. The parameters obtained are as follows:

$$L_\infty = 320,\ K = 0.065,\ t_0 = -0.05,\ r = 0.997$$

Figure 9.12 shows the growth curves for female Beluga showing three stanzas. Growth parameters of the female Beluga were also estimated using FSAS program from the complete sets of mean length of the original data (Table 9.1) and are as follows:

$$L_\infty = 370,\ K = 0.052,\ t_0 = -0.354,\ r = 0.933$$

Fig 9.13 shows the growth curve for female Beluga based on FSAS estimation. The L_∞ estimated by this program is much lower than maximum observed length (420 cm) in the original data, which shows that this program underestimates L_∞.

Table 9.1: Input data and regression for the von Bertalanffy plots of the female Beluga.

age (t)	number	mean length ±1SD	length estimated from line of best fit	incre-ment	-ln [$(L_\infty - L_t) / L_\infty$] L_∞ = 666 cm	-ln [$(L_\infty - L_t) / L_\infty$] L_∞ = 550 cm	-ln [$(L_\infty - L_t) / L_\infty$] L_∞ = 450 cm
8	1	172.0 ±0.00	141.4		.24	.30	.38
9	9	156.2 ± 14.9	149.6	8.2	.25	.32	.40
10	29	171.6 ± 12.5	157.7	8.1	.27	.34	.43
11	43	176.8 ± 22.6	165.7	8.0	.29	.36	.46
12	93	177.3 ± 11.5	173.5	7.9	.30	.38	.49
13	137	181.6 ± 16.2	181.3	7.7	.32	.40	.52
14	251	186.3 ± 15.6	188.9	7.6	.33	.42	.54
15	247	190.2 ± 17.5	196.4	7.5	.35	.44	.57
16	205	201.6 ± 22.7	203.8	7.4	.37	.46	.60
17	124	211.5 ± 19.1	211.0	7.3	.38	.48	.63
18	61	221.1 ± 21.0	218.2	7.1	.40	.51	.66
19	32	233.6 ± 28.1	225.2	7.0	.41	.53	.69
20	23	239.7 ± 28.1	232.1	6.9	.43	.55	.73
21	10	237.1 ± 38.8					
22	9	261.7 ± 18.0					
23	11	267.6 ± 25.1					
24	8	270.6 ± 30.9					
25	5	292.6 ± 16.4					
26	10	283.1 ± 26.1					
27	3	290.7 ± 9.00					
28	6	296.7 ± 26.5					
29	2	291.5 ±12.1					
30	2	289.5 ± 20.5					
31	2	320.0 ± 0.00					
32	0	000.0 ±0.00					
33	2	321.5 ±5.00					
34	2	289.0 ± 8.50					
35	0	000.0 ±0.00					
36	3	321.0 ± 31.5					
37	1	305.0 ± 0.00					
38	1	316.0 ± 0.00					
39	1	214.0 ± 0.00					
40	0	000.0 ±0.00					
41	1	320.0 ± 0.00					
42	0	000.0 ±0.00					
43	0	000.0 ±0.00					
44	1	420.0 ± 0.00					
45	0	000.0 ±0.00					
46	1	343.0 ± 0.00					

For male Beluga the difficulty in estimating the von Bertalanffy parameters was greater. First, the sample sizes were smaller in all years, and secondly, the trend of growth indicated by annual means was more irregular in comparison with females. Therefore the curve does not approximate to the von Bertalanffy, even when the five years are combined. However, by examining every year separately it was found that some part of the data for the year 1992 could be used for a von Bertalanffy plot. Different values of L_∞ (270, 274 and 284 cm) near to L_{max} were used and the best one was found to be 270 cm. Figure 9.14 shows the von Bertalanffy plot for estimation of growth parameters:

$L_\infty = 270$ cm, $K = 0.086$, $t_0 = -0.259$, $r = 0.9099$, $P<0.01$.

Figure 9.15 shows the growth curve of male Beluga showing annual means ±1SD (where $n \geq 2$) and the calculated von Bertalanffy curve for $L_\infty = 270$ cm.

From the FSAS program, using combined years' mean length (column 9 of Table 5.24) and forcing the curve through zero, the growth parameters of male Beluga were estimated as:

$L_\infty = 302$ cm, $K = 0.072$, $t_0 = -0.574$, $r = 0.9679$

Fig 9.16 shows the growth curve of males based on FSAS estimation.

Table 9.2: Male Beluga: input data for estimation of von Bertalanffy growth parameters.

age (t, years)	number	mean length ±SD	-ln [(L_∞ - Lt) / L_∞]
8	1	177.0 ±0.00	
10	2	159.5 ±2.10	0.89
11	9	173.3 ±6.20	1.03
12	40	177.0 ±7.10	1.07
13	57	184.1 ±7.60	1.15
14	58	184.1 ±13.5	1.15
15	41	192.7 ±14.2	1.25
16	24	197.5 ±8.60	1.31
17	7	199.1 ±11.6	1.34
18	1	225.0 ±0.00	1.79
19	1	173.0 ±0.00	
20	1	238.0 ±0.00	
22	1	235.0 ±0.00	

9.3.2 The Stellate Sturgeon

Von Bertalanffy parameters of the female were estimated by iteration using trial values of L_∞ (180, 190 and 213 cm) near to L_{max} (213 cm). The best one was found to be 213 cm. Table 9.3 shows the input data for calculation of the von Bertalanffy parameters (Figure 9.17). The von Bertalanffy parameters were estimated as, $L_\infty = 213$ cm, K = 0.062 and $t_0 = -3.906$, with r = 0.985, df = 12, P<0.01. The high negative value of t_0 is a consequence of juvenile growth (first stanza) being more rapid than is indicated by the single von Bertalanffy equation (see chapter 6).

Figure 9.18 shows the growth of female Stellate Sturgeon showing annual means ±1SD (where $n \geq 2$) and calculated von Bertalanffy curve for $L_\infty = 213$ cm.

From the FSAS program, combined female mean lengths of 1990-1994 (Table 6.23) were used and the parameters estimated as:

$L_\infty = 188$ cm, $K = 0.104$, $t_0 = -0.216$, $r = 0.959$

This again provides an L_∞ much lower than the observed L_{max}.

Figure 9.19 shows the growth curve of the female Stellate Sturgeon based on FSAS.

The von Bertalanffy parameters for the male Stellate Sturgeon were calculated from part of the data (Table 9.3) (175, 181 and 190 cm are L_{max} in the annual samples, and 190 cm was chosen), $L_\infty = 190$ cm, $K = 0.083$ and $t_0 = -2.21$, with $r = 0.935$, $df = 9$, $P<0.01$ (Figure 9.20).

Figure 9.21 shows growth of male Stellate Sturgeon with annual means ±1SD (where $n \geq 2$) and calculated von Bertalanffy curve for $L_\infty = 190$ cm.

Growth parameters of males were estimated from the FSAS program, using mean length of combined years (column 7 of Table 9.3) as,

$L_\infty = 171$ cm, $K = 0.113$, $t_0 = -0.286$, $r = 0.939$

Fig 9.22 shows the growth curve of the male Stellate Sturgeon from the FSAS program estimation.

Table 9.3: Input data and regression for the von Bertalanffy plot, Stellate Sturgeon (female and male separately).

female				male			
age	**number**	**mean length ±SD (cm)**	**-ln [(L_∞ -Lt) / L_∞]**	**age**	**number**	**mean length ±SD (cm)**	**-ln [(L_∞ -Lt) / L_∞]**
5	13	99.40 ± 7.30	0.63	4	3	100.3 ± 7.20	0.0
6	112	102.5 ± 7.50	0.66	5	16	105.2± 7.10	0.0
7	337	105.4 ± 7.10	0.68	6	104	104.8± 7.40	0.80
8	703	108.8 ± 7.20	0.71	7	409	105.7± 6.30	0.81
9	1318	112.8 ± 7.00	0.75	8	960	109.4± 6.30	0.86
10	2581	117.9 ± 6.60	0.81	9	1465	113.0± 6.20	0.90
11	4312	123.4 ± 5.90	0.87	10	1866	116.1± 5.90	0.94
12	7289	128.8 ± 5.00	0.93	11	1363	121.2± 5.80	1.02
13	6146	134.9 ± 5.20	1.00	12	776	125.5± 6.50	1.08
14	3545	140.8 ± 5.50	1.08	13	224	131.3± 7.30	1.17
15	1281	146.7 ± 6.30	1.17	14	66	138.6± 8.20	1.31
16	336	150.8 ± 8.40	1.23	15	30	142.8± 16.1	1.39
17	100	156.2 ± 14.5	1.32	16	14	157.1± 13.0	1.75
18	26	161.4 ± 20.0	1.42	17	5	161.4± 6.20	
19	7	175.7 ±10.8		18	1	117.0± 0.00	
20	3	177.3 ±6.10		19	3	143.7± 40.2	
21	1	171.0 ±0.00		20	1	181.0± 0.00	
22	1	128.0 ±0.00		21	1	170.0±0.00	
23	2	178.0 ± 2.80					
27	1	188.0 ±0.00					

9.3.3 The Persian Sturgeon

Growth parameters were also calculated for female and male Persian Sturgeon, examining different estimates of L_∞ near to L_{max} (214, 225, 271 cm in the annual samples) and using part of the data. Table 9.4 shows the input data for estimation of the von Bertalanffy growth parameters. For females the best value for L_∞ was found to be 225 cm (Figure 9. 23). Growth parameters for females were calculated as, L_∞ = 225 cm, K = 0.066 and t_0 = - 1.388, with r = 0.989, df = 13, P<0.01.

Figure 9.24 shows the growth of females using annual means ±1SD (where

$n \geq 2$) and the calculated von Bertalanffy curve for $L_\infty = 225$ cm. Growth parameters of the female Persian Sturgeon were also estimated from the FSAS program using mean length of combined years (column 3 of Table 9.4) as:

$L_\infty = 207$ cm, $K = 0.079$, $t_0 = -0.166$, $r = 0.991$

Figure 9.25 shows the growth curve of females, using above parameters.

For male Persian Sturgeon the growth parameters were estimated as (183, 190 and 197 cm are L_{max}, in the annual samples, 197 cm was the best), $L_\infty = 197$ cm, $K = 0.084$ and $t_0 = -1.286$, with $r = 0.977$, $df = 10$, $P<0.01$.

Figure 9.27 shows the growth of male Persian Sturgeon showing annual means ±1SD (where $n \geq 2$) and calculated von Bertalanffy curve for $L_\infty = 197$ cm.

From the FSAS program, male growth parameters were estimated (using column 7 of Table 9.4) as:

$L_\infty = 186$, $K = 0.105$, $t_0 = -0.022$, $r = 0.969$

Fig 9.28 shows the growth curve of male Persian Sturgeon calculated from the FSAS program.

Table 9.4: Input data and regression for the von Bertalanffy plot, Persian Sturgeon (female and male separately).

		female				male	
age (t)	number	mean length ±SD (cm)	-ln [(L_∞ -Lt) / L_∞]	age	number	mean length ±SD (cm)	-ln [(L_∞ -Lt) / L_∞]
7	2	115.0 ± 14.1	0.00	7	3	104.6 ± 1.20	0.76
8	6	108.8 ± 4.80	0.66	8	15	112.4 ± 8.00	0.85
9	29	113.6 ± 10.2	0.70	9	52	114.7 ± 7.30	0.87
10	48	118.2 ± 9.90	0.75	10	124	119.7 ± 7.70	0.94
11	67	124.4 ± 9.00	0.80	11	282	125.4 ± 6.90	1.01
12	96	127.7 ± 11.8	0.84	12	530	129.4 ± 7.20	1.07
13	230	131.3 ± 9.30	0.88	13	843	132.0 ± 7.00	1.11
14	769	139.4 ± 8.50	0.97	14	1847	137.9 ± 6.90	1.20
15	1274	147.3 ± 7.40	1.06	15	1482	143.5 ± 6.80	1.30
16	1804	153.5 ± 7.30	1.15	16	647	150.3 ± 7.00	1.44
17	1827	160.3 ± 6.70	1.25	17	176	157.0 ± 7.30	1.59
18	1227	165.6 ± 6.40	1.33	18	30	162.5 ±8.60	1.74
19	748	170.6 ± 7.20	1.42	19	10	157.7 ± 18.6	
20	344	173.0 ± 7.10	1.47	20	3	174.3 ± 20.2	
21	185	176.0 ± 9.00	1.52	21	1	183.0 ± 0.00	
22	136	176.6 ± 7.40	1.54	22	3	176.6 ± 4.90	
23	90	177.5 ± 7.70	1.55	23	1	139.0 ± 0.00	
24	38	179.6 ± 11.2	1.60				
25	31	175.4 ± 11.0					
26	13	184.6 ± 16.0					
27	18	176.3 ±21.0					
28	9	181.3 ± 9.60					
29	2	181.5 ± 00.7					
30	4	183.5 ± 14.9					
31	1	194.0 ± 0.00					
32	2	195.0 ± 21.2					
35	1	200.0 ± 0.00					
39	1	202.0 ± 0.00					

9.3.4 The Russian Sturgeon

The von Bertalanffy growth parameters were estimated for female and male Russian Sturgeon (Table 9. 5). Different values of L_∞ near to L_{max} (annual values 195, 198, 201 and 204 cm) were examined for estimation of the von Bertalanffy growth parameters of the female. An L_∞ of 201 cm provided the best fit (Figure 9.29).

Growth parameters for females were, $L_\infty = 201$ cm, $K = 0.073$ and $t_0 = -1.30$, with $r = 0.983$, df = 14, $P<0.01$).

Figure 9.30 shows growth of the female Russian Sturgeon with annual means ±1SD (where $n \geq 2$) and calculated von Bertalanffy curve for $L_\infty = 201$ cm. From FSAS program the growth parameters of females were estimated (from column 3 of Table 9.5) as,

$$L_\infty = 192 \text{ cm}, K = 0.082, t_0 = -0.901, r = 0.977$$

Fig 9. 31 shows the growth curve of females calculated from the FSAS program.

For male Russian Sturgeon the von Bertalanffy parameters were estimated from part of the data (Table 9.5). An L_∞ of 189 cm provided the best fit and the growth parameters were calculated as $L_\infty = 189$ cm, $K = 0.077$ and $t_0 = -1.55$ with $r = 0.962$, df = 9, $P<0.01$ (Figure 9. 32).

Figure 9. 33 shows the growth of male Russian Sturgeon indicating annual means ±1SD (where $n \geq 2$) and calculated von Bertalanffy curve for $L_\infty = 189$ cm.

Von Bertalanffy parameters for males were also estimated from FSAS program using mean length of male combined years (column 7 of Table 9.5) as:

$$L_\infty = 178 \text{ cm}, K = 0.092, t_0 = -0.271, r = 0.945$$

Fig 9. 34 shows the growth curve of males using the FSAS program.

Table 9. 5: Input data and regression for the von Bertalanffy plot, Russian Sturgeon (female and male Russian Sturgeon separately).

female				male			
age	number	mean length ±SD (cm)	-ln [(L_∞ -Lt) / L_∞]	age	number	mean length ±SD (cm)	-ln [(L_∞ -Lt) / L_∞]
5	1	96.0 0± 0.00	0.00	8	11	106.0 ± 3.50	0.82
7	13	102.9 ± 11.2	0.72	9	59	109.9 ± 9.70	0.87
8	54	104.8 ± 4.90	0.74	10	129	112.0 ± 6.70	0.90
9	129	108.4 ± 7.00	0.77	11	230	114.6 ± 6.80	0.93
10	335	112.0 ± 6.40	0.81	12	324	118.7 ± 8.60	0.99
11	438	116.8 ± 7.30	0.87	13	351	121.0 ± 8.00	1.02
12	734	121.5 ± 7.80	0.93	14	292	126.4 ± 7.40	1.11
13	1237	126.1 ± 8.40	0.99	15	110	134.4 ± 8.30	1.24
14	1917	131.3 ± 7.70	1.06	16	31	140.6 ± 9.50	1.36
15	1545	136.7 ± 7.90	1.14	17	21	144.0 ± 11.3	1.44
16	1010	142.3 ± 7.70	1.23	18	7	152.3 ± 17.6	1.64
17	555	147.3 ± 7.80	1.32	19	3	137.0 ± 25.2	
18	213	152.1 ± 7.90	1.41	21	1	161.0 ±0.000	
19	88	155.0 ± 10.3	1.47	22	1	113.0 ±0.000	
20	44	155.6 ± 12.1	1.49	27	1	169.0 ±0.000	
21	23	167.3 ± 18.1	1.78	31	1	189.0 ±0.000	
22	13	166.9 ± 16.4	1.77				
23	6	157.8 ± 3.60					
24	4	171.0 ± 17.2					
25	10	155.2 ± 16.3					
26	5	164.6 ± 8.40					
27	3	173.3 ± 18.2					
30	3	171.3± 17.2					
37	1	201.0± 0.00					

9. 4 Discussion

As has been shown in previous chapters (5, 6, 7 and 8) the growth in length of these sturgeons is not entirely fitted by a single von Bertalanffy equation derived by standard procedures (Gulland 1969). Since curves fitted through all the data indicate an L_∞ much lower than predicated by the von Bertalanffy method based on the largest samples, more appropriate values were estimated on the basis of L_{max} in the data sets for 1990-1994. Therefore, except for female Beluga, L_{max} the maximum observed length, was used as an estimator for L_∞. Various authors, notably Beverton (1963) and Taylor (1958), have noted that in various stocks there is generally a good agreement, between L_{max}, the largest length recorded from a given stock, and L_∞, the asymptotic length estimated for that stock. Sparre *et al.* (1989) suggested using the largest fish or taking the average of the lengths of, say, the ten largest fish as an estimate of L_∞. In addition, the FSAS computer program was used for parameter estimation.

Estimation using the complete length-at-age set, and the highest value of r yield estimates of L_∞ that are manifestly too high. This was the case, for all species, and Gulland's plot was not applied for any of them, because of very low correlation coefficients (female Beluga, $r = 0.293$; males, $r = 0.505$; female Stellate Sturgeon, $r = 0.105$; males, $r = 0.398$; female Persian Sturgeon, $r = 0.330$, males; $r = 0.063$; female Russian Sturgeon, $r = 0.192$; males, 0.045, for all species $P>0.05$). However, when the data were split into stanzas, the von Bertalanffy plots sometimes worked well for one or both. The first most likely reason for that might the occurrence of different growth rates during different parts of the life span, as has been established in the previous chapters (5-8) for all species. Since sturgeons are long-lived, late maturing species, the change in growth rate which appears to occur at about age 19-25 may be a consequence of maturity, though first maturity tends to be earlier than that (perhaps 15-18). It may be that the relationship between fecundity and body weight differs between first and subsequent maturations, and Raspopov (1987) has noted a lower fecundity for the first time spawning Beluga. Thereafter the females are believed to mature and spawn every 3-5 years. Errors in ageing and small sample sizes for a great part of the data might be another reason for the difficulties in fitting a single curve. A further possibility is that it could be an indication of stock differentiation, since there were large variations in annual mean lengths of all species.

For female Beluga growth has been regarded as comprising three stages, and the von Bertalanffy parameters were calculated for juveniles, for the middle stanza (>8 to 24 years), and third stanza (>24 years). The value of K was highest (0.065) for the first stanza, lower for the middle (0.029), and lower again for the third one (0.023).

Unfortunately there are no available published data on von Bertalanffy parameters of Beluga in the Caspian Sea for comparison. The value of K (0.32-0.451) calculated by Altuf'ev and Romanov (1988) for juvenile Beluga (1 to 7 years old) in ponds, Middle and North Caspian, is much higher than 0.065 estimated here. The values of L_∞ and K for Beluga of the Azov Sea estimated by Pauly (1978, using "raw" age-at-length data from Nikol'skii 1957) were 249 cm and 0.079. The L_∞ (249 cm) is much lower than in the present study and clearly inappropriate for the southern Caspian stock (see Fig 9.13).

The only data which might be comparable with Beluga is that for White Sturgeon (*Acipenser transmontanus*) in North America. The White Sturgeon is the largest freshwater fish in North America (Scote and Crossman 1973). Age estimates exceed 100 years (Rien and Beamesderfer 1992). The von Bertalanffy equation for

White Sturgeon in North America is,

for females, $L_t = 326.6$ [(1-exp (-0.0279 (t+1.125))]

and for males, $L_t = 245.7$ [(1-exp (-0.0445 (t - 0.499))] (Charles, *et al.* 1992). The maximum lengths recorded for the Beluga of both sexes in the present study were higher than the L_∞ calculated for the White Sturgeon.

In summary, results indicate that a single von Bertalanffy equation does not well fit all the data together. Growth of the Beluga is rapid up to the 8th year (Chugunova, 1940; Nikol'skii, 1961), slower through 8-24, after which it becomes still slower and length becomes asymptotic at about 5 m after 100 years (Fig 9.11).

Because of the small sample sizes during the third stanza of other three species, the von Bertalanffy parameters for these species were estimated using all the data, by trial and error, using different values of L_∞ near to L_{max}. However, as has been indicated in previous chapters (5, 6, 7 and 8), annual length increments were different for the middle and third stanzas and must have been higher still during early life; therefore, the von Bertalanffy parameters for each stanza should be different. For example, the values of K for juvenile (1 to 7 years old) Stellate Sturgeon and Russian Sturgeon estimated by Altuf'ev and Romanov (1988) in ponds, Middle and North Caspian were 0.114-0.501 and 0.063 to 0.459 respectively. Estimations of L_∞ and K for Stellate Sturgeon of the Amu-Daria River at 201 cm and 0.06 (Bertalanffy 1951, cited in Pauly, 1978) are comparable with L_∞ (213 cm) and K (0.062) estimated for female Stellate Sturgeon in the present study. For Russian Sturgeon of the Azov Sea the growth parameters estimated by Pauly (1978, using "raw" length-at-age data from

Nikol'skii, 1957), as L_∞ = 253 cm, k = 0.045 and t_0 = -3.5, is not very similar to the present results (for females, L_∞ = 201 cm, K = 0.073, t_0 = -1.3; for males L_∞ = 189 cm, K = 0.077 and t_0 = -1.55).

There are no other published data on the von Bertalanffy parameters of the Caspian Sea sturgeons to compare with. Published estimates of L_∞ and K for *A. fulvescens* are 178 cm and 0.05 (Beverton and Holt 1959), and for *A. transmontanus*, 350 cm and 0.04 respectively (Semakula and Larkin 1968). For all the species in the present study, the von Bertalanffy parameters were different in males and females, because of the smaller maximum length and (probably) shorter life span of males. The values of K estimated for all the species were similar but the maximum length of each species affects the von Bertalanffy equation, because there is a negative correlation between K and L_∞ (Jones, 1976).

Comparing the growth parameters estimated from the FSAS Program and using L_{max}, it seems that the FSAS program tends to have the lower value of r and underestimates L_∞, since almost all of the values are less than annually observed L_{max}. The lower L_∞ results in a higher K and lower t_0. The method of L_{max} may overestimate t_0.

Table 9.6: Von Bertalanffy growth parameters estimated for all species.

species	sexes			FSAS program
			L_∞, K, t_0	L_∞, K, t_0
Beluga	**females**	**first stanza**	320 cm, 0.065, -0.05	370 cm, 0.052, -0.354
		middle stanza	666 cm, 0.068, -7.075	
			550 cm, 0.021, -6.145	
			450 cm, 0.029, -4.871	
		Third stanza	533 cm, 0.023, -4.034	
Beluga	**males**		270 cm, 0.086, -0.259	302 cm, 0.072, -0.574
Stellate Sturgeon	**females**		213 cm, 0.062, -3.906	188 cm, 0.104, -0.216
	males		190 cm, 0.083, -2.21	171 cm, 0.113, -0.286
Persian Sturgeon	**females**		225 cm, 0.066, -1.388	207 cm, 0.079, -0.166
	males		197 cm 0.084, -1.286	186 cm, 0.105, -0.022
Russian Sturgeon	**females**		201 cm, 0.073, -1.30	192 cm, 0.082, -0.901
	males		189 cm, 0.077, -1.55	178 cm, 0.092, -0.271

The main conclusion is that, in these acipenserid species, the von Bertalanffy growth equation does not provide a particularly suitable model. Nevertheless, owing to the widespread use of this model in fisheries research, and its great value in providing comparative data and in determining other population parameters such as natural mortality, M (chapter 10), attempts have been made to obtain the best possible estimates of L_∞, K and t_0, which are shown in Table 9.6.

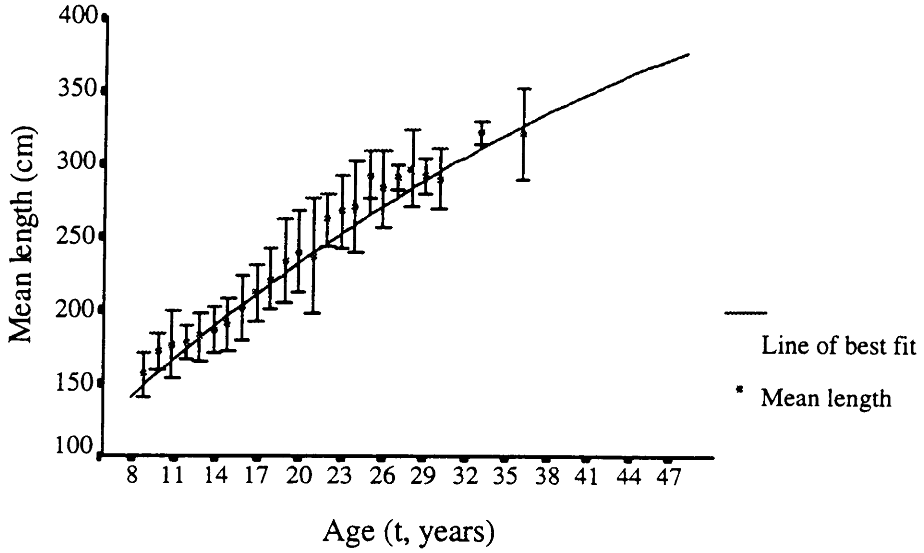


Fig 9.1: Plot of mean length ±1SD against age of the female Beluga with line of best fit (quadratic plot).

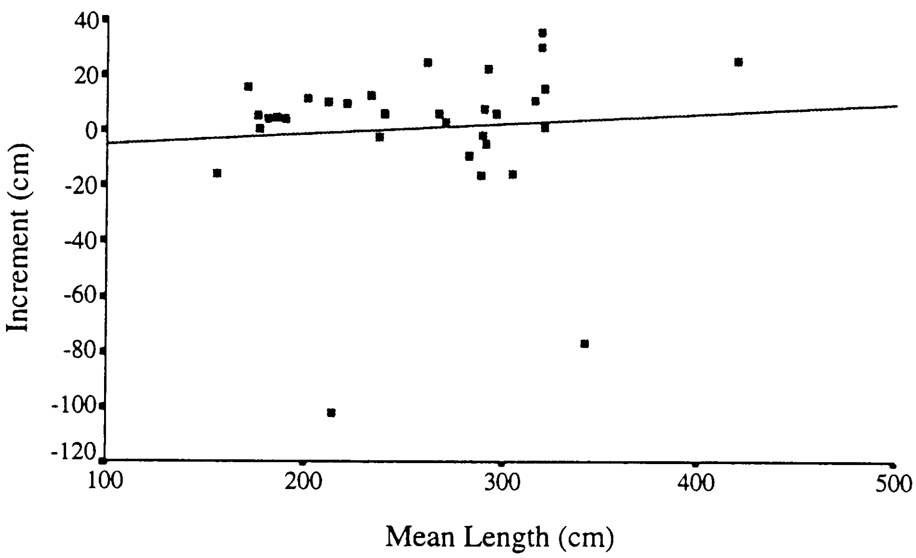


Fig 9.2: Female Beluga: Gulland plot using all data and annual mean length.

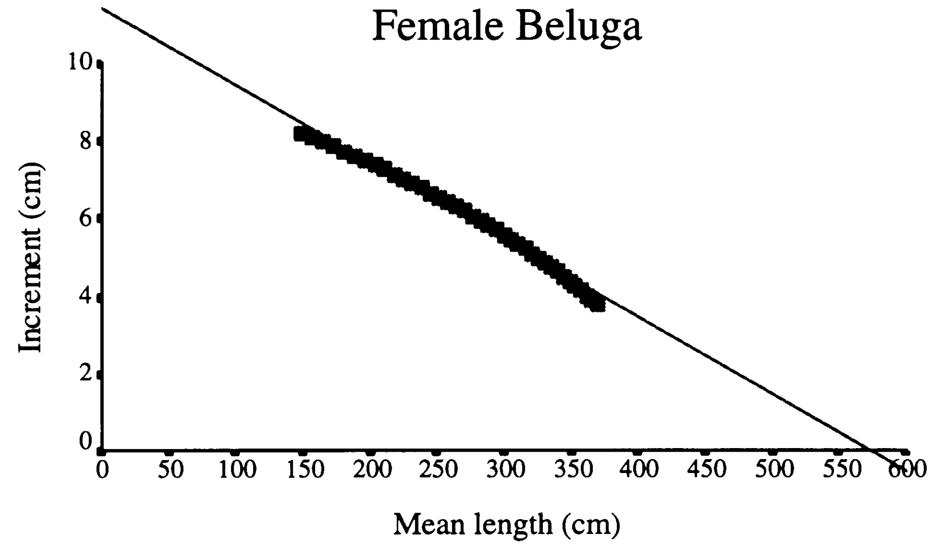


Fig 9.3: Gulland plot using annual mean lengths estimated from line of best fit (L_∞ = 575 cm, K = 0.0159, r = 0.995).

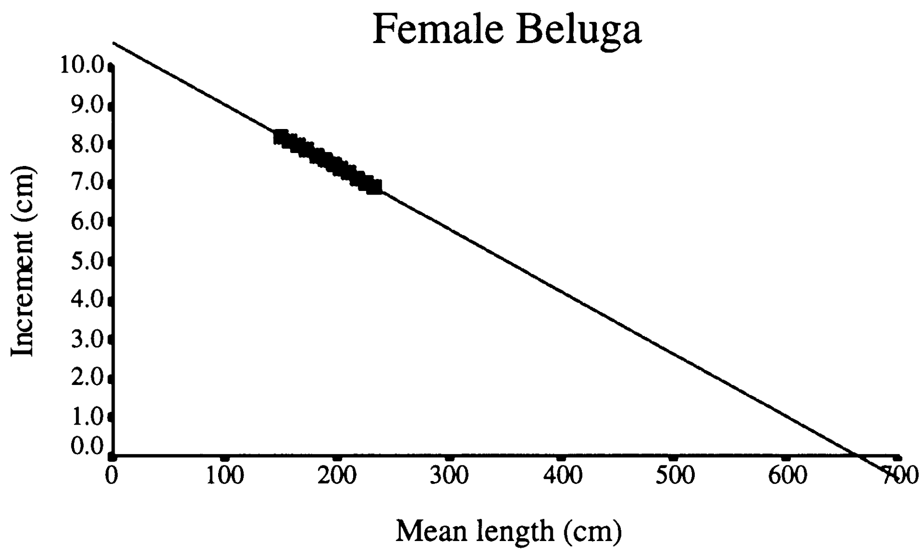


Fig 9.4: Gulland plot using annual mean lengths obtained from the line of best fit, middle stanza (L_∞ = 666 cm, K = 0.0158, r = 0.999).

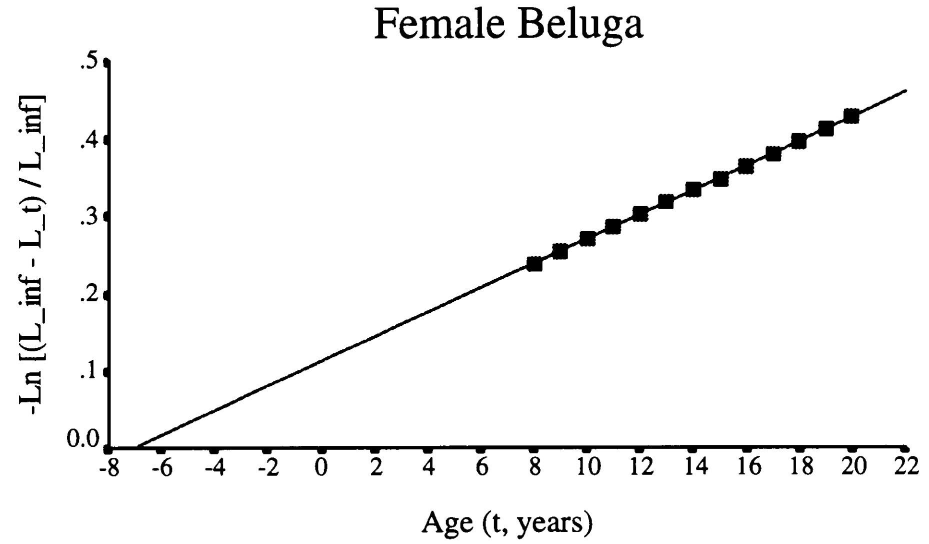


Fig 9.5: Middle stanza: estimation of von Bertalanffy parameters using annual lengths obtained from the line of best fit.
$L_t = 666\ [(1\text{-}\exp(-0.0158(t+7.075)]$

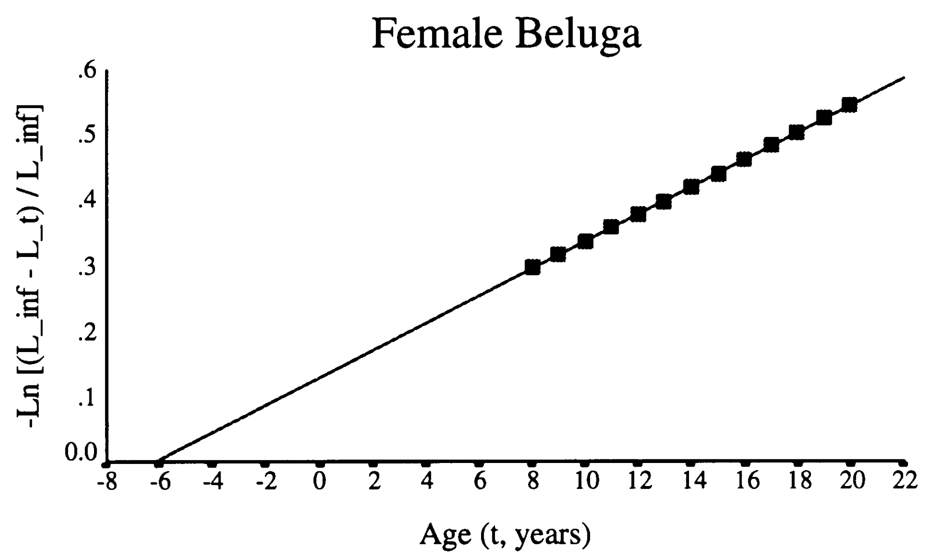


Fig 9.6: Middle stanza: estimation of von Bertalanffy parameters using annual lengths obtained from the line of best fit.
$L_t = 550\ [(1\text{-}\exp(-0.0209(t + 6.153)$

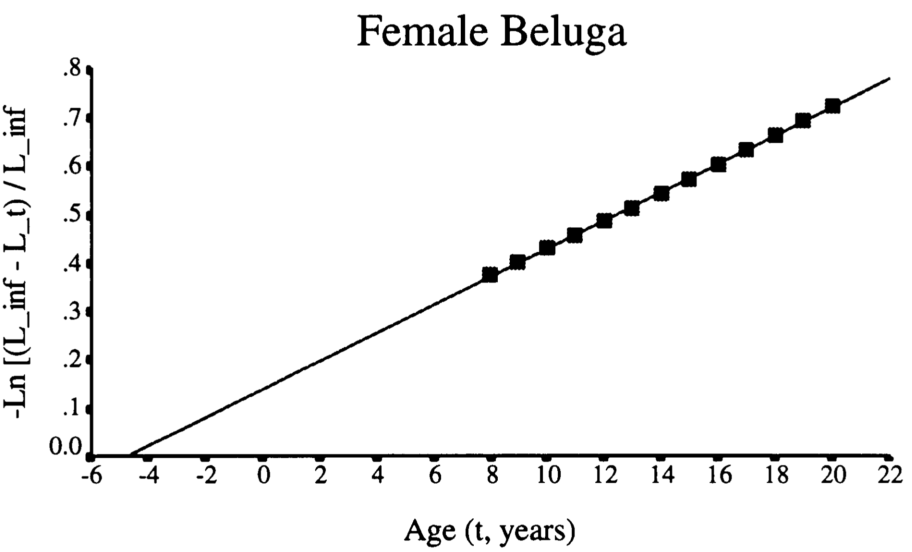


Fig 9.7: Middle stanza: estimation of von Bertalanffy parameters using annual lengths obtained from the line of best fit.

$L_t = 450\ [(1\text{-}\exp(-0.029(t + 4.87)]$

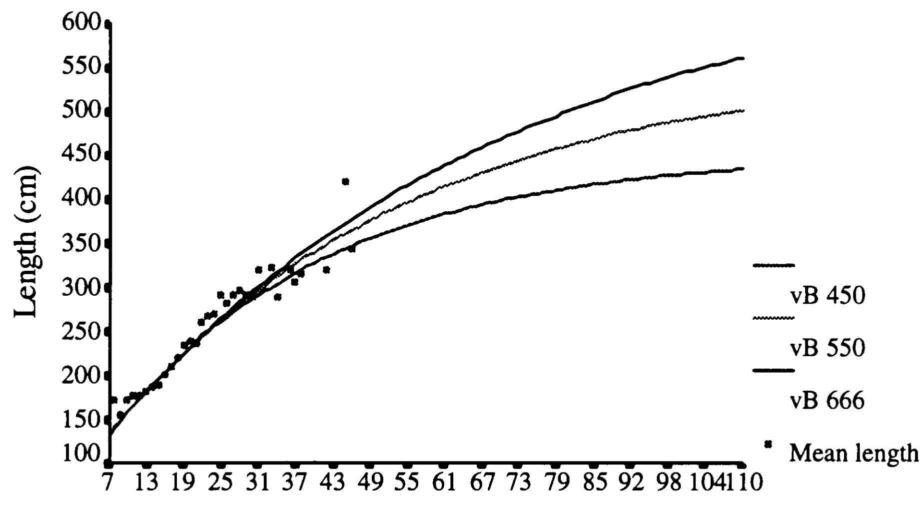


Fig 9.8: Growth of female Beluga showing annual mean length for the middle stanza, with three fitted growth curves.

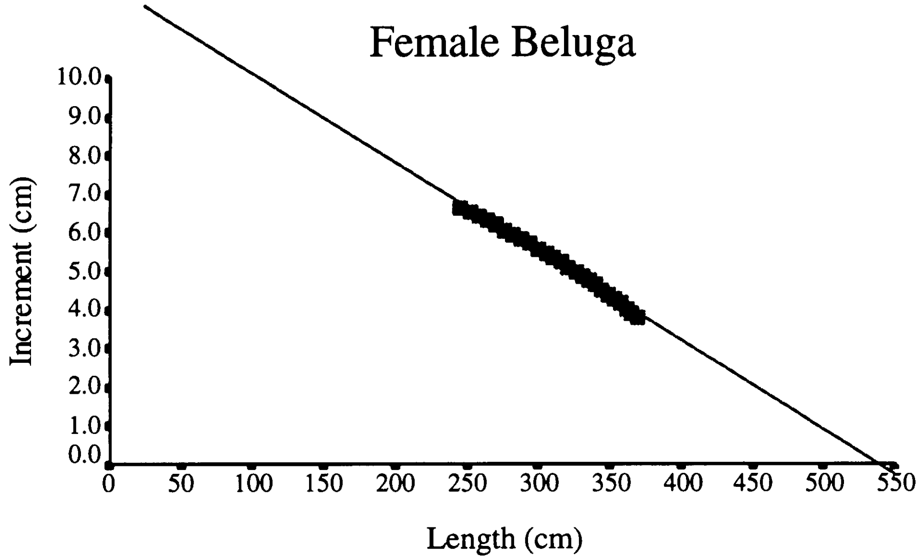


Fig 9.9: Gulland plot for older fish using annual lengths estimated from line of best fit ($L_\infty = 533$ cm, $K = 0.023$, $r = 0.998$).

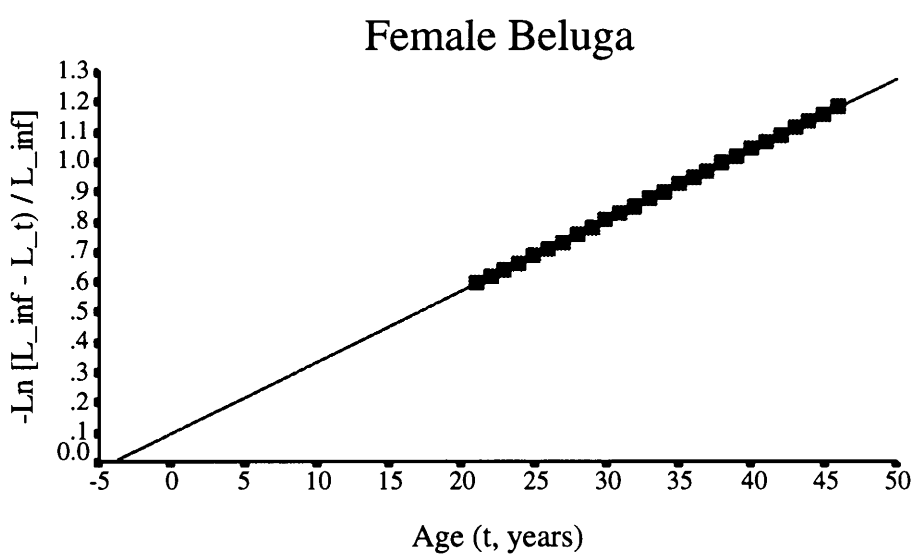


Fig 9.10: Estimation of von Bertalanffy parameters using annual lengths from the line of best fit.
$L_t = 533\ [(1\text{-exp}\ (-0.023\ (t + 4.0338)]$

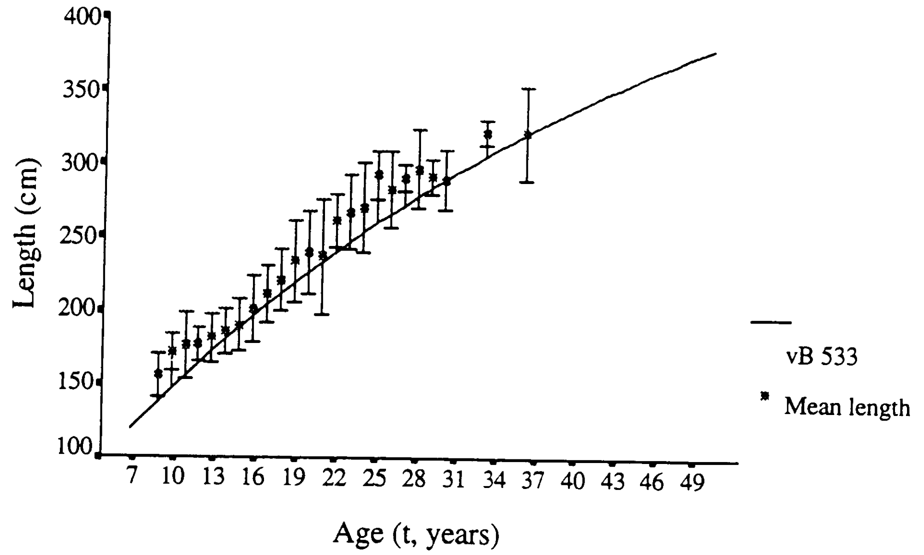


Fig 9.11: Growth of female Beluga showing annual means ±1SD (where n≥2) and calculated von Bertalanffy curve for L_∞ = 533 cm.

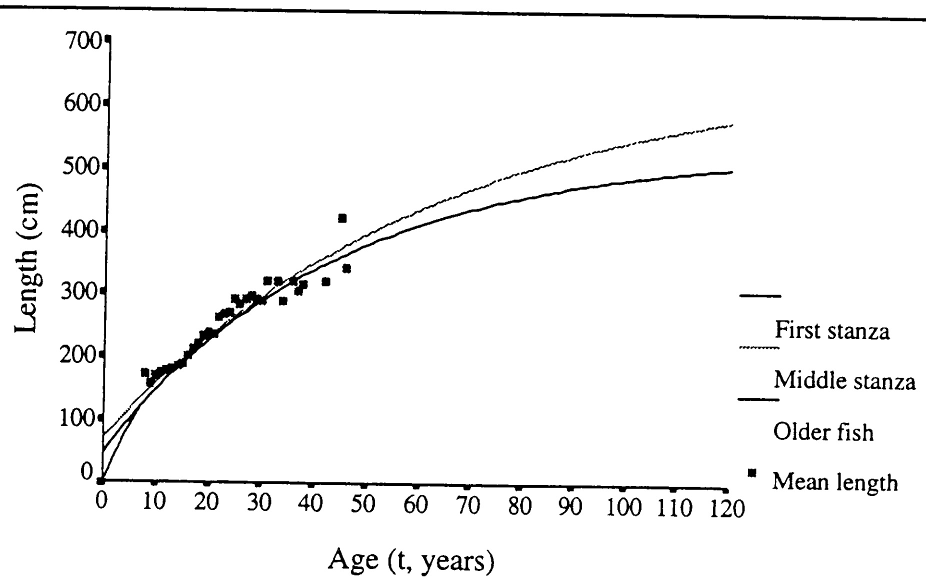


Fig 9.12: Growth curves for female Beluga showing three stanza.

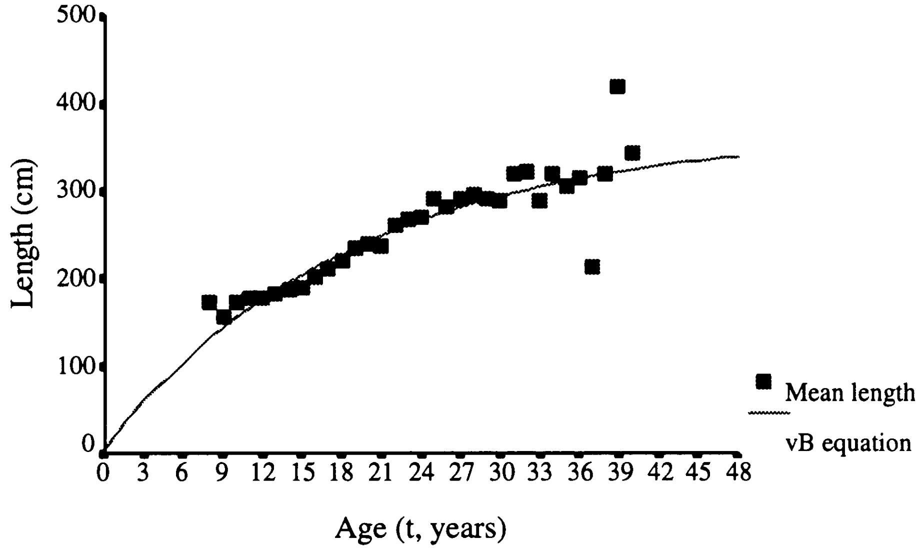


Fig 9.13: Growth curve for female Beluga, estimated by FSAS program for L_∞ = 369.6 cm.

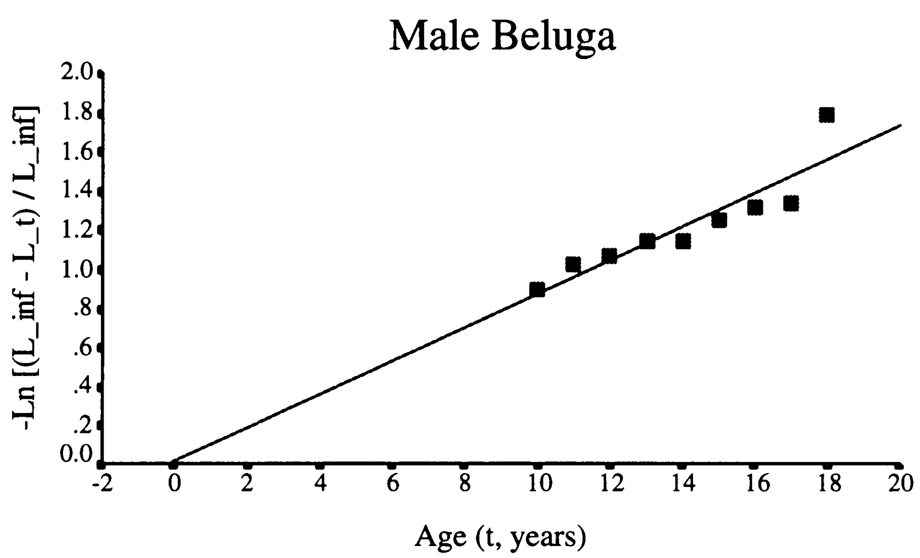


Fig 9.14: Estimation of von Bertalanffy parameters using mean length of year 1992.
L_t = 270 [(1 - exp (-0.0855 (t + 0.259)]

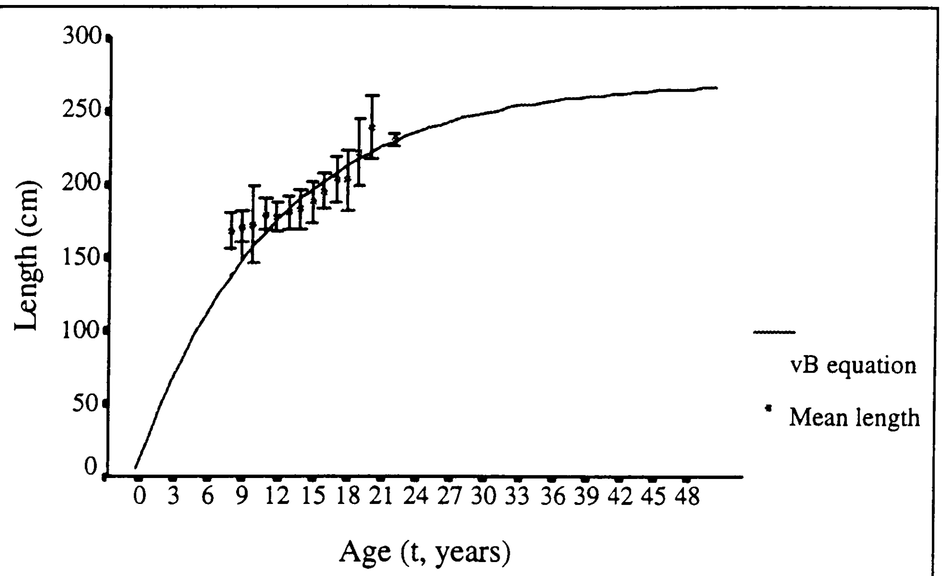


Fig 9.15: Growth curve for male Beluga for L_∞ = 270 cm..

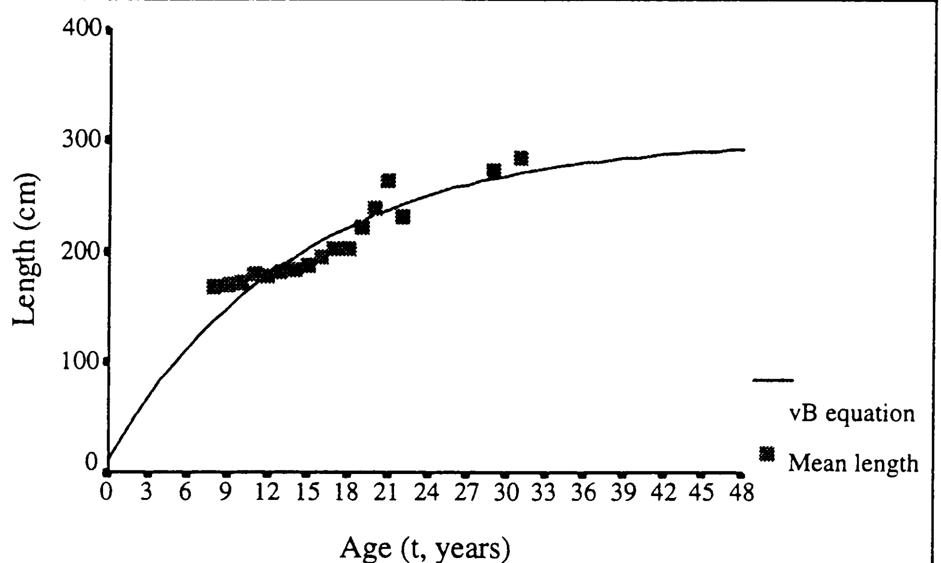


Fig 9.16: Growth curve for male Beluga, estimated by FSAS program for L_∞ = 301.8 cm.

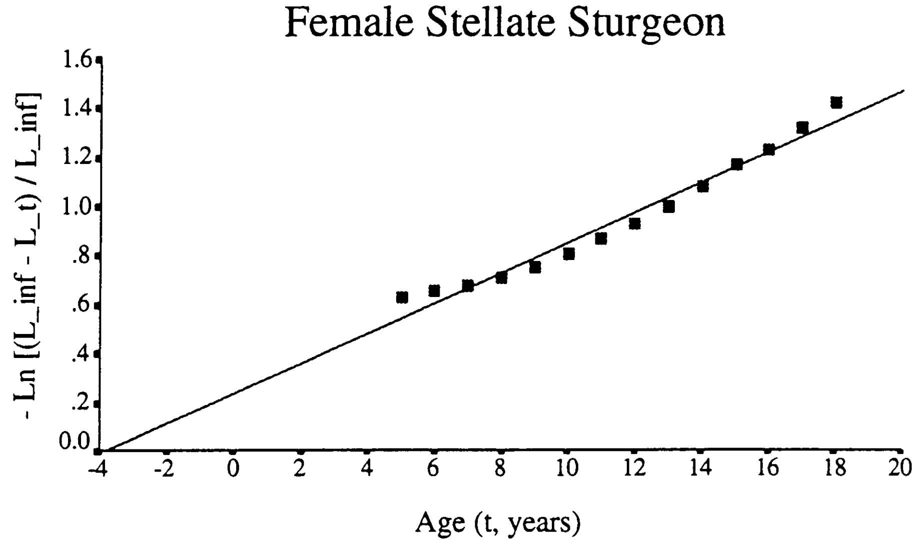


Fig 9.17: Estimation of von Bertalanffy parameters using mean lengths of some part of the original data. $L_t = 213\ [(1\text{-exp}(-0.0615\ (t + 3.906)]$.

Fig 9.18: Growth curve of female Stellate Sturgeon showing annual means ±1SD (where n≥2) and calculated von Bertalanffy curve for $L_\infty = 213$.

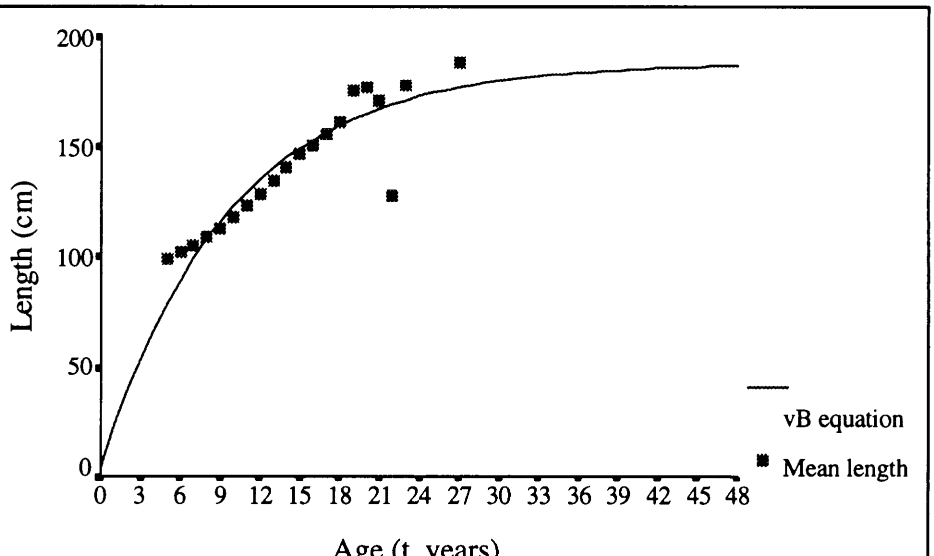


Fig 9.19: Growth curve of female Stellate Sturgeon estimated by FSAS program for $L_\infty = 188$ cm.

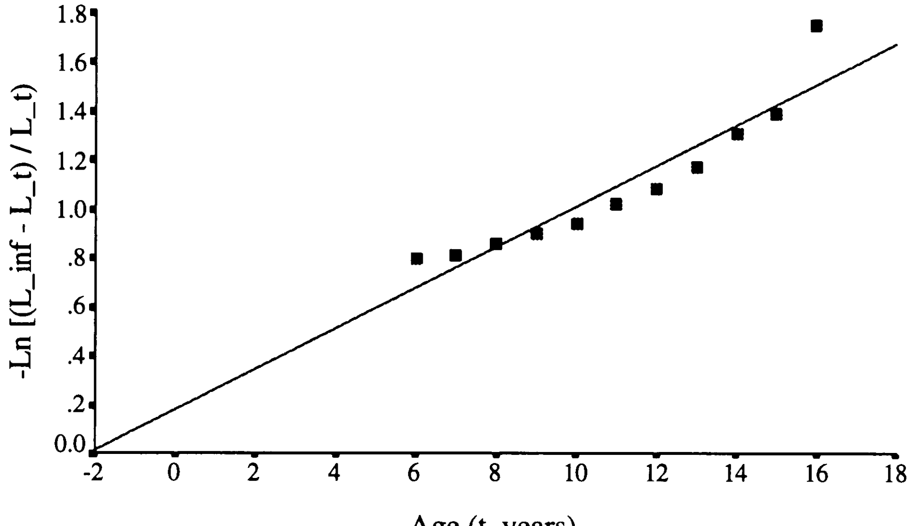


Fig 9.20: Male Stellate Sturgeon: estimation of von Bertalanffy parameters using mean lengths of some part of the original data.
$L_t = 190$ [(1-exp (- 0.0828 (t + 2.217)]

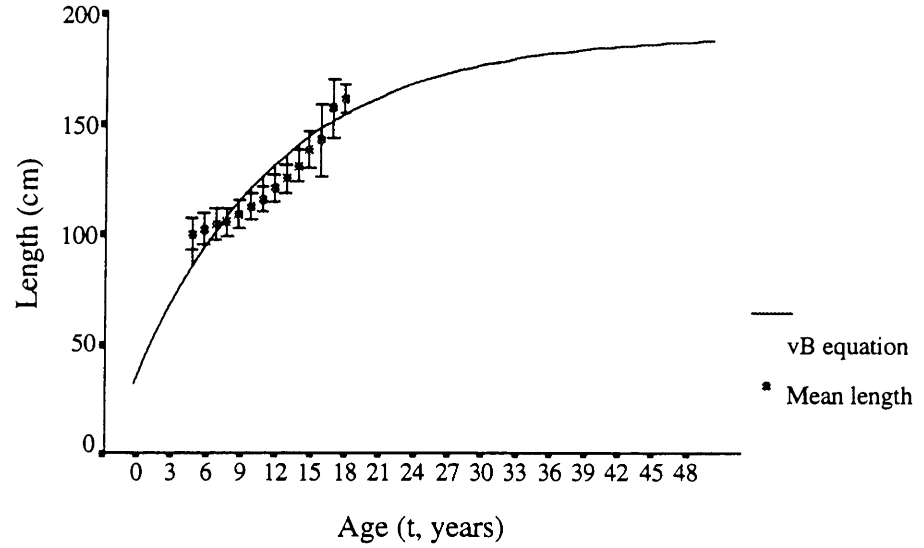


Fig 9.21: Growth curve of male Stellate Sturgeon, showing annual mean ±1SD (where n≥2) and calculated von Bertalanffy for L_∞ = 190 cm.

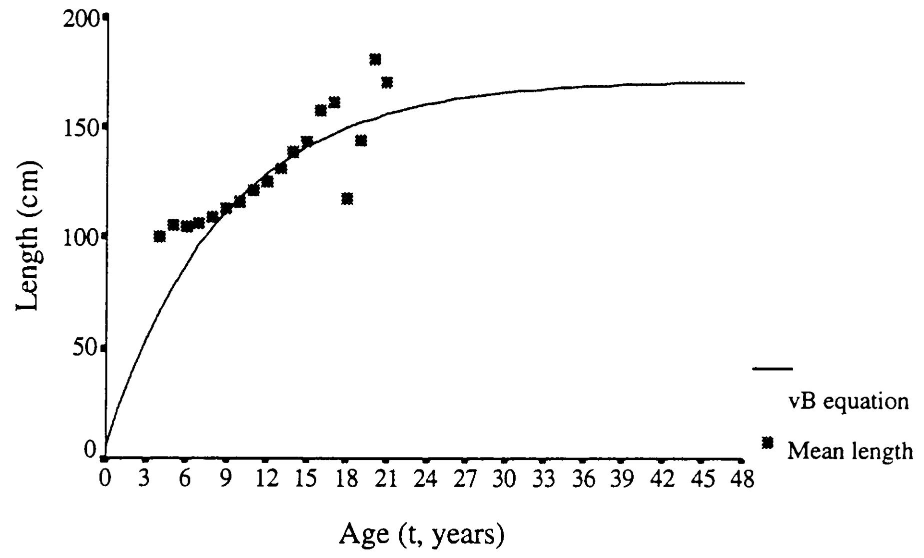


Fig 9.22: Growth curve of male Stellate Sturgeon, estimated by FSAS program for L_∞ = 172.2 cm.

Fig 9.23: Female Persian Sturgeon: estimation of von Bertalanffy parameters using mean lengths of some part of the original data.

$L_t = 225\ [(1 - \exp(-0.0659\ (t + 1.388)]$

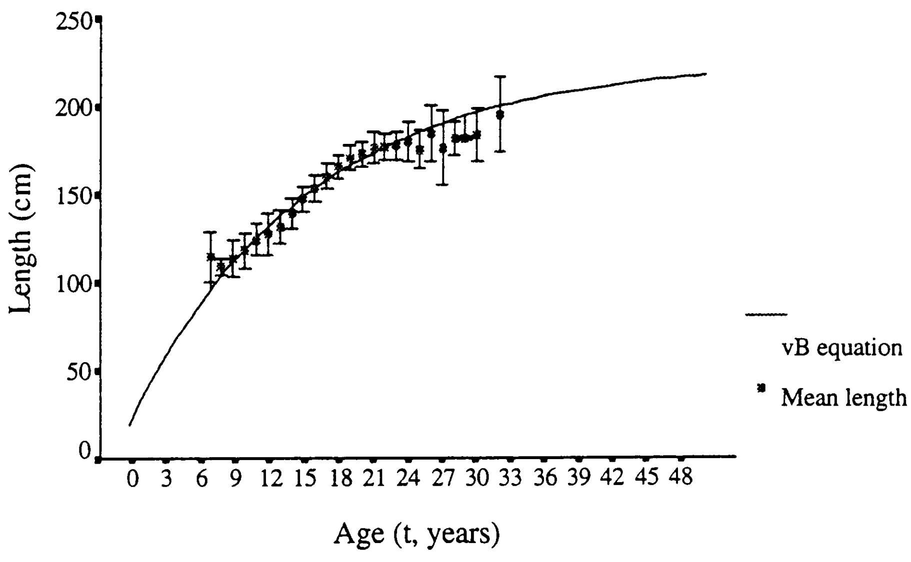


Fig 9.24: Growth curve of female Persian Sturgeon showing annual means ±1SD (where ≥2) and calculated von Bertalanffy curve for $L_\infty = 225$ cm.

Fig 9.25: Growth curve of female Persian Sturgeon, estimated by FSAS program for L_∞ = 207 cm.

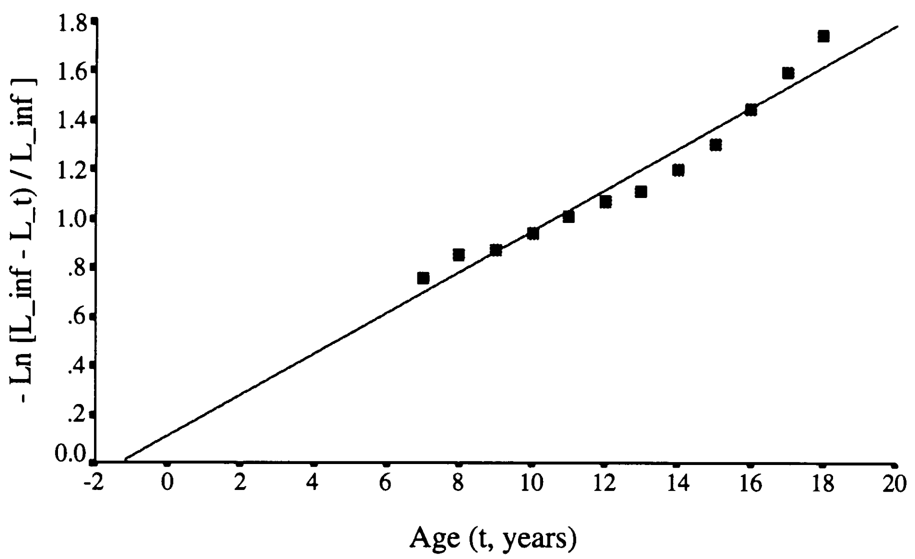


Fig 9.26: Male Persian Sturgeon: estimation of von Bertalanffy parameters using mean lengths of some part of the original data.
L_t = 197 [(1 - exp(-0.084 (t + 1.286)]

Fig 9.27: Growth curve of male Persian Sturgeon showing annual means ±1SD (where n≥2) and calculated von Bertalanffy curve for $L_\infty = 197$ cm.

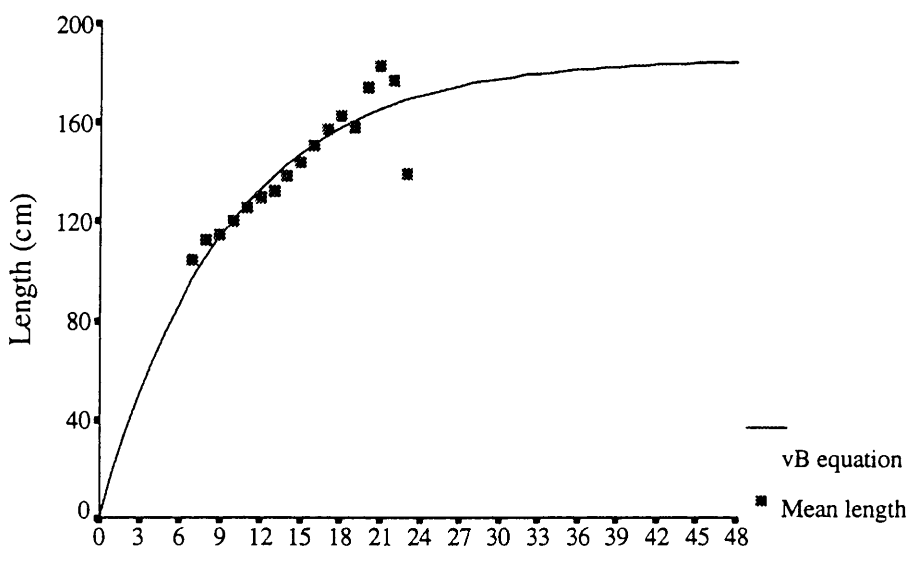


Fig 9.28: Growth curve of male Persian Sturgeon, estimated by FSAS program for $L_\infty = 185.5$ cm.

Fig 9.29: Female Russian Sturgeon: estimation of von Bertalanffy parameters using mean lengths of some part of the original data.

$L_t = 201\ [(1 - \exp(-0.0732\ (t + 1.30))]$

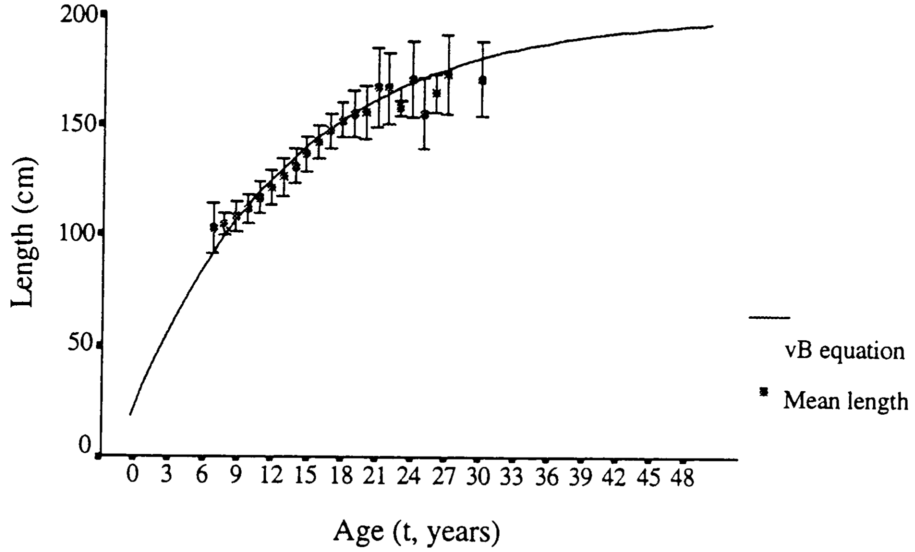


Fig 9.30: Growth of female Russian Sturgeon showing annual means ±1SD (where n ≥2) and calculated von Bertalanffy curve for $L_{\infty} = 201$ cm.

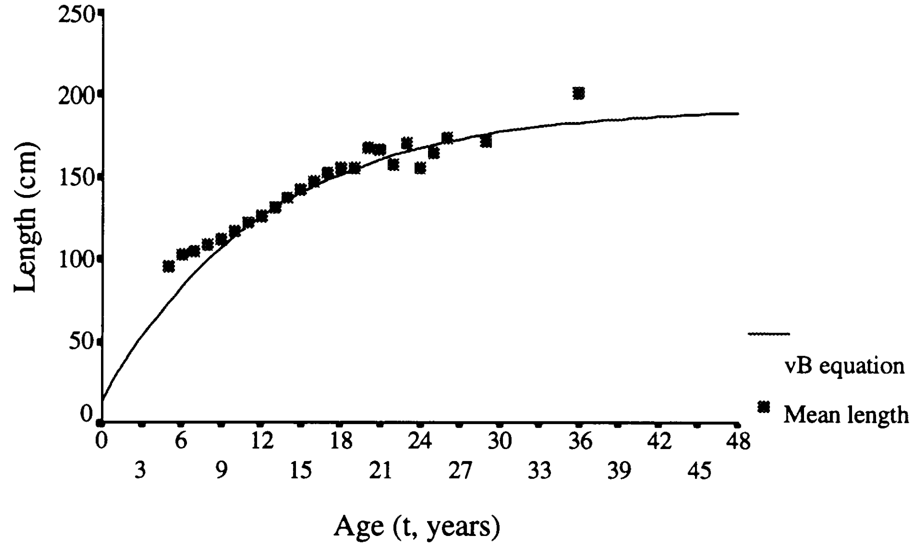


Fig 9.31: Growth curve of female Russian Sturgeon, estimated by FSAS program for $L_\infty = 192.4$ cm.

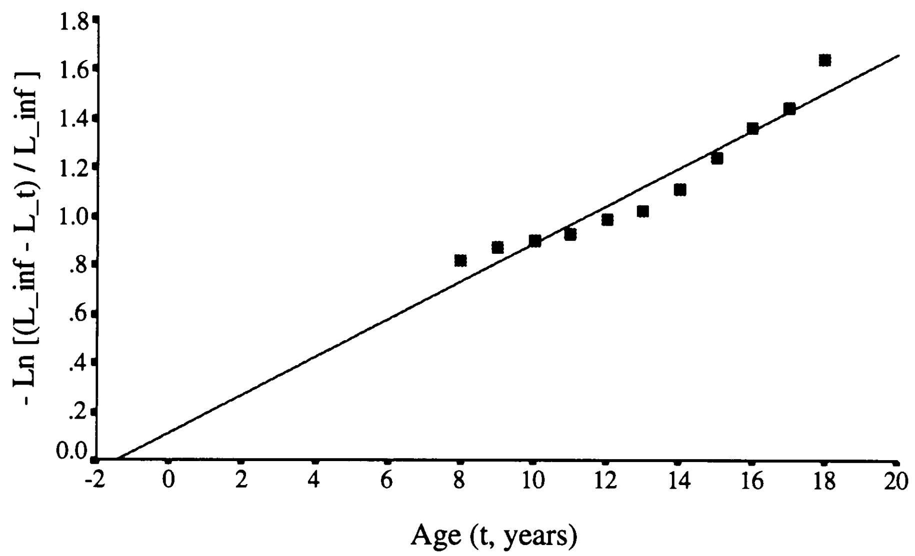


Fig 9.32: Male Russian Sturgeon: estimation of von Bertalanffy parameters using mean lengths of some part of the original data. $L_t = 189 [(1 - \exp (- 0.077 (t + 1.55)]$.

Fig 9.33: Growth of male Russian Sturgeon showing annual means ±1SD (where n≥2) and calculated von Bertalanffy curve for $L_\infty = 189$ cm.

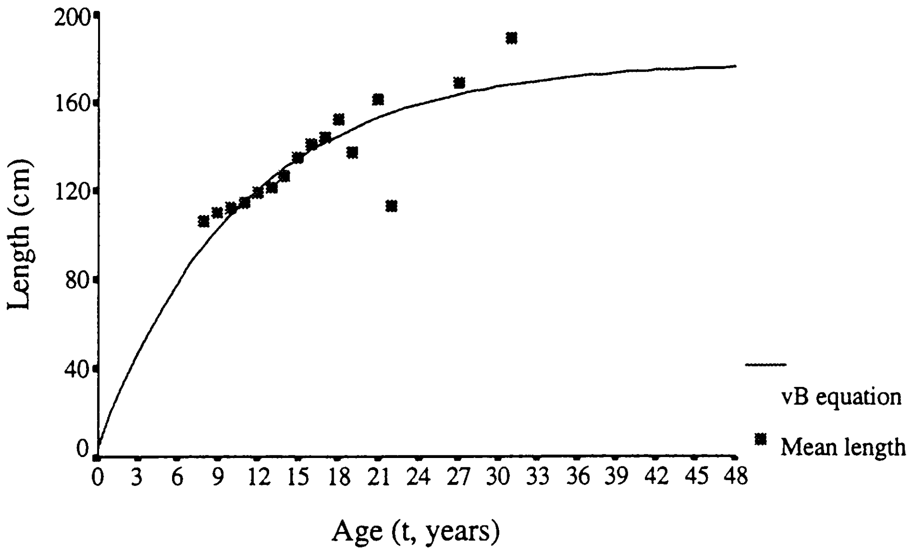


Fig 9.34: Growth curve of male Russian Sturgeon, estimated by FSAS program for $L_\infty = 178$ cm.

CHAPTER 10

Total, natural, and fishing mortality of the Beluga, Stellate, Persian and Russian Sturgeons

10. 1 Introduction

Population dynamics may be considered to embrace birth, recruitment, growth, and mortality. Reproduction compensates for mortality, while growth influences the rate of mortality and reproduction. Mortality rates vary according to the life and growth parameters of the species. Thus, fish of short life mature early and are adapted to a high and variable mortality, and vice versa (Nikols'kii, 1969).

In a fishery, each year a proportion of the fish alive at the beginning of the year will die due to predation, disease, or other natural causes, while others get caught; the remainder will survive until beginning of the next year (Gulland, 1983).

In fishery biology, the most useful manner of expressing the decrease of an age group of fishes through time is by means of the mortality coefficient (Pauly, 1980). In real life the mortality usually varies with the age of the cohort. Small (young) fish are exposed to a greater natural mortality because more predators can eat them. But small fish may on the other hand suffer less fishing mortality than large, older fish because they either have not yet migrated to the fishing grounds or they escape through the meshes of the gear.

The present chapter deals with total (Z), natural (M) and fishing mortality (F) of the Beluga, *Huso huso*, the Stellate Sturgeon, *A. stellatus*, the Persian Sturgeon, *A. persicus*, and the Russian Sturgeon, *A. guldenstadti,* in the fisheries exploited by Iran in the southern part of the Caspian Sea.

10. 2 Methods

10. 2.1 Total Mortality (Z)

The following methods have been used to estimate total mortality rate of the Beluga, Stellate Sturgeon, Persian Sturgeon and Russian Sturgeon.

- Linearized catch curve analysis based on age composition data
- Linearized catch curve analysis based on length composition data
- Beverton and Holt's Z-equation based on length data
- Beverton and Holt's Z-equation based on age data

Mortality rates were estimated for females and males separately because, first, von Bertalanffy growth parameters (used to determine M) have been estimated for females and males separately (pervious chapter); secondly, when securing caviar the sexes were separated in the catch.

Linearized catch curve analysis based on age composition data

To estimate total mortality (Z), catch curves (Gulland, 1983) based on age composition data with constant time intervals (Sparre *et al.* 1989) were applied. The first use of the linearized catch curve dates back to Edser (1908), Heincke (1913) and Baranov (1918), whose work has been reviewed by Beverton and Holt (1956), Chapman and Robson (1960) and Ricker (1975). This method of estimating Z consists of sampling a multi-aged population of fishes, then plotting the natural logarithm (ln) of the number of fishes in the sample (N) against their respective age (t) or:

$$\ln N = a - bt$$

From the regression analysis ($\ln N_t$ vs t) for each year, the total mortality (Z) was estimated as: Z = b, where -b is the slope of the regression.

In order to estimate the best value of Z from the catch curve, according to Pauly (1980), several requirements must be met for the value of -b to be a good estimate of Z. Among these, only those values of ln N which pertain to age groups of fishes fully vulnerable to the fishing gear must be included; this corresponding to the descending part of a catch curve.

Total mortality rates were estimated from age composition for each year of the catch and for combined years, using the descending part of the catch curve (Pauly 1980).

Linearized catch curve analysis based on length composition data

This method does not assume a direct age reading but uses the von Bertalanffy growth equation to convert length into age. This model is discussed by Pauly (1983a, 1984a and b) and reviewed by Sparre *et al.* (1989). It is often called the "length converted catch curve" or the "linearized length converted catch curve". From this method length data are converted into age data, using the inverse von Bertalanffy growth equation:

$$t(L) = t_0 - [1 / K \ln (1 - L / L_\infty)]$$

The time it takes for an average fish to grow from length L1 to length L2 is designated Δt, so Δt can be obtained by subtracting the two inverse von Bertalanffy equations corresponding to L2 and L1 respectively

$$\Delta t = 1 / K \ln [(L_\infty - L1) / (L_\infty - L2)].$$

Then, two values (Z and Y) are calculated as:

$$Y = \ln [C (L1, L2) / \Delta t (L1 , L2)]$$

and $$X = t [(L1 + L2) / 2],$$

(as shown in the Tables later in this chapter), where C is the numbers caught. The plot of Y against X gives the slope -b from which the value of the total mortality Z can be estimated.

Estimation of total mortality from Beverton and Holt's Z-equation based on length data.

The length composition of a population is clearly related to mortality; the lower the mortality, the more old, and therefore large, fish there will be. Beverton and Holt (1956) showed that the functional relationship between mortality and length (Z and $\bar{L}$) is:

$$Z = K [(L_\infty - \bar{L}) / (\bar{L} - L')]$$

where $\bar{L}$ is the mean length of fish of length L' and longer, while L' is some length for which all fish of that length and longer are under full exploitation.

Estimation of the total mortality from Beverton and Holt's Z-equation based on age data

As was the case for the linearized catch curve method, the length-based Beverton and Holt formula has an age-based parallel. The Beverton and Holt Z equation for estimating total mortality from age data is as follows:

$$Z = 1 / (\bar{t} - t')$$

where $\bar{t}$ is the mean age of all fish of age t' and older, and t' is some age for which all fish of that age and older are under full exploitation.

10. 2. 2 Natural Mortality (M)

The exponential coefficient of natural mortality (M) is certainly one of the parameters for which it is very difficult to obtain good estimates. Natural mortality is caused by all possible causes of death except fishing; e.g., predation, including cannibalism, disease, spawning stress, starvation, and old age. The von Bertalanffy growth curve parameter, K, has been demonstrated to be linked to the longevity of the fish and longevity is related to mortality (Beverton and Holt 1959, Tanaka 1960; Holt 1965 and Saville 1977).

As a rough generalization, fish species with a high K also have a high natural mortality, and species with a low K have a low M. A slow growing species (low K) simply cannot survive with a high natural mortality. Natural mortality must also be linked to L_∞ or the maximum weight of the species, W_∞, since large fish have fewer predators than small fish (Sparre *et al.* 1989). It has been suggested that M can be predicted from the body size for certain groups of animals (Taylor, 1960, for bivalves and Peterson and Wroblewski, 1984, for pelagic fish). Rikhter and Efanov (1976) have shown that fish with a high natural mortality mature early in life, compensating for the high M by starting to reproduce earlier. Gunderson and Dygert (1988) found a relationship of M with the ratio of gonad weight to somatic weight, which might be reasonable because fish with a high mortality may compensate by producing more eggs. Nevertheless, for the sturgeons the following methods based on the available data were used to estimate natural mortality.

Pauly's empirical formula

Pauly (1980b) made a multiple regression analysis of M (per year) on K (per year) and L_∞ (cm), based on data from 175 different fish stocks, deriving the empirical linear relationship:

$$\ln M = -0.0152 - 0.279 \ln L_\infty + 0.6543 \ln K + 0.463 \ln T$$

where T is the annual mean temperature (in $^\circ C$) of the water in which the stock in question lives.

Because of the lack of information providing accurate estimates of fishing effort, this formula (which is called Pauly's empirical formula) was used for estimating the natural mortality of sturgeons in the Caspian Sea. The values of K and L_∞ were estimated in the previous chapter (chapter 9) for each species. The average annual temperature of the Caspian Sea was calculated as $12^\circ C$, based on data supplied by Mazandarn Province research centre.

Rikhter and Efanov's formula

The Rikhter and Efanov's formula was also applied for estimating natural mortality of the sturgeons. Rikhter and Efanov (1976) showed a close association between M and T_{m50}, the age when 50% of the population is mature, which is reviewed by Sparre *et al.* (1989).

$$M = 1.521 / (T_{m50}^{\ 0.720}) - 0.155 \text{ per year}$$

10. 2. 3 Fishing Mortality (F)

Once the values of total and natural mortality have been calculated or estimated, the value of fishing mortalities can be derived by splitting total mortality in to natural mortality and fishing mortality as follows:

$$F = Z\text{-}M$$

10. 3 Results

10. 3. 1 Total mortality

The Beluga

Linearized catch curve based on age composition

Total mortality of female and male Beluga estimated (Table 10.1) from the descending limb of the catch curve using combined years data (1990-1994) are as follows:

For females, $Z = 0.48$ per year, $r = 0.982$, $P<0.01$

For males, $Z = 0.76$ per year, $r = 0.992$, $P<0.01$

Figures 10.1 and 10.2 show the catch curve for estimating the overall Z for female and male Beluga.

Table 10.1: Linearized catch curve analysis based on age composition data for female and male Beluga (1990-1994).

Females			Males			
age	**number**	**ln (number)**	**age**	**number**	**ln (number)**	**remarks**
8	1	0.00	8	2	0.69	
9	9	2.20	9	7	1.95	
10	29	3.37	10	18	2.89	not used
11	43	3.76	11	36	3.58	in analysis
12	93	4.53	12	80	4.38	
13	137	4.92	13	124	4.82	
			14	187	5.23	
14	251	5.53	15	205	5.32	
15	247	5.51	16	121	4.80	used in
16	204	5.32	17	41	3.71	analysis
17	124	4.82	18	16	2.77	
18	61	4.11	19	11	2.40	
19	32	3.47	20	5	1.61	
20	23	3.14				
21	10	2.30				
22	9	2.20	21	1	0.00	
23	11	2.40	22	3	1.10	not used
24	8	2.08	29	1	0.00	in analysis
25	5	1.61	31	1	0.00	
26	10	2.30				
27	3	1.10				
28	6	1.79				
29	2	0.69				
30	2	0.69				
31	2	0.69				
33	2	0.69				
34	2	0.69				
36	3	1.10				

Linearized catch curve based on length composition

Total mortalities of female and male Beluga were estimated from the catch curve based on length composition data (1990-1994). Tables 10.2 and 10.3 show the arrangement of data for estimating total mortality of females and males. L_∞ and K were estimated in previous chapter.

Table 10.2: Linearized catch curve based on length composition data for female Beluga (1990-1994, $L_{\infty} = 533$, $K = 0.023$).

L1 - L2	C(L1, L2)	t (L)	Δt	t [(L1 + L2) /2] X	ln [C(L1, L2) / Δt] Y	
90-110	1	8.05	2.01	9.05	-0.70	
110-130	1	10.05	2.11	11.11	-0.75	not used in
130-150	11	12.16	2.21	13.27	1.60	analysis
150-170	153	14.38	2.33	15.54	4.18	
170-190	480	16.71	2.47	17.94	5.27	
190-210	387	19.17	2.61	20.48	5.00	
210-230	128	21.79	2.78	23.18	3.83	used in
230-250	66	24.57	2.97	26.05	3.10	analysis
250-270	44	27.54	3.19	29.13	2.62	
270-290	35	30.73	3.44	32.45	2.32	
290-310	15	34.17	3.74	36.04	1.39	
310-330	9	37.90	4.09	39.95	0.79	
330-350	3	41.99				

Table 10.3: Linearized catch curve based on length composition data for male Beluga (1990-1994, $L_{\infty} = 301.8$, $K = 0.072$).

L1 - L2	C(L1, L2)	t (L)	Δt	t [(L1 + L2) /2] X	ln [C(L1, L2) / Δt] Y	
110-130	1	5.60	2.24	6.72	-.81	
130-150	6	7.85	1.72	8.71	1.25	not used in
150-170	97	9.57	1.97	10.56	3.90	analysis
170-190	430	11.54	2.30	12.69	5.23	
190-210	263	13.83	2.75	15.21	4.56	used in
210-230	42	16.59	3.43	18.30	2.50	analysis
230-250	13	20.02	4.57	22.30	1.05	
250-270	5	24.59	6.85	28.01	-.31	
270-290	2	31.44				

Total mortalities of female and male Beluga estimated from the descending limb of the catch curve are as follows:

Females, $Z = 0.21$ per year, $r = 0.987$, $P<0.01$

Males, $Z = 0.38$ per year, $r = 0.983$, $P<0.01$

Estimation of total mortality from Beverton and Holt's Z-equation based on length data.

For females, $\bar{L} = 199.1$ cm, $L' = 170.0$ cm, while L_∞ and K were calculated in the previous chapter. Total mortality was estimated as,

$$Z = 0.023[(533 - 199.1) / (199.1-170)] = 0.26 \text{ per year.}$$

For males, $\bar{L} = 187.3$ cm, $L' = 170$ cm, and total mortality was estimated as,

$$Z = 0.072 [(301.8 - 187.3) / (187.3 - 170)] = 0.47 \text{ per year.}$$

Estimation of total mortality from Beverton and Holt's Z-equation based on age data

For female Beluga, $\bar{t} = 15.5$ year, $t' = 14$ year, from which total mortality was be estimated as,

$$Z = 1 / (15.5 - 14) = 0.67 \text{ per year.}$$

For male Beluga, $\bar{t} = 14.32$, $t' = 13$, from which total mortality was estimated as,

$$Z = 1 /(14.32 - 13) = 0.75 \text{ per year.}$$

Total mortality of male and female Beluga estimated by different methods are shown in Table 10.4. As can be seen, the same values of total mortality were derived from age-based and length-based catch curves for female Beluga. The value of Z estimated for males from age-based catch curves was much higher than for females, the steeper slope reflecting the smaller numbers of males in the older (>16) age groups.

Table 10.4: Total mortality of female and male Beluga for combined years (n = 1335 for females and 859 for males).

sex	Females				Males			
method	**catch curve (age)**	**catch curve (length)**	**B&H length**	**B&H age**	**catch curve (age)**	**catch curve (length)**	**B&H length**	**B&H age**
Z	0.48	0.48	0.21	0.67	0.67	0.38	0.22	0.75
r	0.982	0.984			0.992	0.981		
P	P<0.01	P<0.01			P<0.01	P<0.01		

The Stellate Sturgeon

Linearized catch curve based on age composition

Table 10. 5 shows the arrangement of data for estimating total mortality of female and male Stellate Sturgeon.

For females, $Z = 1.1$ per year, $r = 0.988$, $P<0.01$, $n = 28095$ (Fig 10.3)

for males, $Z = 0.90$ per year, $r = 0.992$, $P<0.01$, $n = 7304$ (Fig 10.4)

Table 10.5: Linearized catch curve analysis based on age composition data for female and male Stellate Sturgeon (1990-1994).

Females			Males			
age	**number**	**ln (number)**	**age**	**number**	**ln (number)**	**remarks**
5	13	2.56	4	3	1.10	
6	111	4.71	5	16	2.77	
7	334	5.81	6	104	4.64	not used
8	701	6.55	7	409	6.01	in
9	1317	7.18	8	960	6.87	analysis
10	2578	7.85	9	1465	7.29	
11	4310	8.37				
12	7284	8.89	10	1864	7.53	
13	6144	8.72	11	1362	7.22	
14	3545	8.17	12	776	6.65	used in
15	1281	7.16	13	224	5.41	analysis
16	336	5.82	14	66	4.19	
17	100	4.61	15	30	3.40	
18	26	3.26	16	14	2.64	
19	7	1.95	17	5	1.61	
20	3	1.10				
21	1	0.00	18	1	0.00	
22	1	0.00	19	3	1.10	not used
23	2	0.69	20	1	0.00	in
27	1	0.00	21	1	0.00	analysis

Linearized catch curve based on length composition

Tables 10.6 and 10.7 show the arrangement of data for female and male Stellate Sturgeon. Total mortality estimated from this method:

for females, $Z = 0.52$ per year, $r = 0.983$, $P<0.01$, $n = 28095$

for males, $Z = 0.62$ per year, $r = 0.997$, $P<0.01$, $n = 7304$

Table 10.6: Linearized catch curve based on length composition data for female Stellate Sturgeon (1990-1994, L_∞ = 188 cm, K = 0.104).

L1 - L2	**C(L1, L2)**	**t (L)**	**Δt**	**t [(L1 + L2) /2]** **X**	**ln [C(L1, L2) / Δt]** **Y**	
80-90	2	5.32	0.93	5.79	.76	
90-100	242	6.25	1.03	6.77	5.46	not used in
100-110	1456	7.29	1.16	7.87	7.14	analysis
110-120	4020	8.45	1.32	9.10	8.02	
120-130	9107	9.76	1.53	10.53	8.69	
130-140	9010	11.29	1.82	12.20	8.51	used in
140-150	3599	13.11	2.24	14.23	7.38	analysis
150-160	550	15.35	2.93	16.81	5.23	
160-170	75	18.28	4.24	20.40	2.87	
170-180	24	22.52	7.78	26.41	1.13	
180-190	7	30.31				
190-200	1					
200-210	1					
210-220	1					

Table 10.7: Linearized catch curve based on length composition data for male Stellate Sturgeon (1990-1994, L_∞ = 171.2 cm, K = 0.113).

L1 - L2	**C(L1, L2)**	**t (L)**	**Δt**	**t [(L1 + L2) /2]** **X**	**ln [C(L1, L2) / Δt]** **Y**	
80-90	4	5.57	1.03	6.09	1.36	
90-100	219	6.60	1.16	7.18	5.24	not used
100-110	1668	7.76	1.34	8.43	7.13	in analysis
110-120	3154	9.10	1.58	9.89	7.60	
120-130	1749	10.68	1.92	11.64	6.81	used in
130-140	407	12.61	2.46	13.84	5.11	analysis
140-150	78	15.07	3.42	16.78	3.13	
150-160	12	18.49	5.65	21.31	.75	
160-170	8	24.13	19.77	34.02	-.90	
170-180	1	43.90				
180-190	4					

Estimation of total mortality from Beverton and Holt's Z-equation based on length data.

For females $\bar{L} = 129.4$ cm, L' = 120 cm, $L_{\infty} = 188$ cm and K = 0.104, from which total mortality of female was calculated as,

$$Z = 0.104[(188-129.4) / (129.4 - 120)] = 0.65 \text{ per year}$$

For males $\bar{L} = 116.7$ cm, L' = 110 cm, $L\infty = 171.2$ cm, K = 0.113, which gives the value of total mortality for males as,

$$Z = 0.113 [(171.2 - 116.7) / (116.7-110)] = 0.92 \text{ per year}$$

Estimation of total mortality from Beverton and Holt's Z-equation based on age data

For females $\bar{t}$ = 12.02 years and t' = 11 years, which gives the value of total mortality as, $Z = 1/ (12.02-11.0) = 0.98$ per year.

For males, $\bar{t}$ = 9.9 years, t' = 9 years, from which total mortality of males was estimated as, $Z = 1/ (9.9 - 9.0) = 1.1$ per year

Total mortality of male and female Stellate Sturgeon estimated by different methods are shown in Table 10.8.

Table 10.8: Total mortality of female and male Stellate Sturgeon for combined years (n = 28095 for females and 7304 for males).

sex	Females				Males			
method	**catch curve (age)**	**catch curve (length)**	**B&H length**	**B&H age**	**catch curve (age)**	**catch curve (length)**	**B&H length**	**B&H age**
Z	1.1	0.52	0.65	0.98	0.90	0.62	0.92	1.1
r	0.988	0.983			0.992	0.997		
P	P<0.01	P<0.01			P<0.01	P<0.01		

The Persian Sturgeon

Linearized catch curve based on age composition

Total instantaneous mortality rates (Z) were calculated from catch curves based on age for 1990 to 1994 combined (Table 10.9). Total mortality were estimated from the descending limb of the curves (Figs 10.5-10.6):

for females, $Z = 0.51$ per year, $n = 9981$, $r = 0.989$, $P<0.01$

for males, $Z = 1.1$ per year, $n = 6606$, $r = 0.985$, $P<0.01$

Table 10.9: Linearized catch curve analysis based on age composition data for female and male Persian Sturgeon (1990-1994).

Females			Males			
age	number	ln (number)	age	number	ln (number)	remarks
7	2	.69	7	3	1.10	
8	6	1.79	8	15	2.71	
9	29	3.37	9	56	4.03	not used
10	53	3.97	10	129	4.86	in
11	82	4.41	11	303	5.71	analysis
12	114	4.74	12	602	6.40	
13	266	5.58	13	955	6.86	
14	911	6.81				
15	1423	7.26				
16	2032	7.62	14	2041	7.62	
17	1997	7.60	15	1552	7.35	
18	1330	7.19	16	695	6.54	used in
19	803	6.69	17	200	5.30	analysis
20	366	5.90	18	36	3.58	
21	192	5.26	19	10	2.30	
22	149	5.00	20	4	1.39	
23	93	4.53				
24	43	3.76				
25	34	3.53				
26	14	2.64				
27	19	2.94	21	1	0.00	
28	10	2.30	22	3	1.10	not used
29	2	.69	23	1	0.00	in
30	5	1.61				analysis
31	1	.00				
32	2	.69				
33	1	.00				
35	1	.00				
39	1	.00				

Linearized catch curve based on length composition

Tables 10.10 and 10.11 show the arrangement of data for estimating total mortality from length composition data catch curve:

For females, $Z = 0.30$ per year, $n = 9981$, $r = 0.995$, $P<0.01$

for males, Z = 0.40 per year, n = 6606, r = 0.990, P<0.01

Table 10.10: Linearized catch curve based on length composition data for female Persian Sturgeon (1990-1994, L_∞ = 207.0 cm, K = 0.079).

L1 - L2	C(L1, L2)	t (L)	Δt	t [(L1 + L2) /2] X	ln [C(L1, L2) / Δt] Y	
90-100	1	7.70	1.21	8.31	-.19	
100-110	34	8.91	1.32	9.57	3.25	not used in
110-120	118	10.23	1.47	10.97	4.39	analysis
120-130	342	11.70	1.65	12.53	5.34	
130-140	799	13.35	1.88	14.29	6.05	
140-150	2024	15.23	2.18	16.32	6.83	
150-160	2729	17.41	2.60	18.71	6.95	used in
160-170	2506	20.01	3.23	21.63	6.65	analysis
170-180	1122	23.24	4.25	25.37	5.58	
180-190	257	27.50	6.25	30.62	3.72	
190-200	41	33.74	11.98	39.73	1.23	
200-210	4	45.72				

Table 10.11: Linearized catch curve based on length composition data for male Persian Sturgeon (1990-1994, L_∞ = 185.5 cm, K = 0.105).

L1 - L2	C(L1, L2)	t (L)	Δt	t [(L1 + L2) /2] X	ln [C(L1, L2) / Δt] Y	
90-100	1	6.31	1.05	6.83	-.05	
100-110	47	7.36	1.18	7.95	3.68	not used in
110-120	299	8.54	1.35	9.21	5.40	analysis
120-130	1166	9.89	1.57	10.68	6.61	
130-140	2206	11.46	1.89	12.41	7.06	
140-150	2104	13.35	2.36	14.53	6.79	used in
150-160	653	15.71	3.14	17.28	5.34	analysis
160-170	105	18.85	4.73	21.22	3.10	
170-180	22	23.58	9.84	28.50	.80	
180-190	2	33.42				
190-200	1					

Estimation of total mortality from Beverton and Holt's Z-equation based on length data.

For females, $\bar{L}$ = 156.5 cm, L' = 140.0 cm, L_∞ = 207.0 cm, K = 0.079, from which total mortality was estimated as,

$Z = 0.079\ [(207 - 156.5) / (156.5 - 140)] = 0.24$

For males, $\bar{L}$ = 138.7 cm, L' = 130 cm, L_∞ = 185.5 cm, K = 0.105, and total mortality was estimated as,

$Z = 0.105[(185.5 - 138.7) / (138.7 - 130)] = 0.56$

Estimation of total mortality from Beverton and Holt's Z-equation based on age data

For females,$\bar{t}$ = 16.76 year and t' = 15 year from which the value of total mortality as was estimated, $Z = 1 / (16.76 - 15) = 0.57$

For males. $\bar{t}$ = 13.98 year, t' = 12 year, from which total mortality was estimated as, $Z = 1/ (13.89- 12) = 0.53$

Table 10.12 shows the values of Z estimated by different methods. As for Beluga the values of Z estimated from catch curves based on age data are much lower in females than males, which is again related to the small number of males in the older age groups (>20).

Table 10.12: Total mortality of female and male Persian Sturgeon from different methods (n = 9981 for females and 6606 for males).

sex	Females				Males			
method	catch curve (age)	catch curve (length)	B&H length	B&H age	catch curve (age)	catch curve (length)	B&H length	B&H age
Z	0.51	0.30	0.24	0.57	1.1	0.40	0.56	0.53
r	0.989	0.995			0.982	0.990		
P	P<0.01	P<0.01			P<0.01	P<0.01		

The Russian Sturgeon

Linearized catch curve based on age composition

Total mortality rates (Z) for female and male Russian Sturgeon were calculated from catch curves (Figures 10.7-10.8). Table 10.13 shows the age composition of females and males.

For females, $Z = 0.67$ per year, $n = 8381$, $r = 0.995$, $P<0.01$

For males, $Z = 0.82$ per year, $n = 1572$, $r = 0.991$, $P<0.01$

Table 10.13: Linearized catch curve analysis based on age composition data for female and male Russian Sturgeon (1990-1994).

Females			Males			
age	number	ln (number)	age	number	ln (number)	remarks
5	1	0.00	8	11	2.40	not used in analysis
7	13	2.56	9	59	4.08	
8	54	3.99	10	129	4.86	
9	129	4.86	11	230	5.44	
10	335	5.81	12	324	5.78	
11	438	6.08				
12	734	6.60				
13	1237	7.12				
14	1917	7.56	13	351	5.86	used in analysis
15	1545	7.34	14	292	5.68	
16	1010	6.92	15	110	4.70	
17	555	6.32	16	31	3.43	
18	213	5.36	17	21	3.04	
19	88	4.48	18	7	1.95	
20	44	3.78	19	3	1.10	
21	23	3.14				
22	13	2.56				
23	6	1.79				
24	4	1.39				
25	10	2.30	21	1	0.00	not used in analysis
26	5	1.61	22	1	0.00	
27	3	1.10	27	1	0.00	
30	3	1.10	31	1	0.00	
37	1	0.00				

Linearized catch curve based on length composition

Tables 10.14-10.15 show the arrangement of data for estimating total mortality of females and males.

For females, $Z = 0.33$ per year, $n = 8381$, $r = 0.997$, $P<0.01$

For males, $Z = 0.46$ per year, $n = 1572$, $r = 0.991$, $P<0.01$

Table 10.14: Linearized catch curve based on length composition data for female Russian Sturgeon (1990-1994, L_{∞} = 192.4 cm, K = 0.082).

L1 - L2	C(L1, L2)	t (L)	Δt	t [(L1 + L2) /2] X	ln [C(L1, L2) / Δt] Y	
90-100	47	7.69	1.25	8.32	3.62	
100-110	429	8.95	2.98	10.44	4.97	not used
110-120	1204	11.92	1.81	12.83	6.50	in analysis
120-130	2062	13.74	2.13	14.80	6.87	
130-140	2420	15.87	2.58	17.16	6.84	
140-150	1609	18.45	3.28	20.09	6.20	used in
150-160	461	21.73	4.50	23.98	4.63	analysis
160-170	118	26.24	7.21	29.84	2.79	
170-180	18	33.45	20.04	43.47	-0.11	
180-190	6	53.49				
190-200	5					

Table 10.15: Linearized catch curve based on length composition data for male Russian Sturgeon (1990-1994, L_{∞} = 178 cm, K = 0.092).

L1 - L2	C(L1, L2)	t (L)	Δt	t [(L1 + L2) /2] X	ln [C(L1, L2) / Δt] Y	remarks
90-100	15	7.15	1.19	7.75	2.54	not used
100-110	220	8.34	1.33	9.01	5.11	in
						analysis
110-120	601	9.67	1.52	10.43	5.98	
120-130	456	11.19	1.76	12.07	5.56	used in
130-140	187	12.95	2.10	14.00	4.49	analysis
140-150	70	15.05	2.61	16.36	3.29	
150-160	14	17.66	3.43	19.38	1.41	
160-170	7	21.09	5.04	23.62	0.33	
170-180	1	26.14	9.67	30.97	-2.27	
180-190	1	35.81				

Estimation of total mortality from Beverton and Holt's Z-equation based on length data.

For females, $\bar{L}$ = 132.1 cm, L' = 120.0 cm, L_∞ = 192.4 cm, and K = 0.082, from which total mortality was estimated as,

$$Z = 0.082\ [(192.4 - 132.1) / (132.1 - 120)] = 0.41 \text{ per year}$$

For males, $\bar{L}$ = 121.3 cm, L' = 110 cm, L_∞ = 178.0 cm, K = 0.092 and total mortality was estimated as:

$$Z = 0.092\ [(178.0 - 121.3) / (121.3 - 110)] = 0.46 \text{ per year}$$

Estimation of total mortality from Beverton and Holt's Z-equation based on age data

For females, mean age was calculated as $\bar{t}$ = 14.0 year, and t' = 12.0 year, total mortality from this method was estimated as:

$$Z = 1 /(14.0-12.0) = 0.50 \text{ per year}$$

For males, mean age was calculated as, $\bar{t}$ = 12.5 year, t' = 11.0 year, which gives total mortality as,

$$Z = 1 / (12.5 - 11.0) = 0.67 \text{ per year}$$

Table 10.16 shows the values of total mortality of Russian Sturgeon estimated by different methods.

Table 10.16: Total mortality of female and male Russian Sturgeon from different methods (n = 8381 for females and 1572 for males).

sex	Females				Males			
method	**catch curve (age)**	**catch curve (length)**	**B&H length**	**B&H age**	**catch curve (age)**	**catch curve (length)**	**B&H length**	**B&H age**
Z	0.67	0.33	0.41	0.50	0.82	0.46	0.46	0.67
r	0.995	0.997			0.991	0.991		
p	P<0.01	P<0.01			P<0.01	P<0.01		

10. 3 .2 Natural Mortality (M)

Pauly's empirical formula

Natural mortalities for all species were estimated using Pauly's empirical equation, based on von Bertalanffy parameters. For all species, two sets of growth parameters estimated from both L_{max} and by FSAS (Fishery Science Application System) were used. Table 10.16 shows the natural mortalities estimated for each species with value of L_{∞} and K.

Table 10.17: Natural mortality of the sturgeons estimated from Pauly's empirical formula.

	Beluga		Stellate Sturgeon		Persian Sturgeon		Russian Sturgeon	
sex	♀	♂	♀	♂	♀	♂	♀	♂
L_∞ (cm) by FSAS	370	302	188	171	207	186	192	178
K	0.052	0.072	0.104	0.113	0.079	0.105	0.082	0.092
M	0.08	0.11	0.16	0.18	0.13	0.16	0.14	0.15
L_∞ (cm) by L_{max}	533	270	213	190	225	197	201	189
K	0.023	0.086	0.062	0.083	0.066	0.084	0.073	0.077
M	0.04	0.13	0.11	0.14	0.11	0.14	0.12	0.13

Rikhter and Efanov's formula

Natural mortalities were also estimated from this method and are given in Table 10. 18. L_{m50} was derived from the number of mature fish for each species in the catches.

Table 10.18: Natural mortality of sturgeons estimated from Rikhter and Efanov's formula.

	Beluga		Stellate Sturgeon		Persian Sturgeon		Russian Sturgeon	
sex	♀	♂	♀	♂	♀	♂	♀	♂
T_{m50} (year)	18	16	14	13	17	15	16	14
M	0.03	0.05	0.07	0.08	0.04	0.06	0.05	0.07

Comparing the natural mortality estimated from both methods, the values estimated from Pauly's formula seem to be high except for female Beluga, especially when the growth parameter estimated by FSAS program were used, probably because of the underestimation of L_∞ by this program.

10. 3. 3 Fishing Mortality

Values of fishing mortality (F) were estimated from Z and M, using values of Z from catch curves and M estimated from Rikhter and Efanov's formula (Table 10.18). The values of Z estimated from catch curves based on age for male Stellate, Persian and Russian Sturgeon seem to be very high, therefore, for estimating of fishing mortality of the males of these species, the values of Z estimated from length data were used. Table 10.19 shows the values of fishing mortality estimated for each sex.

Table 10.19: Fishing mortalities of female and male sturgeon in the south part of the Caspian Sea.

	Beluga		**Stellate Sturgeon**		**Persian Sturgeon**		**Russian Sturgeon**	
sex	♀	♂	♀	♂	♀	♂	♀	♂
Z	0.48	0.38	1.1	0.62	0.51	0.40	0.67	0.46
M	0.03	0.05	0.07	0.08	0.04	0.06	0.05	0.07
F	0.45	0.33	1.03	0.54	0.47	0.34	0.62	0.39

10. 4 Discussion

When estimating the value of Z from the catch curve, any points which are systematically deviating from the straight line are excluded (Sparre *et al.* 1989). However, it is difficult to give a general rule for when this deviation is sufficiently large to justify the exclusion of the point. In the sturgeons, because of the large range of age groups in the catches, choosing which points to exclude is especially difficult. As can be seen from Tables and Figures (10.1, 10.2, 10.3 etc.) some older age groups were excluded because of the very small numbers in the sample.

Comparison of the results shows that values of Z estimated by the various methods are very different. The values of Z for male Stellate, Persian and Russian Sturgeon estimated from catch curves based on age data were very high in comparison with females, probably because of small number of males in the older age groups. As would be expected for long-lived species (Beverton and Holt, 1959) natural mortality estimates are low. In addition, since these populations are fished heavily, a high proportion of Z was actually fishing mortality. These values of Z were not used in estimating fishing mortality. Table 10.19 shows the values of Z, M and F for each species. There are no other available data on total mortality of sturgeon in the Caspian Sea. For Beluga, as the older age groups are progressively less well represented in the catch, the estimates of the total mortality are almost certainly too high, specially for the male. For the other three species, because a high portion of the calculated Z was fishing mortality, and considering the amount of the catch, the estimations for these species are reasonable.

Semakula and Larkin (1986) used catch data from commercial fisheries and estimates total mortality (Z= 0.219) of the White Sturgeon (*A. transmontanus*) of the Fraser River, from the descending axis of the gill net selectivity curve. Total mortality (Z) for *A. brevirostrum* in the St John River Estuary (Canada) was estimated by Dadswell (1979) as 0.12-0.15. These values are much lower than these of the Caspian Sea species, because they less exploited.

There are no other available data relating to the estimation of natural mortality of the sturgeon in the Caspian Sea. The values of natural mortality for *A. fulvescens* in Wisconsin, USA, are 0.01(Beverton and Holt, 1959), for *A. transmontanus* in the Fraser River, Canada, 0.05 (Semakula and Larkin, 1969) and for *A. medirostris* in the Gulf of California 0.03 (Pycha 1956). In the present study natural mortalities estimated from Pauly's empirical formula are much higher (Table 10.18) than the above except for female Beluga (0.04), which is similar to *A. transmontanus* (0.05). Natural mortalities estimated from Rikhter and Efanov's formula (Table 10.19) for all species are smaller and seem more reasonable, because of longevity. Thus estimates for female and male Beluga (0.03, 0.05), female and male Persian Sturgeon (0.04, 0.06) and female Russian Sturgeon (0.05) are similar to those for *A. transmontanus* (0.05, Fraser River, Canada) though higher than those of *A. fulvescens* (0.01) and *A. medirostris* (0.03). However, for female Stellate Sturgeon, M for both females and males (0.07, 0.08) is much higher than in the above-mentioned species. As natural mortality is not constant for all age (size) groups within a species, because a small specimen is exposed to a larger predation mortality than a large one, for the Sturgeons with long life span it would be perhaps more realistic to estimate the value of M for each stanza when there are sufficient data.

The values of fishing mortality (F) estimated for females and males of each species are presented in Table 10.19. The average fishing mortalities for females and males together were 0.39 for Beluga, 0.79 for Stellate, 0.41 for Persian and 0.51 for Russian Sturgeon. The catch of sturgeon in the Caspian Sea is made up of less than 10% Beluga, 40% to 50% Russian and Persian Sturgeon, and over 45% Stellate Sturgeon (Kosarev and Yablonskaya 1994; Moghim, director of stock assessment section of the Mazandran province research centre, Pers. Com.,). Concerning these proportions, it seems that the fishing mortality (like total mortality) estimated for Beluga is too high. For the Persian Sturgeon, as most of the catches of this species come from the southern part, this estimate may be reasonable, but for the whole Caspian Sea might be high. In the Caspian Sea there are no available data on fishing mortality for comparison. As well, there are no proper data on fishing efforts to estimate the biomass of these species by means of cohorts.

However, during the current 5 year period a sharp decline in sturgeon catches has been observed (see Table 1.1). Thus, in 1982, catches in the Caspian basin were as large as 27,000 tonnes, but they were only 12,442 tonnes in 1992 and 7,274 tonnes in 1993. In addition, analysis of age composition shows that most of the specimens of Beluga (southern basin) are now under 20 years old. The age of the Russian Sturgeon occurring in the sea is under 30 years. Individuals of age 5-16 years comprise 88.5 percent; of age 16-20 years 10.7 percent, and 20 years 0.8 percent. Stellate Sturgeon (southern basin) are under 25 years old . Individuals of age 5-14 years make up 93.7 percent, of 13-20 years 6.3 percent, with very few individuals over 20 years. Persian Sturgeon occurring in the southern Caspian Sea are under 35 years old; individuals of 6-17 comprise 68.0 percent, of age of 18-20, 25.7 percent, over 20 years 6.3 percent. Vlasenko (1992) reported nearly the same situation for the age composition of the sturgeons for the whole Caspian Sea, which shows that the catches of sturgeons in the whole Caspian Sea are now mostly composed of first time spawning individuals. Moreover, the present study shows that the mean length of Russian, Persian and Stellate Sturgeon decreased significantly from 1990 to 1994 (see Tables, 6.11, 7.11 and 8.11). The mean size of Beluga was unchanged (see Table 5.11). Vlasenko (1992) reported the same situation for the Beluga and Russian Sturgeon for the whole Caspian Sea.

According to the summer surveys conducted by the USSR, during the period 1983-1991, the catches of Russian Sturgeon adults (the main stock) decreased from 1.1 specimens per tow to 0.54; the catches of Stellate Sturgeon decreased from 1.3 specimens per tow to 0.61 and of Beluga from 0.29 specimens per tow to 0.27 (Vlasenko, 1992). All these indicate that the current fishing mortality of the sturgeons in the Caspian Sea is high. Thus, to improve the present situation of the Caspian Sea, it is necessary to reduce the fishing mortality (legal and illegal).

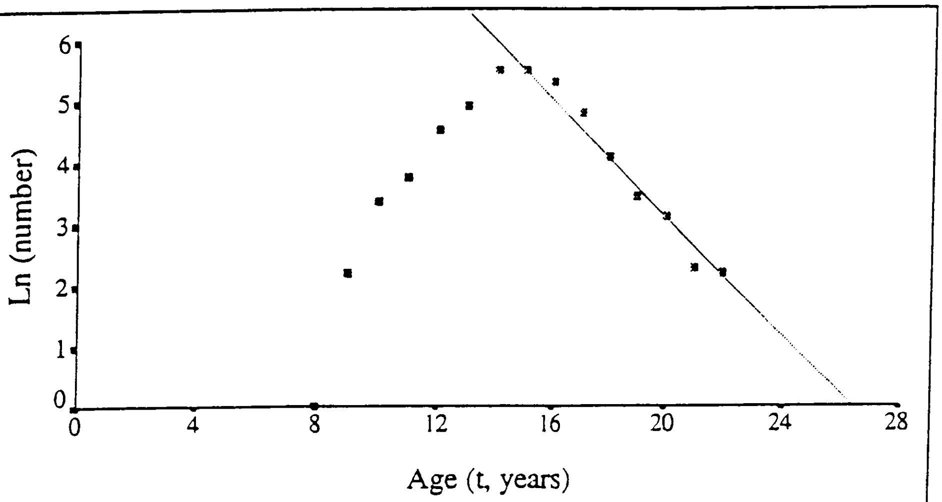


Fig 10.1: Female Beluga : estimation of total mortality 'Z' from descending limb of the catch curve ($Z = 0.48$, $r = 0.982$, $P<0.01$).

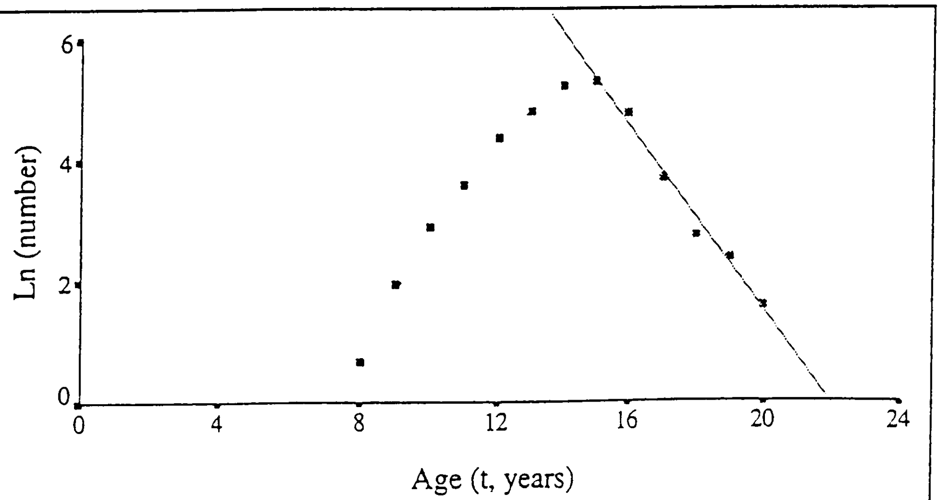


Fig 10.2: Male Beluga: estimation of total mortality 'Z' from descending limb of the catch curve ($Z = 0.76$, $r = 0.992$, $P<0.01$).

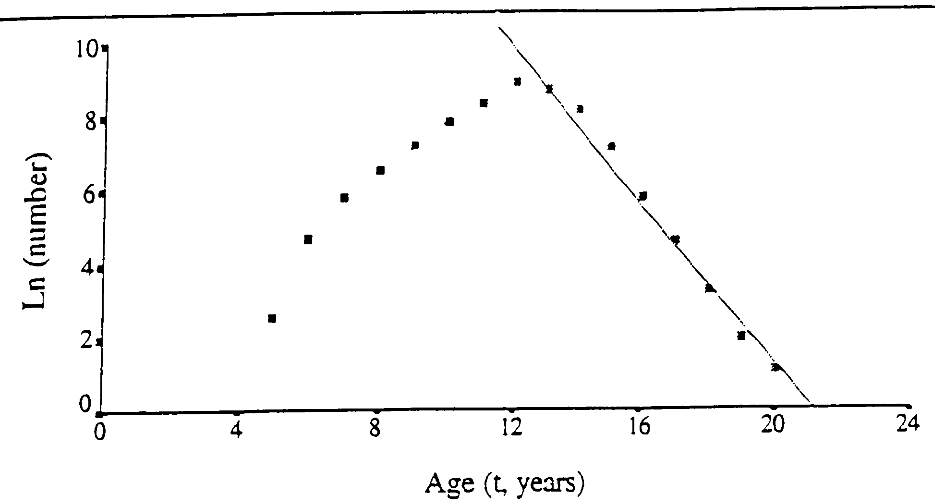


Fig 10.3: Female Stellate Sturgeon: estimation of total mortaliy 'Z' from descending limb of the catch curve ($Z = 1.1$, $r = 0.988$, $P<0.01$).

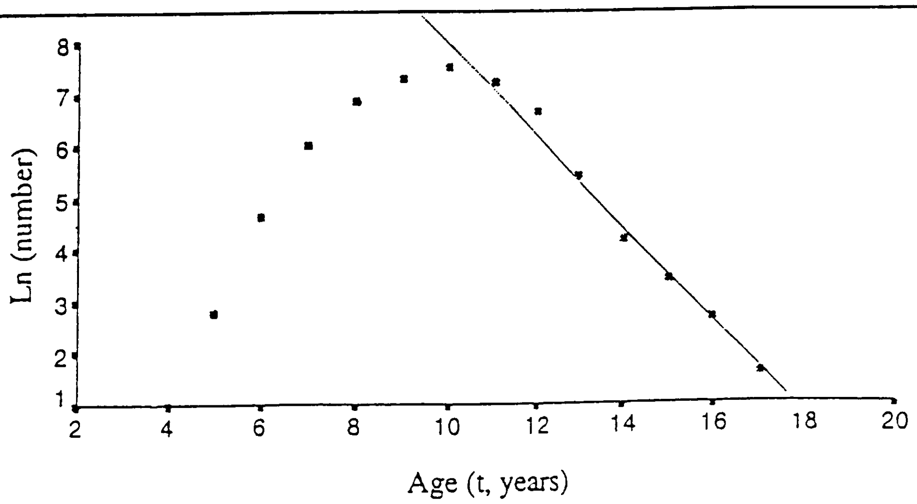


Fig 10.4: Male Stellate Sturgeon: estimation of total mortality 'Z' from descending limb of the catch curve ($Z = 0.90$, $r = 0.992$, $P<0.01$).

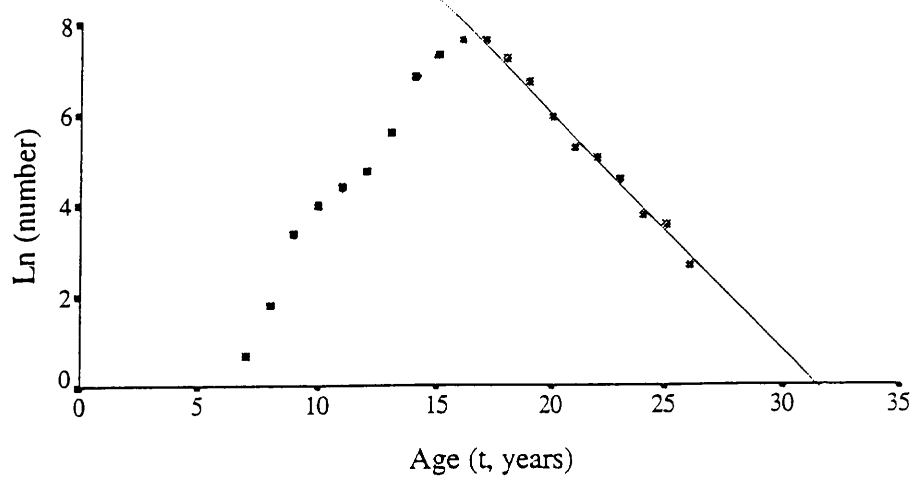


Fig 10.5: Female Persian Sturgeon: estimation of total mortality 'Z' from descending limb of the catch curve ($Z = 0.51$, $r = 0.989$, $P<0.01$).

Fig 10.6: Male Persian Sturgeon: estimation of total mortality 'Z' from descending limb of the catch curve ($Z = 1.1$, $r = 0.985$, $P<0.01$).

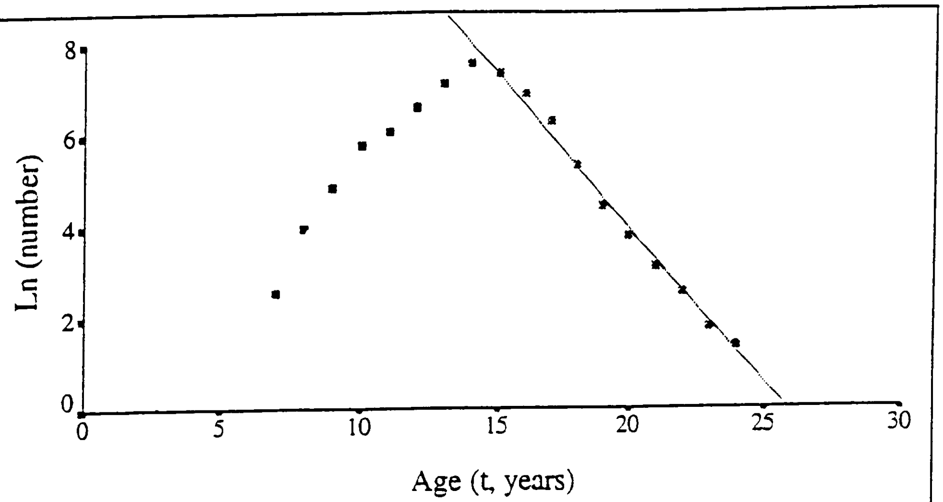


Fig 10.7: Female Russian Sturgeon: estimation of total mortality 'Z' from descending limb of the catch curve (Z = 0.67, r = 0.995, P<0.01).

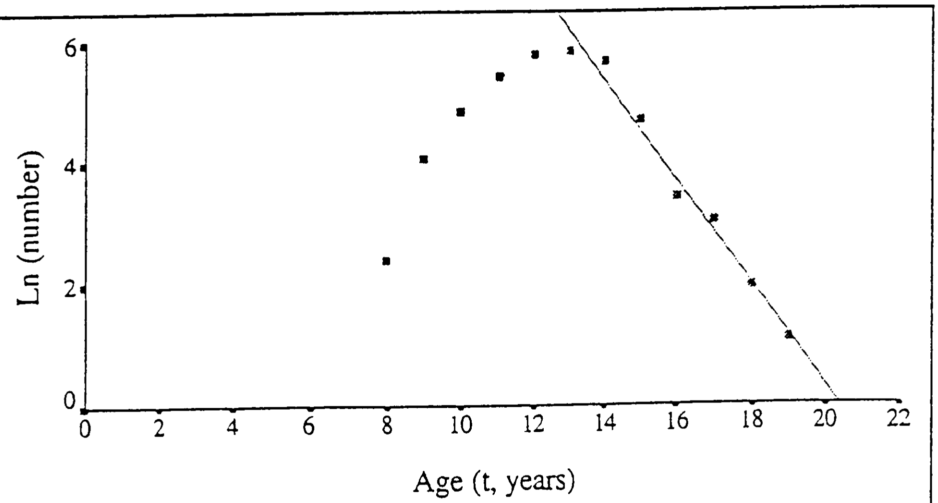


Fig 10.8: Male Russian Sturgeon: estimation of total mortality 'Z' from descending limb of the catch curve (Z = 0.82, r = 0.991, P<0.01).

CHAPTER 11

Yield-per-recruit

11.1 Introduction

Recruitment is the process of entry to a fishery, i.e. fishes first become liable to capture, and therefore enter the exploited phase of the population. Whether or not newly recruited fish are retained by the fishing gear in use, depends on its selectivite properties and the size of the fish (Beverton and Holt 1957). Fishing mortality can vary, due to recruitment or selection, over a range of ages (or sizes), but for purposes of discussion and analysis it is easier, and often acceptable in practice, to treat recruitment or selection as being abrupt or knife-edged. That is that no fish enter the fishery until they reach an age T_r, but all fish of age T_r and older are fully recruited. Similarly, selection may be supposed to act so that fishing mortality is zero until the fish reach the mean selection age T_c, and then undergo the full, constant fishing mortality (Gulland 1983).

Because of fluctuations in recruitment yield, is often expressed as yield per recruit. The yield per recruit model (Beverton and Holt, 1957) is in principle a model describing the state of the stock and the yield in a situation when the fishing pattern has been the same for such a long time that all living fish have been exposed to it since they recruited. Yield-per-recruit is greatly influenced by fishing mortality and the shape of the yield curve depends greatly on growth parameters and natural mortality. Where K and M are low, the highest yields will be obtained at low F, simply because the fish will have the chance to grow bigger.

The purpose of this chapter is to estimate the yield-per-recruit curve for each species, based on growth parameters and mortality rates estimated in previous chapters, and to provide advice for sturgeon fishery managements in the Caspian Sea, in terms of yield-per-recruit and the fishing mortality, 'F_s' that is necessary to achieve the maximum sustainable yield, MSY.

11. 2 Method

The following Beverton and Holt yield-per-recruit model (1957), written in the form suggested by Gulland (1969), and reviewed in Sparre *et al.* (1989), was applied for calculating yield-per-recruit, or providing advice in terms of yield-per-recruit.

$$Y/R = F \exp[-M (T_c-T_r)] W_\infty [(1/Z)-(3S)/(Z+K) + (3S^2)/(Z+2K)-(S^3)/(Z+3K)]$$

where:

$S = \exp[-K(T_c - t_0)]$

K = von Bertalanffy growth parameter

t_0 = von Bertalanffy growth parameter

T_r = age at recruitment

T_c = age at first capture

W_∞ = asymptotic body weight

F = fishing mortality

M = natural mortality

Z = total mortality

Von Bertalanffy growth parameters were estimated for each species in chapter 9. Ages at recruitment (T_r) and first capture (T_c) were derived from the catch curves based on age composition data of each species (chapter 10). The values of W_∞, were calculated from the weight-length relationship (Tables. 5.14, 5.15; 6.14, 6.15; 7.14, 7.15; 8.14, 8.15) using L_∞ estimated for each species (Chapter 9).

11. 3 Results

11. 3. 1 Beluga

For female Beluga a yield per recruit curve was produced as a function of F for the following parameter values (Fig 11.1):

$K = 0.0524$ $T_c = 14.0$ year $t_0 = -0.354$ year

$M = 0.03$ $T_r = 9.0$ year $W_\infty = 497.0$ kg

It was found that F = 0.07 gives the maximum Y/R, the "maximum sustainable yield per recruit":

MSY/R = 107.5 kg per recruit,

which corresponds to the optimum fishing mortality:

$F_s = 0.07$ per year.

For male Beluga Y/R calculated using the following parameter values (Fig 11.2):

$K = 0.072$ $T_c = 13.0$ year $t_0 = - 0.754$ year

$M = 0.05$ $T_r = 8.0$ $W_\infty = 247.3$ kg

The optimum value of fishing mortality for male Beluga was found to be $F_s = 0.16$, which gives the maximum sustainable yield as, MSY/R = 57.6 kg per recruit

11. 3. 2 Stellate Sturgeon

Yield-per-recruit was calculated for female Stellate Sturgeon as a function of F, using following parameter values (Fig 11.3):

$K = 0.104$ $T_c = 11.0$ year $t_0 = -0.261$year

$M = 0.07$ $T_r = 5.0$ year $W_\infty = 31.0$ kg

F = 0.42 gives the maximum Y/R as:

MSY/R = 7.34 kg.

For males the following Y/R was estimated using the following parameter values (Fig 11.4):

$K = 0.113$ $T_c = 9.0$ year $t_0 = -0.286$ year

$M = 0.08$ $T_r = 4$ year $W_\infty = 17.3$ kg

F = 0.3 gives the maximum Y/R = 3.7 kg.

11. 3 . 3 Persian Sturgeon

For female Persian Sturgeon by testing various F-values it was found that F = 0.16 gives the maximum Y/R = 16.8 kg (Fig 11.5).

The following parameter values were used,

$K = 0.079$ $T_c = 14.0$ year $t_0 = -0.166$ year

$M = 0.04$ $T_r = 7.0$ year $W_\infty = 60.5$ kg

For male, Persian Sturgeon F = 0.34 gives the maximum Y/R = 6.7 kg (Fig 11.6). The following parameter values were used,

$K = 0.105$ $T_c = 12.0$ year $t_0 = -0.022$ year

$M = 0.06$ $T_r = 7.0$ year $W_\infty = 22.3$ kg

11. 3. 4 Russian Sturgeon

For female Russian Sturgeon, by testing different F-values it was found that $F = 0.21$ gives the maximum $Y/R = 15.8$ kg (Fig 11.7).

The following parameters were used,

$K = 0.082$ $T_c = 12.0$ year $t_0 = -0.901$ year

$M = 0.05$ $T_r = 6.0$ year $W_\infty = 64.955$ kg

For males, $F = 0.37$ gives the maximum $Y/R = 7.42$ kg (Fig 11.8) using the following parameter values:

$K = 0.092$ $T_c = 12.0$ year $t_0 = -0.271$ year

$M = 0.07$ $T_r = 6.0$ year $W_\infty = 33.2$ kg

11. 4 Discussion

Inspection of the yield-per-recruit model (Figs 11.1-11.8) for sturgeons in the Caspian Sea shows that the fishing mortality should be reduced by decreasing fishing effort. Table 11.1 shows the current fishing mortality of the sturgeons (estimated in a previous chapter) and the value of F_s which gives the maximum value of Y/R.

Table 11.1: Results of yield per recruit curve, F_s and current fishing mortality (F) of the sturgeons in the Caspian Sea.

	Beluga		**Stellate Sturgeon**		**Persian Sturgeon**		**Russian Sturgeon**	
sex	♀	♂	♀	♂	♀	♂	♀	♂
F	0.45	0.33	1.03	0.54	0.47	0.34	0.62	0.39
F_s	0.07	0.16	0.42	0.30	0.16	0.34	0.21	0.37

As is clear from the results, for some species the current fishing mortality is more than twice the F_s. This result confirms the overfishing of the sturgeons in the Caspian Sea. The dramatic reductions in the annual catches of the sturgeons (e.g. from 15.55 tonnes in 1990 to 7.43 in 1993, see Chapter 1) support the validity of this calculation. Several other authors such as Smith (1990), Birstein (1993), Bemis and Findeis (1994), and Dumont (1995), have confirmed the overfishing of the sturgeons in the Caspian Sea. The non-observance of fishery regulations after the breakup of the Soviet Union contributed to a drastic decline in the number of sturgeons. The newly-formed states (Azerbaijan, Turkmenistan, Kazakhistan) that now ring the Caspian Sea do not control sturgeon fishing and poaching for caviar has increased dramatically. According to the estimate of the oldest European caviar trading company, Dieckmann & Hansen, in 1995 (Desalle and Birstein 1996), international markets require 450 tonnes of black caviar whereas the legal production of caviar in Russia and Iran was

228 tonnes. The figures from the US Commerce Department indicate that caviar imports have increased by 100% since 1990 (DeSalle and Birstein, 1996).

According to Valentin Artyomov, a member of the Russian Fisheries Committee (Abzeeyan Monthly Magazin, 1996), the number of the sturgeons in the Caspian Sea has plunged from 200 million in 1990 to 50 to 60 million in 1995. He commented that everyone is fishing as they see fit and, since there is no law and no agreement, the sturgeons will simply disappear. The decline in numbers has been attributed to pollution and low water levels, but Artyomov (1996) has said that poaching and disputes over fishing rights remain the biggest obstacle to the sturgeon's survival. While, in the past, both the Soviet Union and Iran enjoyed the right to fish about 20,000 tonnes of sturgeons every year, today Russia legally fishes only around 1,000 tonnes a year (Artyomov 1996). Nevertheless, because the level of poaching has soared, he said he believed that far more than 40,000 tonnes were being fished every year.

As a result, the population sizes of commercial sturgeon species have fallen dramatically during the past few years (Birstein 1993; Bemis and Findeis 1994). Indeed it has even been suggested (Dumont 1995) that the sturgeon's only chance of survival may be in captivity. The results of the present chapter provide a guide-line for harvesting sturgeon in Caspian Sea.

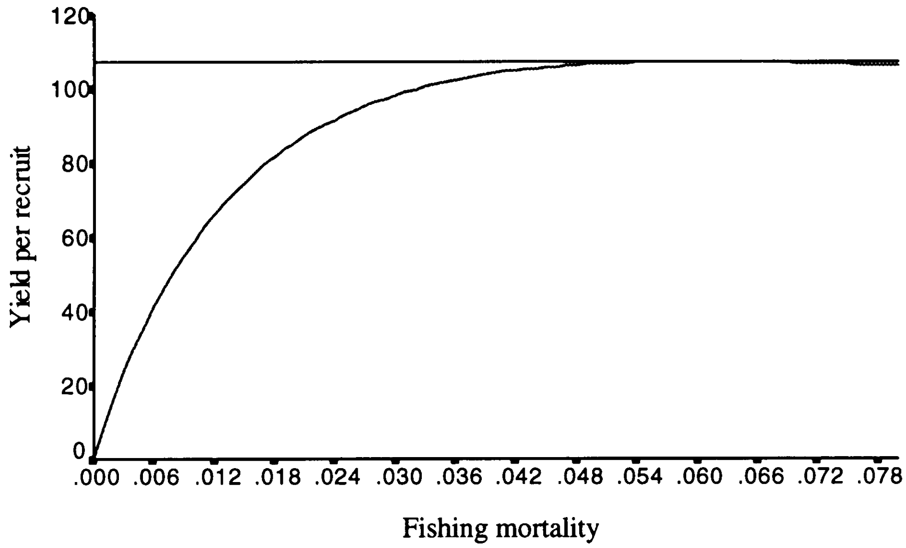


Fig 11.1: Yield per recruit curve for female Beluga showing the yield as a function of the fishing mortality ($F_s = 0.07$).

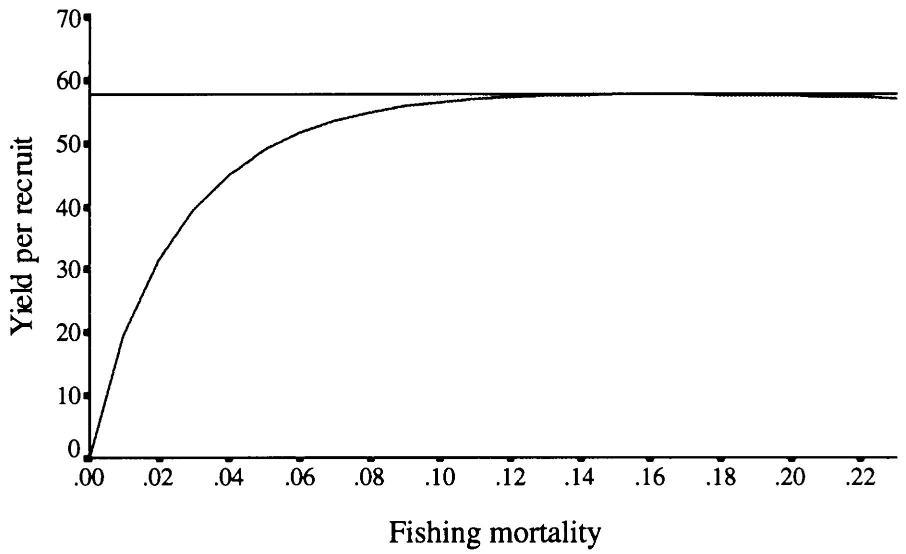


Fig 11.2: Yield per recruit curve for male Beluga showing the yield as a function of the fishing mortality ($F_s = 0.16$).

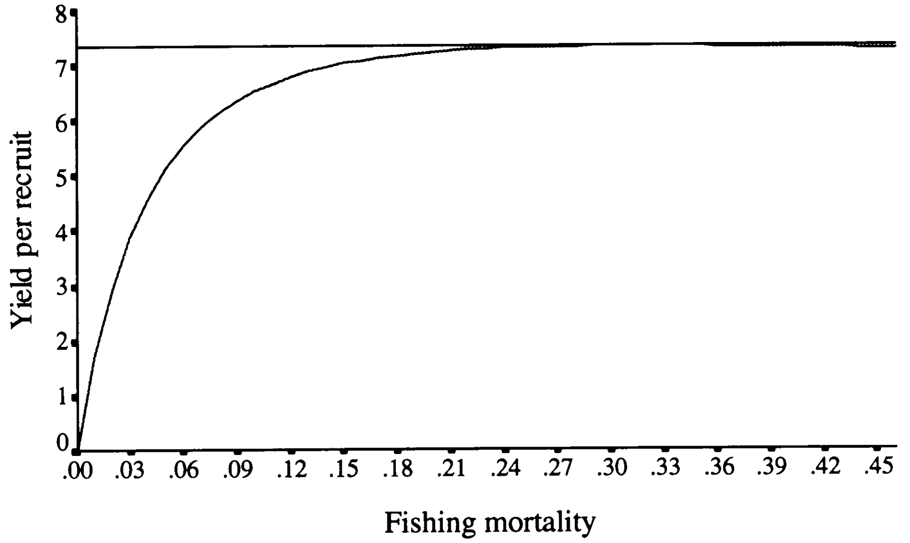


Fig 11.3: Yield per recruit curve for female Stellate Sturgeon showing the yield as a function of the fishing mortality ($F_S = 0.42$).

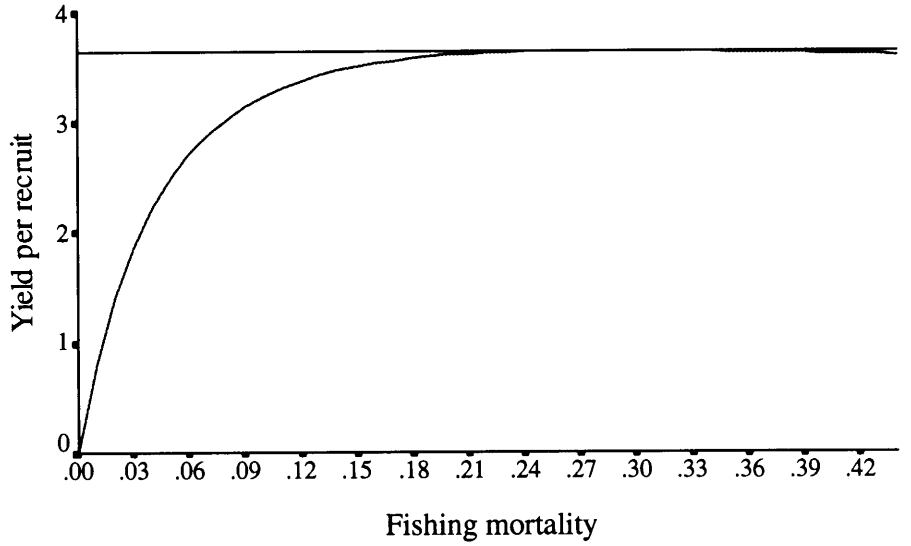


Fig 11.4: Yield per recruit curve for male Stellate Sturgeon showing the yield as a function of the fishing mortality ($F_S = 0.30$).

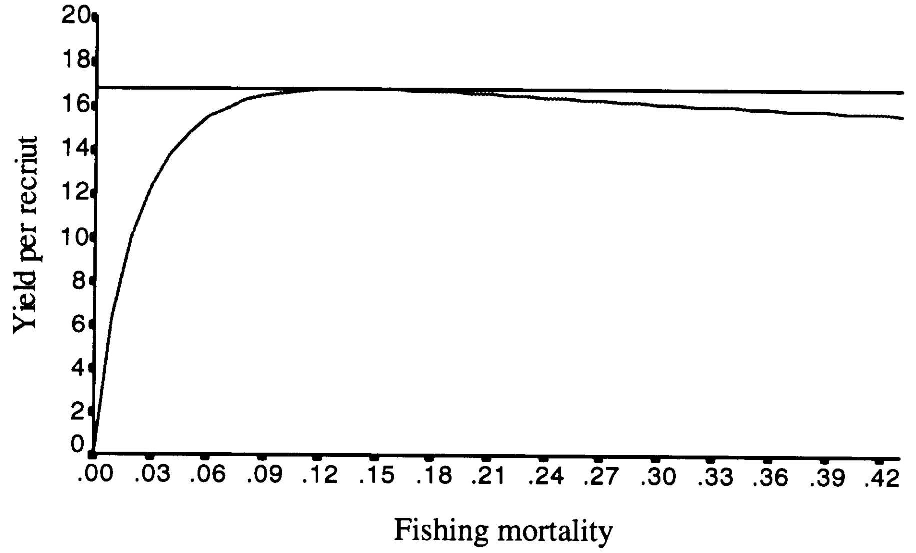


Fig 11.5: Yield per recruit curve for female Persian Sturgeon showing the yield as a function of the fishing mortality ($F_s = 0.16$).

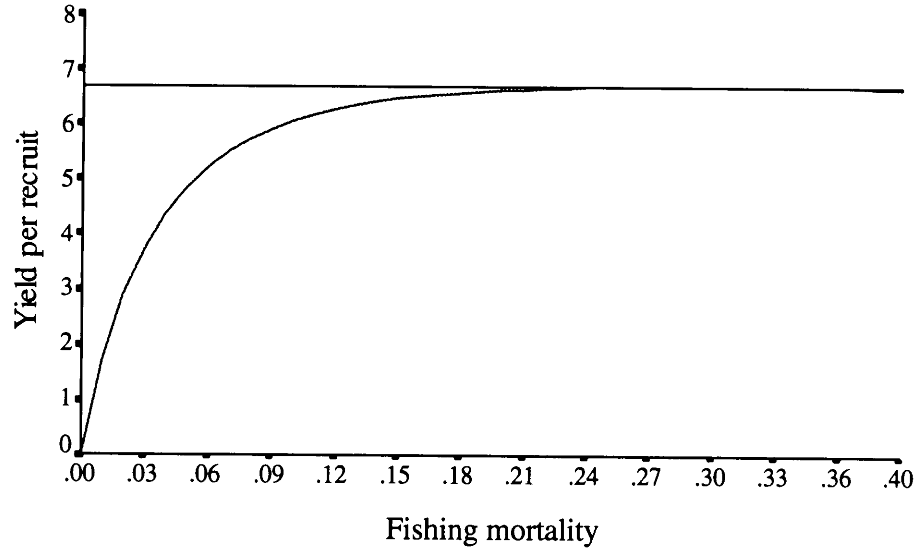


Fig 11.6: Yield per recruit curve for male Persian Sturgeon showing the yield as a function of the fishing mortality ($F_s = 0.34$).

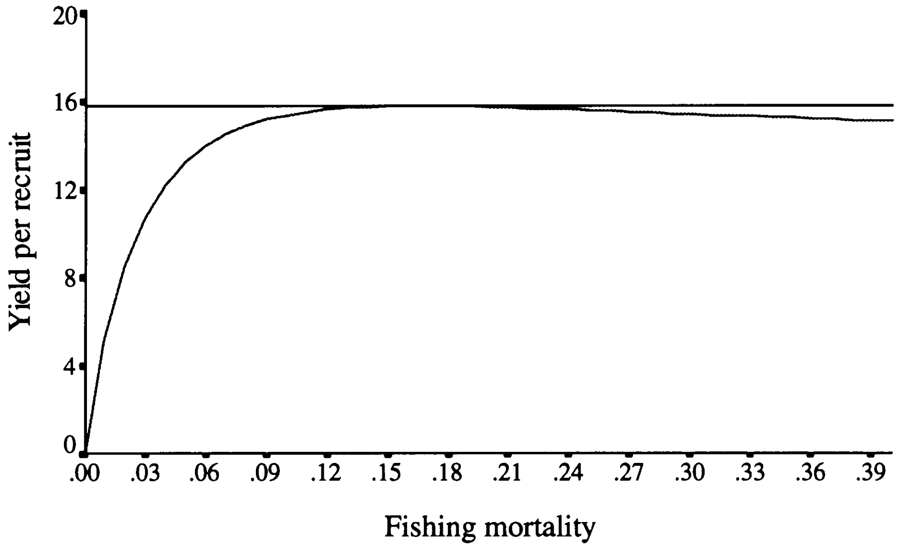


Fig 11.7: Yield per recruit curve for female Russian Sturgeon showing the yield as a function of the fishing mortality ($F_s = 0.21$).

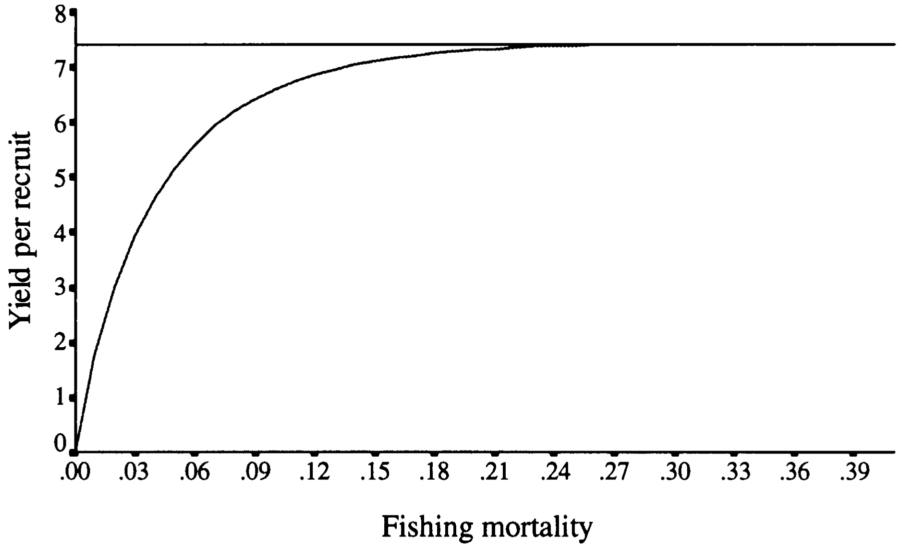


Fig 11.8: Yield per recruit curve of the male Russian Sturgeon showing the yield as a function of the fishing mortality ($F_s = 0.37$).

CHAPTER 12

GENERAL DISCUSSION

Sturgeon stocks have been depressed throughout the world because of demand for their highly valued flesh and caviar produced from their eggs. Human activities in watersheds where sturgeon live have affected their habitat. At present, the population of sturgeon in the Caspian Sea depends on both natural and artificial reproduction. The efficiency of natural reproduction is determined by the flow in the rivers (Vlasenko *et al.* 1981) and other environmental factors.

Studies have been made on the population dynamics of the four important species of sturgeon found in the southern Caspian Sea, based on five years' catches (1990-1994). The study attempted to determine the sex ratio, age, length, weight, the relationships between length, weight and age, growth rates, and mortality rates. The population age structure was found to lack older fish: for Beluga more than one half and for other species at least one third of the potential age groups were absent.

Pectoral fin sections were used for age determination, but the accuracy and ease of age estimation from pectoral fin rays were different for each species and depended on the age and size of the fish. Delineation of annuli was most difficult in older fish, probably because of slow growth: fish that grow slowly do not appear to form a detectable growth zone every year. The large variations which have been found in annual increment in length and weight of these species, especially in Beluga, might be a consequence of errors in ageing; therefore it is necessary for the future to find a more accurate way of age determination in sturgeon species. In the present study, an additional reader, with 2 to 3 years experience ageing sturgeons, examined the annuli at the same time, but the percentage of discrepancies between me and other reader which occurred for one or two years plus and minus was not recorded. According to Rien and Beanesderfer (1994), age determinations from pectoral fin rays in White Sturgeon are not precise and underestimate the age of older fish. Chilton and Beamish (1982) have used the break-and-burn technique with otoliths for ageing many long lived species and reported a more accurate alternative for ageing sturgeons. Although otoliths have been used to age lake sturgeon *Acipenser fulvescens* (Harkness 1923; Schnebereger and Woodbury, 1994), they were found to be difficult to process and read due to their brittleness. Otoliths have not been used in Caspian Sea sturgeon.

The sex composition of all four species under study in southern Caspian shows a predominance of females (female Beluga 61%; female Stellate Sturgeon 79%; female Persian Sturgeon 61%, and female Russian Sturgeon 84%). According to Rezvani (1989) females of Stellate, Persian and Russian Sturgeon were likewise predominant (more than 70%) in the Iranian catches during 1969-1970, 1986-1987 and 1988-1989. For Beluga also, the proportion of females was higher (more than 60%) in 1986-1987 and 1988-1989, but for 1969-1970 the females comprised only 47%.

For all the species the ranges of the ages were limited, and the number of older (older than 20 years) age groups in the catches was negligible. Analysis of the age structure shows that the present (1990-1994) catches of sturgeons in the southern Caspian include mainly first spawning fish; therefore it seems that the harvesters are now seriously reducing the potential for reproduction, except in a limited number of fish which are captured for artificial propagation. According to Raspopov (1987), the main part of the catches of Beluga in the Volga River during 1970-1985 were also first spawning fish.

The most important way to maintain sturgeon populations is by rational fishing. This cannot be done without knowledge of the biological bases for regulation of fishing. The von Bertalanffy growth parameters, total, natural and fishing mortality rates for each species must be known. Assessment of the events during the life of a cohort of fish is largely a matter of the balance between decreasing numbers, and increasing individual weight. For example, when evaluating the effects of change in the mesh size used in a trawl fishery, the critical factor is the amount of growth made during the short period between the time when the fish would have been retained by the original smaller mesh and when actually caught by the larger mesh (Gulland, 1983).

The results of the present study suggest that growth can be divided into three distinct stanzas, characterized by different values of the von Bertalanffy parameters, during the life of these sturgeons. Initially, before they enter the fishery, growth rate is high; between about ages 9 to 21, in the classes that dominate the fishery, growth rate is intermediate; and from about 24 onwards it appears slower. The results also show that, because of the variation in growth rates, von Bertalanffy parameters cannot be derived simply by using Gulland and Holt plot. Although the parameters were estimated using FSAS (Fishery Science Application System) computer program, by forcing the curve through zero, it appears that this program underestimates L_∞ for the whole life span of the sturgeon, as there are many specimens in the annual catches that are larger than the estimated L_∞. Table 12.1 shows the values of L_∞ and K estimated by both methods for each species.

Table 12.1: L_∞ and K estimated for each species by two methods.

Species	sexes	by using L_{max} L_∞, K	by FSAS program L_∞, K
Beluga	**female**	533 cm, 0.023	370 cm, 0.052
	male	270 cm, 0.086	302 cm, 0.072
Stellate Sturgeon	**female**	213 cm, 0.062	188 cm, 0.104
	male	190 cm, 0.083	171 cm, 0.113
Persian Sturgeon	**female**	225 cm, 0.066	207 cm, 0.079
	male	197 cm, 0.084	186 cm, 0.105
Russian Sturgeon	**female**	201 cm, 0.077	192 cm, 0.082
	male	189 cm, 0.077	178 cm, 0.092

Note: L_{max} was not used for estimation of L_∞ and K for the female Beluga (see chapter 9).

Since sturgeons are long-lived, late maturing species, the change in growth rate which appears to occur at about age 20-25 may be a consequence of maturity, though first maturity tends to be earlier than that (perhaps 15-18), at which, however fecundity is lower (Raspopov 1987). Thereafter the females are believed to mature and spawn every 3-5 years. Thus, for female Beluga, the best way of calculating von Bertalanffy parameters was to regard the growth as comprising three stages, and the von Bertalanffy parameters were estimated for juveniles, for the middle stanza and for older fish separately. The value of L_∞ for the female Beluga was estimated as 320 cm for juveniles, 450-666 cm for the middle stanza, and 533 cm for the older fish.

The value of K for the female Beluga was estimated as 0.065 for the juveniles, 0.029-0.016 for the middle stanza, and 0.023 for older fish.

Total mortalities (Z) were estimated for each species using different methods of estimation (see chapter 10). The preferred values of Z are 0.48 and 0.38 for female and male Beluga; 1.1 and 0.62 for female and male Stellate Sturgeon; 0.51 and 0.40 for female and male Persian Sturgeon, and 0.67 and 0.46 for female and male Russian Sturgeon respectively.

For each species the natural mortalities (M) were estimated using Pauly's empirical formula (1980b) and Rikhter and Efanov's formula (1976) (see chapter 10). The preferred values of M are, 0.03 and 0.05 for female and male Beluga; 0.07 and 0.08 for female and male Stellate Sturgeon; 0.04 and 0.06 for female and male Persian Sturgeon, and 0.05 and 0.07 for female and male Russian Sturgeon respectively.

Current fishing mortalities (F) were estimated by subtracting natural mortality from total mortality, for females and males of each species (Table 10.9). The averaged fishing mortalities for females and males together were 0.39 for Beluga, 0.79 for Stellate, 0.41 for Persian and 0.51 for Russian Sturgeon. The results of a yield per recruit estimation (see chapter 11) suggest that current fishing mortality of sturgeons in the Caspian Sea should be reduced.

In conclusion, all parameters estimated for each species are given in Table 12.2.

Table 12.2: Growth parameters, total, natural and current fishing mortalities, and optimum fishing mortalities (F_s) for each species.

Species	sex	using L_{max} L_∞, K	FSAS program L_∞, K	Z from different methods	M from different methods	Fishing mortality	F_s
Beluga	female juvenile	320 cm, 0.065					
	female middle stanza	666 cm, 0.016 550 cm, 0.021 450 cm, 0.029	370 cm, 0.052	0.21-0.67	0.03-0.04	0.45	0.07
	female older fish	533 cm, 0.023					
	male	270 cm, 0.086	302 cm, 0.072	0.22-0.75	0.05-0.11	0.33	0.16
Stellate Sturgeon	female	213 cm, 0.062	188 cm, 0.104	0.52-1.1	0.07-0.16	1.03	0.42
	male	190 cm, 0.083	171 cm, 0.113	0.62-1.1	0.08-0.18	0.54	0.30
Persian Sturgeon	female	225 cm, 0.066	207 cm, 0.079	0.24-0.57	0.04-0.13	0.47	0.16
	male	197 cm, 0.084	186 cm, 0.105	0.40-1.1	0.06-0.16	0.34	0.34
Russian Sturgeon	female	201 cm, 0.073	192 cm, 0.082	0.33-0.67	0.05-0.14	0.62	0.21
	male	189 cm, 0.077	178 cm, 0.092	0.46-0.82	0.07-0.15	0.39	0.37

However, overall results of the present study show the crucial condition of the sturgeons in the Caspian Sea. According to news from the Abzeeyan Monthly Magazine (1996), in spite of increasing fishing effort in the south part of the Caspian Sea, the catches of sturgeons have decreased every year since 1992. In order to conserve the unique sturgeons of the Caspian Sea it is necessary that measures be taken to diminish the impact of fishing on the stock. These measures must include regulation to reduce the level of fishing effort.

The sturgeon stock in the sea currently multiplies through a combination of natural and artificial reproduction. According to Vlasenko (1992) prior to the Volga flow regulation (1958), the area of sturgeon spawning grounds was as large as 3,600 ha. But as a result of the construction of dams and storage reservoirs 85 percent of the spawning grounds have been lost. Thus, almost 100 percent of the Beluga spawning grounds, 70 percent of the Russian Sturgeon spawning grounds and 40 percent of the Stellate Sturgeon spawning grounds have been taken away. The area of natural spawning grounds in the Kura River has been reduced to 160 ha, in the Terek River to 132 ha, and in the Sulk River to 202 ha. The only unregulated river flowing into the Caspian Sea is the Ural with largest area (1,400 ha) of the sturgeon spawning grounds.

The efficiency of sturgeon natural reproduction is depend on the water level in the rivers of the Caspian Sea (Vlasenko 1992). In the past years when the water level in the rivers was rather high and the volumes of river discharge were 175 km^3 in the Volga, 10 km^3 in the Ural, 9 km^3 in the Kara and 6 km^3 in the Terek, the efficiency of natural reproduction was 5-6 times higher than in the low-water years.

According to the above-mentioned author, since the Volgograd dam was constructed there has been a tendency towards a gradual decline in the efficiency of sturgeon natural reproduction. All these show that the maintenance of natural reproduction is an essential condition of the sturgeon preservation.

Recommendation

The annual catches of sturgeon in the Caspian Sea have dropped sharply in recent years. For example, the sturgeon catches were 27,000 tonnes in 1982, but 13,558 tonnes in 1991, which means that the catches of 1982 were more than twice those of 1991 and certainly annual catches have been lower during recent years since 1991. This, together with decline in the representation of older fish, shows that the sturgeon populations in the Caspian Sea are being overfished. Therefore, there must be a regulatory agreement between the countries around the Caspian Sea for rational harvesting. The coefficient of fishing mortality (F), for Stellate, Persian, and Russian Sturgeons should be reduced (see Table 11.1 for the value of F_s for each species).

Because of late maturation and a long period of marine feeding up to the first spawning, migratory sturgeons are adversely affected by a marine fishery. Mostly immature fish are caught so that the migration of mature fish into the rivers, and consequently recruitment from natural reproduction, decrease. The negative and harmful effect of catching of immature sturgeons has been emphasized by Marti (1972). Practically it is impossible to ban fishing in the Caspian Sea, because countries such as Iran do not have enough rivers for harvesting sturgeons. However, the harvesting of immature sturgeon should be avoided and those immature fishes which are captured by gill nets should be discarded.

The length (*TL*) at first spawning time for the female Stellate Sturgeon varies between 118 and 123 cm, 90-106 cm for males; and Russian Sturgeon of both sexes not less than 100 to 110 cm (Borzenko 1942, Chugunov and Chugunova 1964). The present (1990-1994) catch of both species contained few individuals less than 120 cm of total length, but still included many immature fish. This suggests that introducing a lager mesh regulation for harvesting the Stellate, Persian and Russian Sturgeons in the Caspian sea is necessary. Actually there is no way to avoid the capture of immature fish of a large sturgeon such as Beluga by gill nets set for smaller sturgeon. The catch is multi-species and regulating mesh size for only single species is impossible. A practical possibility could be to release the under-size fish after capturing them.

The sturgeon farms in the lower reaches of the Kura and Volga rivers began operations in the mid-1950s. According to Brannikova (1987) the efficiency of farm fish culture is evident in the case of Beluga in the Caspian basin, as its natural reproduction is now extremely limited. Fortunately, in both Iran and Russia, the artificial propagation of sturgeon is well developed and every year many fingerlings are released in the sea from both sides, but the environmental condition of the Caspian Sea should also be taken into consideration. According to Raspopov (1993), the decline in growth rates of Beluga caught in the Volga between 1970 and 1987, might an indication that living conditions of the Beluga in the Caspian Sea are unsatisfactory.

It seems that the populations of the Beluga, probably because of the higher quality of its caviar, are more depleted, and the number and quality of spawners have become limited. Therefore, in order to maintain the spawning stock, the harvesting of Beluga (except for artificial propagation) should be much restricted for a period of several years.

It is vital to establish an organization of countries around the Caspian Sea, which will record regularly for all species information on catches, and especially fishing effort, and share the information between the countries for further study. The absence of proper data on effort makes it impossible to advise on regulation of fisheries by means of fishing effort (other than to reduce it). It is essential for future management that fishing effort is properly recorded.

The lack of information on juvenile stages of the sturgeon forces the researcher in future to use other fishing methods, for example bottom trawling. After breakdown of former Soviet Union, the poaching of the sturgeon in the Caspian Sea has become regular, and effective measures against poaching should be taken into consideration.

Since gill netting with small mesh size for teleost species has destructive effects on juvenile sturgeons, the Iranian Government has fortunately stopped gill netting for teleost species since 1995 (Abzeeyan Monthly Magazin 1996).

REFERENCES

Abdurakhmanov, Yu. A. 1962. Ryby presnykh vod Azerbaidzhana. Izd. Akad. Nauk Azerb. SSR, Baku. "cited in" *Freshwater Fishes of Europe*, vol. 1. ed. J. Holcik, 1989. AULA Verlag. Wiesbaden, Germany.

Adamovich, V. 1884. Ikra (istoricheskaya spravka, dobyvanie, tekhnicheskaya obrabotka). Niva 8. 183-186. "cited in" *Freshwater Fishes of Europe*, vol. 1. ed. J. Holcik, 1989. AULA Verlag. Wiesbaden, Germany.

Antipa, GR. 1933. Les sturions de la Mer Noire; leur biologie et les mesures necessaries pour leur protection. Bull. Sect. Sci. Acad. Roumaine 16 (4-5): 1-17."cited in" *Freshwater Fishes of Europe*, vol. 1. ed. J. Holcik, 1989. AULA Verlag. Wiesbaden, Germany..

Aleev, Yu. G. 1963. Funktsional'nye osnov-y vneshnego stroeniya ryby. Izd. Akad. Nauk SSSR, Moskva.1963. "cited in" *Freshwater Fishes of Europe*, vol. 1. ed. J. Holcik, 1989. AULA Verlag. Wiesbaden, Germany.

Ambroz, A. I. 1960. Beluga Chernogo morya. Uchenye zapiski Kishinevskogo univ. 56: 5-200. "cited in" *Freshwater Fishes of Europe*, vol. 1. ed. J. Holcik, 1989. AULA Verlag. Wiesbaden, Germany.

Artyukhin, E. N. 1979. The Persian sturgeon in the rivers of Northern Caspian and prospects of its utilization in sturgeon farming. In *Biological basis of sturgeon farming in the water reservoir of the USSR . Nauka press, Moscow.* pp. 105-115 (in Russian)

Artyukhin, E. N. 1983. Differentiation of the Persian sturgeon populations and prospects of its commercial culture in Volga. In *Biological basis of sturgeon farming. Nauka press, Moscow*, pp. 54-61 (in Russian).

Artyukhin, E. N. and Z. G. Zakrua, 1986. Taxonomic status of sturgeon of the Rioni River (Black Sea basin),*Vopr Ichthyol,* No. 1: 61-67.

Altuf 'ev. YU. V. and Romanov, A. A. 1988. Regional differences in growth of juvnile sturgeons during ontogeny. *Vopr Ichthyol*, No. 3, pp. 426-433.

Artyukhin, E. N. 1988. The nature and origin of summer spawning in Sturgeons. *Vopr Ichthyol*, No. 5 , pp. 717-723.

Babushkin, N. YA, and M. P. Borzenko, 1951. Sturgeon of the Caspian (in Russian). Pishchepromizdat, Moscow, pp. 5-67.

Babushkin N. YA. 1964. The biology and fishery of the Caspian Sea Beluga sturgeon "*Huso huso*" *Trudy VNIRO* 52: 183-258.

Bagenal. T. B. and Tesch. F. W. 1978. Age and growth. Pages 101-136, in T. B. Bagenal, ed. *Methods for assessment of fish production in fresh waters*, 3rd edition. Blackwell Scientific Publications, Oxford, England.

Banarescu, P. 1964. Pisces - Osteichthyes. Fauna Republicii Populare Romine. 13. Editure Academiei Republicii Populare Romine Bucuresti. "cited in" *Freshwater Fishes of Europe*, vol. 1. ed. J. Holcik, 1989. AULA Verlag. Wiesbaden, Germany.

Baranov. F. T. 1918. On the question of the biological basis of fisheries. *Nauchnyi issledovatelskii ikhtiologischeskii Institut Isvestia*, 1. 81-128.

Barannikov, I. A. 1972. Pathway and function basis for infra-population differentitation in acipenserid fishes. Leningr. Gos. Univ., *Trudy Lab. Vosp. Rybn. Zapas.*, Leningrad, pp. 167-179.

Barannikov, I. A. 1975. Funktsional'nye osnovy migratsii ryb. Izd. Nauka, Leningrad "cited in" *Freshwater Fishes of Europe*, vol. 1. ed. J. Holcik, 1989. AULA Verlag. Wiesbaden, Germany.

Barannikov, I. A. 1987. Review of sturgeon farming in the Soviet Union.*Vopr Ichthyol*, No. 5, pp. 735-746.

Batychkov, G. A. 1963. Pervye rezul'taty massovogo mecheniya osetra v Volge vyshei nizhe Volgogradskoi plotiny. In: *Tezisy dokladov soveshchaniya molo dykh uchenykh VNIRO*, Izd. Rybnoe khozyaistvo, Moskva. pp. 86-87.

Belyaev, V. N. 1932. Osetr (*Acipenser guldenstadti* Br.) Byulleten, Vsekaspiikoi nauchnoi rybokhozyaistvennoi ekspeditsii 5 - 6 : 66 - 77. "cited in" *Freshwater Fishes of Europe*, vol. 1. ed. J. Holcik, 1989. AULA Verlag. Wiesbaden, Germany.

Belyaeva, V. N. and Kazanchov, E. N. 1989. *Caspian Sea, Ichthyofauna and fishery resources*. Moscow, 216 p.

Bemis, W. E. and Findeis, E. K. 1994. The sturgeons' plight. *Nature* 370, 602.

Berdichevskii , L. S., T. F. Dementena, A. A. Popova, and T. N. Shubina, 1982. Razvitie ikhtiologicheskikh issledovanil na Kaspiiskom more. In: *Istoriya regio nal'nykh issledovani biologicheskikh resursov gidrosfery i ikh ispol'zovaniya. Izd. Nauka*, Moskva. pp. 33-66.

Berdichevskii, L. S., and I. N. Petrenko, 1979. Biologicheskie osnovy regulirovaniya vidovogo sostava osetrovykh ryb Kaspiya. In: *Biologicheskie osnovy razvitiya osetrovogo khozyaistva v vodoemakh SSSR. Izd.* Nauka, Moskova. pp. 34-38.

Berg, L S., 1933. *Freshwater Fshes of the U.S.S.R. and adjacent counteries.* Part 2., (in Russian) . All-Union Lake and River Fisheries Research Institute, Leningrad, pp. 545-903.

Berg, L. S. 1940. *Classification of Fishes. zool. Inst. Trudy,* 5: 85-517.

Berg, L.S., 1948. On the position of the Acipenseriformes in the system of fishes. *zool. Inst. Trudy.* 7: 7-57 (In Russian).

Bertalanffy. L. Von. 1934. Untersuchungen uber die Gesetzlichkeiten des Wachstums. 1. Allgemeine Grundlagen der Theorie. *Roux'Arch. Entwicklungsmech. Org.,* 131: 613-53.

Bertalanffy. L. Von. 1938. A quantitative theory of organic growth (Inquiries on Growth Laws. 11). *Human Biology,* 10, (2), 181-213. pp. 23, 32.

Bertalanffy. L. Von. 1951. General System Theory: A new approach to unity of science. Contributions I, V and VI. *Human Biology,* 23, (4), 302-61.

Ber, K. M. 1860. Issledovaniya o sostoyanii rybolovstva v Rossii. 2. Sankt-peterburg. "cited in" *Freshwater Fishes of Europe,* vol. 1. ed. J. Holcik, 1989. AULA Verlag. Wiesbaden, Germany.

Beverton R. J. H. and Holt. S. J. 1956. A review of methods for estimating mortality rates in exploited fish populations, with special references to sources of bias in catch sampling. *Rapp. P.-V. Reun. CIEM.* 140: 67-83.

Beverton R. J. H. and Holt. S. J. 1957. On the dynamics of exploited fish populations. *Fish. Invest.,* Ser. 2, 19: 533p.

Beverton R. J. H. and Holt. S. J. 1959. A review of the life spans and mortality rates of fish in nature, and their relationship to growth and other physiological characteristic. In *Ciba Foundation Colloquium on Ageing. 5. The life span of animals.* Edited by G. E. W. Wolstenholme and M. J. O' Connor. Churchill, London. pp. 142-180.

Beverton, R. J. H. 1963. Maturation, growth and mortality of clupeid and engraulid stocks in relation to fishing . *Rapp. PV.-Reun. CIEM,* 154: 44-67.

Biliy, M. D. 1950. Growth patterns of fishes. Kiev, AN USSR. Cited in Growth rate of Caspian Sea Beluga. *Vopr Ichthyol*, 33 (3), 417-426) ed. Raspopov. V. M. 1993.

Binkowski, P. F. and Doroshov, S. I. 1985. North American Sturgeon: biology and aquaculture potential. *Environmental Biology of Fishes*. 14: 7-8.

Birstein, V. J. 1993. Sturgeons and paddlefishies: threatened fishes in need of conservation. *Cone, Biol.* 7: 773-787.

Borodin, N. A. 1897. Report of excursion for zoological purpose during summer 1895 of cruiser "Uralets" in the northern part of the Caspian Sea. *Vest. rhybopromsti*, 12, No. 1, pp. 1 - 31.

Borzenko, M. P., 1932. Sevryuga (*Acipenser stellatus* Pall.) Byull. *Vsekaspilsko nauchno-rbokhozyalstvennol ekspeditsii* 5-6: 77-84.

Borzenko, M. P. 1942. The Caspian Sea sevryuga (systematics, biology and fishery). *Izvestiya Azerbaidzhansko, n-i. rybokhoz st.*, 7: 3-114..

Borzenko, M. P.,1954. Condition of the reserves and reproduction of sturgeons in the Kura River after the construction of the Mingechaur hydrocomplex. Proceedings of conference on the problems of regeneration of the Fish Reserves of the Kura River in relation to the structure of the Mingechaur Hydrocomplex (in Russian). Izd-vo AN AzSSR, Baku, pp. 57 - 66.

Borzenko, M. P. 1964. The present state of Sevryuga stocks in the Caspian following regulation of discharge and a forecast of future changes. *Trudy VNIRO* 52:259-286.

Brennan. J. S. 1988. Age determination and verification of California White Sturgeon (*Acipenser transmontanus*): A comparative analysis. Master's thesis. San Jose State University, San Jose, California.

Brennan. J. S. and Cailliet, G. M. 1989. Comparative age-determination techniques for White Sturgeon in California. *Trans. Amer. Fish. Soc.* 118: 296-310.

Carlson, D. M., Plieger. W. L., Trial. L. And Haverland. P. S. 1985. Distribution, biology and hybridization of *Scaphirhynchus albus* and *S. platorhynchcus* in the Missouri and Mississippi Rivers. pp 51-59. In: F.P. Binkowski and S.I. Dorosov (eds) *North American sturgeons: biology and aquaculture potential*, Dr. W. Junk publishers, Dordrecht.

Caspian Sea, 1986. Hydrology and hydrochemistry. Moscow, 260 p. In: Kosarev, A. N. And Yablonskaya, E. A. 1994(eds) *The Caspian Sea*. SPB Academic, The Netherlands, 259 p.

Chapman. D. G. and Robson. D. S. 1960. The analysis of a catch curve. *Biometrics*. 16(3): 354-68.

Chilton, D. E. and Beamish, R. J. 1982. Age determination methods for fishes studied by the ground-fish program at the Pacific Biological Station.*Can. J. Fish. Aquat. Sci.* 39: 277-287.

Chugunov, N. L. 1926. Determination of the age and growth rate of fish by bones. *Siberian Ichthyol. Lab.* Rept., Krasonyarsk.

Chugunov, N. L. 1928. Biologiya molodi promyslovykh ryb Volgo-Kaspiiskogo ralona. *Trudy Astrakhanskoi nauchnoi rybokhozyalstvennoi stantsii* 6: 282-294.

Chugunov, N. L. and N. 1. Chugunova, 1964. Comparative commercial-biological characteristics of the Azov Sea Sturgeons. *Tr. VNII morsk. ryb. khoz-va I okeanogr.*, 52, pp. 87-182.

Chugunova, N. I. 1952. *Methods for studying the age and growth of fish.* Sov. Nauka, Moskow.

Chugunova, N. I. 1963. *Age and growth sudies in fish.* Published for the National Science Foundation, Washington, D.C. by the Israel Program for Scientific Translations, Jerusalem. pp.120.

Conte. F. S, Doroshov, S. I. and Lutes. P. B. 1988. Hatchery manual for White Sturgeon (*Acipenser transmontanus* Richardson) with application to other North American Acipenseridae. University of California Cooperative Extension Publication 3322. 104 pp.

Cuerrier, J. P. 1951. The use of pectoral fin rays for determining age of sturgeon and other species of fish. *Canadian Fish Culturist* 11: 10-18.

Cushing, D. H. 1981. *Fishery Biology. A study in population dynamics*. Madison, University of Wisconsin press, 200p.

Dadswell, M. J. 1979. Biology and population characteristics of the shortnose sturgeon, *Acipenser brevirostrum* LeSueur 1818 (Osteichthyes:Acipenseridae) in the Saint John River Estuary, New Brunswick, Canada. *Can. J. Zool.* 57: 2186-2210.

Dementyeva, T. F and Prikhodko, B. I. 1975. Reason for Anchovy kilka stock fluctuation. *Trudy VNIRO*, Vol. 108, pp. 154-8.

Derzhavin, A. N. 1922. The Sevryuga, a biological study (In Russian). *Iza. Bakin. ikht. laboratorii*, 1: 1-383.

Derzahvin, A. N. 1947. Regeneration of the sturgeon reserves (in Russian). *Iza-vo AN Azerb SSR, Baku*, p. 248.

Desalle, R. And Birstien, V. J. 1996. PCR indentification of black caviar. *Nature* 381, 197-198.

Djisalov, N. 1983. Analiz promysla prokhodnykh osetrovykh v yugoslavskoi chasti Dunaya v 1981 godu. Materialy 24. sessii Smeshannoi komissii po primeneniyu Soglasheniya o rybolovstve v vodakh Dunaya, zaklyuchennogo mezhdu pravitel'stvami SSSR, NRB, VNR, SRR, CHSSR I SFRYU. Moskva: 150-157. "cited in" *Freshwater Fishes of Europe*, vol. 1. ed. J. Holcik, 1989. AULA Verlag. Wiesbaden, Germany.

Doroshov, S. I. 1985. Biology and culture of sturgeon, Acipenseriformes. J. F. Muir and R. J. Robert, editors. *Recent advances in aquaculture* Vol 2, p. 251-273.

Dumont, H. 1995. Ecocide in the Caspian Sea. *Nature*. 377, 673-674.

Edser, T. 1908. Note on the number of plaice at each length in certain samples from the southern part of the North Sea, 1906. *J. R. Stat. Soc.*, 71:686-90.

Elanidze, R. F. 1983. Ikhtiofauna rek I ozer Gruzii.Metsniereba, Tbilisi. "cited in" *Freshwater Fishes of Europe*, vol. 1. ed. J. Holcik, 1989. AULA Verlag. Wiesbaden, Germany.

Emadi, H. 1989. Evaluation of sturgeon catches in the Iranian part of the Caspian Sea with particular emphasis on *Huso huso*. *Iranian fisheries*. P. O. Box 14155-3789 Tehran Iran.

Fadeeva, T. A. 1980. Sostoyanie polovykh zhelez i razmerno-vozrastnoi sostav sevryugi *Acipenser stellatus* Pallas Kaspiiskogo morya v morskoi period zhizni. *Vopr Ichthyol.* 20: 833-843..

Fadeyeva. T. A. 1981. Male gonad development and the size-age composition of the Caspian Sevryuga, *Acipenser stellatus*, during the marine period of life. All - Union Research Institute for Sea Fisheries and Oceanography (*VNIRO*), Moscow. p. 54-64.

FAO (Food and Agricultural Oganization), 1992. Yb. Fish Stat, Catches and Landings. Vol 74. pp-155.

FAO (Food and Agricultural Oganization), 1993. Yb. Fish Stat, Catches and Landings. Vol 76. pp-156.

Gaschutz. G., Pauly, D. And David, N. 1980. A verstaile BASIC Program for fitting weight and seasonally oscillating growth data. ICES, Stat. Comm., C. M. 180/D: 6, 23pp.

Ghazel. A. 1987. Artificial reproduction of the Beluga (*Huso huso*). Published in International Conference, *The rational utilisation of Caspian Sea resource*, Iranian fisheries. P. O. Box 14155-3789 Tehran Iran. (In Persian).

Graham. M. 1935. Modern theory of exploiting a fishery, and application to North Sea trawling. *J. Cons. Int. Explor. Mer*, 10, 264-274.

Gorbachev, N. N., Dubinin, V. I. and Pashkin, L. M. 1984. Chislennost, vnutripopulyatsionnyi sostav i kachestvennaya struktura prokhodnykh osetroykh v skopleniyakh u plotiny Volgogradskogo gidrouzla v 1983g. In *Osetrovoe khozyaistvo vodoemov SSSR. Izd. Volgogradskaya pravda, Volgograd* pp. 96- 98. (In Russian).

Grimm, O.A. 1893. Vzglyad na godovye i mesyachnye ulovy krasnoi ryby. Vestnik rybopromyshlennosti 11-12: 377-394. "cited in" *Freshwater Fishes of Europe*, vol. 1. ed. J. Holcik, 1989. AULA Verlag. Wiesbaden, Germany.

Guenette, S. D., Fortin, R., Leclerc, J., Fournier, G. and Dumont, P. 1992. La periodicite de la croissance chez la femell de i'esturgeon jaune (*Acipenser fulvecens*) du fleuve Saint-Laurent est-elle reliee a la periodicite de la reproduction. *Can. J. Fish. Sci.* 49: 1336-1342.

Gulland, J. A. 1969. Manual of methods for fish stock assessment. Part 1. Fish population analyses. F. A. O. Manuals in fisheries Scince, No. 4. 154 p.

Gulland, J. A. 1983. *Fish stock assessment (A manual of basic methods).* Marine Resources Service, Fishery Resources and Enviroment Division, Food and Agriculture Organization of the United Nations, Rome, Italy. 220 pp.

Gulland, J. A. 1988. *Fish population dynamics*: the implication for management. Chichester, John Wiley and Sons Ltd., 422p. 2nd ed.

Gunrderson, D. R. And Dygert. P. H. 1988. Reproduction effort as a predictor of natural mortality rate. *J. Cons.Int. Explor. Mer*, 44:200-9.

Hall, J. W., Smith, T.I.J., and Lamprecht, S. D. 1991. Movements and habitates of Shortnose Sturgeon (*Acipenser brevirostrum*) in the Savana River. *Copiea* 1991: 695-702.

Harkness, W. J. K. 1923. The rate of growth and the food of the Lake Sturgeon (*Acipenser rubiscundus*). Pages 15-42 *in* Publications of the Ontario Fisheries Research Laboratory, 18, University of Toronto, Toronto.

Heincke, F. 1913. Investigations on the plaice. General report. 1. The plaice fishery and protective regulations. Part. 1. *Rapp. P.-V. Reun. CIEM.* 17A: 1-153.

Held, J. W. 1969. Some early summer foods of the shovelnose sturgeon in the Missouri River. *Trans. Amer. Fish. Soc.* 98: 514-517.

Holci'k, J. 1959. Nalez jesetra hviezdnateho (*Acipenser stellatus* Pallas, 1771) v Dunaji pri Komarne. *Acta Rer. Nature. Mus.* Slov. 5:39-43.

Holci'k, J. 1989. *The freshwater fishes of Europe*, Vol I, part 2, General introduction to fishes, Acipenseriformes. AULA Verlag. Wiesbaden, Germany.

Holt. S. J. 1965. A note on the relationship between mortality rate and the duration of life in an exploited fish population. *ICNAF Res.-Bull.*, (2): 73-5.

Jearald, A. Jr. 1983. Age determination. Pages 301-324. In: L. A. Nielsen and D. L. Johnson, eds. *Fisheries techniques.* American Society, Bethesda, Maryland.

Jones, R. 1976. Growth of fishes, p. 251-279. *In* D. H. Cushing and J. J. Walsh (eds), *The ecology of the seas.* Blackwell, London. 467p.

Jones, R. 1981. The use of length composition data in fish stock assessments (with notes on VPA and cohort analysis), *FAO Fisheries Circular.* No. 733. 60p.

Jones, R. 1984. Assessing the effects of changes in exploitation pattern using length composition data (with notes on VPA and cohort analysis). *FAO Fish. Tech.* Pap., (256): 118 p.

Kazanskii. B. N. 1962. Eksperimental'nyi analiz sezonnosti razmnozheniyaosetrovykh Volgi v svyazi s yavleniem vnutrividovoi biologicheskoi differentsiatsii. Uchen. zapiski Leningradskogo gos. univ., seriya biol. 48: 19-45. "cited in" *Freshwater Fishes of Europe*, vol. 1. ed. J. Holcik, 1989. AULA Verlag. Wiesbaden, Germany.

Kazanskii, B. N. 1979. Ekologo-evolyutsionnye printsipy organizatsii osetrovogo khozyaistva v basseine yuzhnykh morei SSSR. In: *Biologicheskie osnovy razvitiya osetrovogo khozyalstva v vodoemakh SSSR*. Izd. Nauka, Moskva. pp. 22-33 (In Russian).

Kazancheev, E. N. 1981. *Fishes of the Caspian Sea*. Moscow. 166p.

Keenlyne, K. D., and Jenkins, L. G. 1993. Age at sexual maturity of the pallid sturgeon. *Trans. Amer. Fish. Soc.* 122: 393-396.

Kessler, K. F. 1877. Ryby, vodyashchiesya i vstrechayushchiesya v Aralokas piisko-pontiiskoi ikhtiologicheskoi oblasti. *Trud-y Aralo-kaspiiskoi kompleksnoT ekspeditsii* 4. Sankt-Petersburg (In Russian).

Khodorevskaya, R. P. 1984. Sostoyanie zapasov osetrovykh v Kaspiiskom basseine. In: *Osetrovoe khozyaistvo vodoemov SSSR. Izd. Volgogradskaya pravda*, Volgograd. pp. 373--376 (In Russian).

Khodorevskaya, R. P. 1986b. Sostoyanie zapasov osetrovykh Volgo-Kaspilskogo raiona. In: *Formirovanie zapasov osetrovykh v usloviyakh kompleksnogo ispol'zovaniya vodnykh resursov. Izd. Volgogradskaya pravda*, Volgograd. pp. 355--356 (In Russian).

Kirikov, S. V. 1966. Promyslovye zhivotnye, prirodnaya sreda i chelovek. *Izd. Nauka*, Moskva (In Russian).

Kirilyuk, M. M. and A. A. Rovnin, 1983. Sostoyanie nerestovogo stada, vozrastnoi sostav i usloviya razmnozheniya osetrovykh v 1981. Materialy 24. sessii Smeshannoi komissii po primeneniyu Soglasheniya o rybolovstve v vodakh Dunaya, zaklyuchennogo mezhdu pravitel'stvami SSSR, NRB, VNR, SRR, CHSSR I SFRYU. Moskva: 28 -36. "cited in" *Freshwater Fishes of Europe*, vol. 1. ed. J. Holcik, 1989. AULA Verlag. Wiesbaden, Germany.

Kohlhorst , D. W., Miller. L. W., and Orsi. J. J. 1980. Age and growth of White Sturgeon collected in the Sacramento-San Joaquin estuary, California: 1965-1970 and 1973-1976. *Calif. Fish and Game* 66: 83-95.

Kohlhorst, D. W., Botsford, L. S., Bernnan, L. S., and Cailliet, G. M. 1991. Aspects of the structure and dynamics of exploited central California population of White Sturgeon (*Acipenser transmontanus*). pp. 277-293. In: P. Williot (ed) *Actes du premier colloque internatinal sur i,sturgeon, Centre National du Machinisme Agricole du Genie Rural des Eaux et Fes forets*, Bordeaux.

Korobochkina, Z. S. 1951. Skat i pitanie molodi osetrovykh na Danu. Rybnoe khozyaistvo 8: 49-52. "cited in" *Freshwater Fishes of Europe*, vol. 1. ed. J. Holcik, 1989. AULA Verlag. Wiesbaden, Germany.

Korobochkina, Z. S.1964. Principal stages in development of sturgeon fishery in the Caspian basin. *Trudy. VNIRO*, 52 (1), 59-86 (In Russian).

Khoroshko, P. N. 1970. K ekologii neresta ostra izmenennnoi Volgi. *Trudy TSNIORKH* 2: 105-111(In Russian).

Kosarev, A. N. And Yablonskaya, E. A. 1994. *The Caspian Sea*. SPB Academic, The Netherlands, 259 p.

Kozhin, N. 1. 1964. Sturgeons of the USSR and their reproduction. *Trudy VNIRO* 52: 21-58. (In Russian).

Krasikov, E. V. 1981. Nekotorye dannye o skorosti dvizheniya osetra i sevryugi vo vremya nerestovoi i pokatnol migratsii. In: *Ratsional'nye osnovy vedeniya osetrovogo khozyaistva. Izd. Volgogradskaya pravda*,Volgograd, pp. 126-127 (In Russian).

Krasikov, E. V. and 1. V. Krasavtsev. 1986. Kachestvennaya kharakteristika kaspi Tskogo osetra po materialam tralovykh s"emok 1981-1985 gg. In: *Formi rovanie zapasov osetrovykh v usloviyakh kompleksnogo ispol'zovaniya vodnykh resursov. Izd. Volgogradskaya pravda*, Volgograd. pp. 156-158 (In Russian).

Legeza, M. I.and I. A. Voinova, 1966. Vozrastnaya struktura nersetovykh populyatsii osetrovykh r. Kury. *Trudy Azerb. otdeleniya TSNIORKH* 4: 126-34 (In Russian).

Legeza, M. I. 1967. Sostav i struktura osetrovykh ryb r. Kury na fone sokrashcheniya zapasov. izmeneniya rezhima reki. In: *Tezisy dokadov TSNIORKH, posvyashchennykh 50 - letiyu Velikoi Oktyabar' skoi sotsialisticheskoi revolyutsii Baku*, pp. 47-48 (In Russian).

Legeza, M. 1. 1973. Sovremennoe raspredelenie osetrovykh ryb (sem.Acipenseridae) v Kaspiiskom more. *Vopr Ichthyol.* 13: 1008-1017.

Levin, A. V. A. P. Bezrukavnikov, and M. I. Pirogovski. 1981. Osobennosti vertikal'nogo raspredeleniya osetrovykh v Severnom Kaspii. In: *Ratsional'nye osnovy vedeniya osetrovogo khozyaistva. Tezisy dokladov nanchno-prak-ticheskoi konferentsii.* Volgograd. pp. 143-144 (In Russian).

Lukin, A. V. 1937. Biologicheskii analiz ulovov osetra v srednem techenii r. Volgi (Tatarskaya respublikam *Akad. Nauka, SSSR seriya biologicheskaya* 1: 211-220 (In Russian).

Lukin, A. V. 1949. Russkii osetr-*Acipenser guldenstadti* Brandt. In: L. S. Berg, A. S. Bogdanov, N. I. Kozhin, and T. S. Rass (eds) *Promyslovye ryby SSSR. Opisaniya ryb. Pishchepromizdat*, Moskva. pp. 57-61 (In Russian).

Luk'yanenko, V. I., Karataeva, B. B., Altuf'ev, Yu. V. and Umerov, Zh. B.,1972. Populyatsionnaya struktura kaspiiskikh osetrovykh v svyazi a problemoi ikh zavodskogo vosproizvodstva. In: *Biologicheskie resursy Kaspiiskogo morya. Izd. Volga*, Astrakhan'. pp. 105-106.

Luk' yanenko, V. I. Zh. G. Umerov and B.B. Karataeva. 1974. The south Caspian sturgeon - an independent species of *Acipenser. Isv. AN SSSR*, No. 5. pp. 736-739.

Mageramov, Ch. M. 1968. Poyavlenie volzhskogo osetra v r. Kure. In: Osetrovye i problemy osetrovogo khozyaistva. Izd. Leningeradskogo univ., Leningrad. pp. 289-293. "cited in" *Freshwater Fishes of Europe*, vol. 1. ed. J. Holcik, 1989. AULA Verlag. Wiesbaden, Germany.

Mageramov, Ch. M. 1972. Poyavlenie volzhskogo osetra v r. Kura. In: *Osetrovye iproblemy osetrovogo khozyaistva. Izd. Pishchevaya promyshlennost*, Moskva. PP. 289-293 (In Russian).

Markarova, I. A and Alekperov, A. P. 1988. Age composition of sturgeons (Acipenseridae) occuring along the western shores of the south Caspian. *Vopr Ichthyol.* No. 6, pp. 993-997.

Mailyan, R. A. and Makhmudbekov, A. A. 1970. Estestvennye nerestilishchai skat kurinskikh osetrovykh (In Russian). *Trudy TSNIORKH* 2. 95-104.

Manea, Gh. 1966. Contribuilt la studiul sturionilur din apele Romaniei si al reproducerii ler in legatura cu constructiile hidroenergetic pe Dunarea inferioara. 1. Une aspecte ale biologici sturtionilor. *Bul. Inst. Cerc. Piscicole* 25 (4): 62 - 86. "cited in" *Freshwater Fishes of Europe*, vol. 1. ed. J. Holcik, 1989. AULA Verlag. Wiesbaden, Germany.

Markov, G. S.,Trusov, V. Z and Reshetnikova, A. V. 1964. Vliyanie nerestovykh migratsil russkogo osetra na ego parazitofaunu. *Uchenye zapiski Volgograd skogo pedagogicheskogo inst.* 16: 111-124.

Marti, V. Yu. 1940. Classification and biology of Russian sturgeon of the Caucasian coast of Black Sea. *Zool. Zhurn.*, 19, No. 6, pp. 865-872 .

Mason, W. T., Jr, and Clugston. J. P. 1993. Foods of the Gulf sturgeon in the Suwannee River. *Trans. Amer. Fish. Soc.* 122: 378-385.

McCabe, G.T., Jr., Emmett, R.L. and Hinton. S.A. 1993. Feeding ecology of juvenile White Sturgeon (*Acipenser transmontanus*) in the lower Columbia River. *Northwest Sci.* 67(3): 170-180.

McEnroe, M., and Cech, J.J, 1987. Osmoregulation in White Sturgeon: Life History Aspects. Department of Wildlife and Fisheries Biology, University of California, Davis, California 95616, USA.

Mil'shtein, V. V. 1964. Ecology of young sturgeon in ponds. (In Russian). *Trudy VNIRO*, 56: 9-23.

Mina, M. V. and G. A. Klevezal. 1976. Growth of animals (Analysis at the individual level of the organism). Nauka Press, Moscow. "cited in" Raspopov. V. M. 1993. Growth rate of Caspian Sea Beluga.*Vopr Ichthyol.* 33 (3), 417-426.

Mordukhai-Boltovskoi, F. D. 1978. Composition and distribution of the Caspian fauna according to contemporary data. Elements of the water ecosystem. Moscow. pp. 100-139.

Musaev, P. G. 1972. Sostoyanie nerestovol populyatsii osetra r. Terek v 1971 godu. In: *Tezisy Otchetnoi sessii TSNIORKH. Izd.* Volga, Astrakhan'. pp. 104-105.

Nikol'skii. G. V. 1957. *Spezielle Fischkunde*. VEB Deutscher Verlag der Wissenschaften: Berlin, 632 pp.

Nikol'skii. G. V. 1961. *Special ichthyology*. Published for the National Science Fundation, Washington, D. C. 538 pp.

Nikol'skii. G. V. 1969. *Theory of fish population dynamics*. Oliver and Boyd, Edinburgh. 323. p.

Obruchev, D. V. (ed), 1964. Osnovy paleontologii. Izd. Nauka, Moskova. In *freshwater Fishes of Europe*, vol. 1. edt. J. Holcik, 1989. AULA. Verlag. Wiesbaden, Germany.

Parker, R. R. and Larkin, P. A. 1959. A concept of growth in fishes. *J. Fish. Res. Board Can.*, 16 (5): 721-45.

Pashkin, L. M. 1972a. Biological characteristics of the Volga population of Beluga (giant sturgeon) and Stellate Sturgeon. *Tr. Volgograd. otd. Gos. NIORKH*, 6: 28-47.

Pauly, D. 1978. A preliminary compilation of fish length growth parameters. *Ber. Inst. Meereskd. Christian-Albrechts-Univ.Kiel*, (55): 200p.

Pauly, D. 1978a. A discussion of the potential use in population dynamics of the interrelationships between natural mortality, growth parameters and mean environmental temperature in 122 fish stock. *ICES CM.* 1978 / G: 28 Demersal Fish committee: 36 p.

Pauly, D. 1980a. A selection of simple methods for the assessment of tropical fish stocks. *FAO Fisheries Circular*, No. 729: 54pp.

Pauly, D. 1980b. On the interrelationship between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. *J. Cons. int. Explor. Mer*, 39 (2): 175-192.

Pauly, D. 1981. The relationships between gill surface area and growth performance in fish: a generalization of von Bertalanffy's theory of growth. *Meeres-forsch./Rep. Mar. Res.*, 28 (4): 251-82.

Pauly, D. 1983a. Some simple methods for the assessment of tropical fish stocks. *FAO Fish. Tech. Pap.* (234): 52pp.

Pauly, D. 1983b. Length-converted catch curvees. A powerful tool for fisheries research in the tropics. (Part 1). *ICLARM Fishbyte.* 1 (2): 9-13.

Pauly, D. 1984a. Fish population dynamics in tropical waters: a manual for use with programmable calculators. *ICLARM Stud. Rev.* 8: 325 p.

Pauly, D. 1984b. Length-converted catch curvees. A powerful tool for fisheries research in the tropics. (Part 2). *ICLARM Fishbyte.* 2 (1): 17-19.

Pauly, D and Morgan G. R. (eds). 1987. Length-based methods in fisheries research. *ICLARM Fishbyte*, 2(1): 21.

Pavlov, A. V. 1964. Materials on migration of the sturgeon and composition of the population of sturgeons in the Volga River in 1958-1962. *Tr. Vses. n-i. in-ta morsk. rybn. kh-va i okeanogr.*, 45, No. 2, pp. 137-159.

Pavlov, P. I. 1967. Morfologicheskie osobennosti dunaiskoi belugi *Huso huso* poticus Sal'nikov et Maltiatskii. Gidrobiologicheskii zhurnal 3: 39-42. "cited in" *Freshwater fishes of Europe*, vol. 1. ed. J. Holcik, 1989. AULA Verlag. Wiesbaden, Germany.

Pavlov, A. V. and Elizarov, G. A. 1969. Izuchenie biologii volzhskogo osetra putem massovogo mecheniya. *Vopr Ichthyol.* 9: 461-473.

Pavlov, A. V. and G. A. Elizarov, 1970. O povtronom sozrevanii volzhskogo osetra (In Russian). *Trudy TSNIO* 2: 52-56.

Pavlov, A. V. 1971. Biological characteristics of the spawning population of the Volga sturgeon and the pattern of ascent and descent of its breeders in different branches of the Volga River in 1963-1968. In *Aktual'nye voprosy osetrovogo khozyaistva* (Current issues in sturgeon fishery). Astrahkan. 168-176.

Pavlov, A . V. and Zakharov, S. S. 1971. The distribution, qualitative composition and abundance of sturgeon in the Northern Caspian in 1967. *Trudy TSNIORKH* 3: pp. 235-268.

Pavlov, A. V. and Slivka. A. P. 1971. The migration of sturgeons (Acipenseridae) in the Volga during the winter. Central Sturgeon Fisheries Reseach Institute (TSNIORKH), Astrakhan. pp. 541-545.

Pavlov, A. V. 1972. Analiz nerestovoi populyatsii volzhskogo osetra v 1968 g. *Trudy TSNIO* 4: 14-25.

Pavlov, A. V. and Slivka. A. P. 1972. The migration of sturgeon (Acipenseridae) in the Volga during the Winter. *Vopr Ichthyol.* No. 3, pp. 584 - 588.

Pavlov, A. V., and Zhuravleva. O. L. 1984. Kharakteristika kachestvennogo sostava nerestovoi populyatsii russkogo osetra v r. Volge v 1981-1983 gg. In: *Osetrovoe khozyaistvo vodoemov SSSR. Izd. Volgogradskaya pravda*, Volgograd. pp. 241-243.

Pavlov, A. V. and Zhuravleva. O. L. 1986a. Kharakteristika kachestvennol struk tury nerestovogo stada russkogo osetravr. Volge za posledniepyat'let (1981-1985gg.). "cited in" *Freshwater Fishes of Europe*, vol. 1. ed. J. Holcik, 1989. AULA Verlag. Wiesbaden, Germany.

Peseride, N. E. 1961. Zadachi po razvedeniyu ostrovykh ryb v del'te r. Ural. In: Marterialy k konferentsii rabotnikov rybnoi promyshlennosti

Kazakhskoi SSR. *Alma-Ata. pp*. 56-60.

Peseridi, N. E. 1966. Sostoyanie gonad proivoditelei osetra v r. Ural v period nerestovoi migratisii. *Rybnye resursy vodoemov Kazzkhstana i ikh ispol' zovanie* 5: 10-30.

Peseridi, N. E. 1986. *Acipenser guldenstadti* Brandt - russki osetr. In: E. V. and V. P. Mitrofanov (EDS), Ryby Kazakhstana. 1. Mionogovye, osetrovye, seldeevye, lososevye, shchukovye. *Izd. Nauka, Kazakhskoi SSR, Alma - Ata*. pp. 71-99.

Peseridi, N. E., 1971. Seasonal dynamics of the sturgeon run in the lower reaches of the Ural River. *Trudy TSNIORKH* 3: 355-358.

Peterson, I. and Wroblewski. 1984. Mortality rate of fishes in the pelagic ecosystem. *Can. J. Fish. Aquat. Sci*. 41: 1117-20.

Petrov, V. V. 1927: Materialy po izucheniyu rosta I vozrasta kaspiTskikh osetrovykh. *Izvestiya Otdela prikladnol ikhtiologii* 6 (2): 156-215.

Pirogovskiy, M. I. and Fadeyeva, T.A. 1982. The size- age composition of the Stellate Sturgeon, *Acipenser stellatus*, during the marine period of life. Central Sturgeon fisheries Research Institute (TSNIORKH), Astrakhan; All union Researh Institute for Sea Fisheries and Oceanography (VNIRO), Moscow.

Pirogovskii, M. I. 1983. K voprosu ob effektivnosti osetrovodstva v Volga-kas piiskom raione. In: biologicheskie osnovy osetrovodstva. *Izd. Nauka,Moskva*. pp. 191- 200.

Piskunov, 1. A., 1965. Raspredelenie osetrovykh v Kaspiiskom more. In: Izmenenie biologicheskikh kompleksov Kaspilskogo morya za poslednie desyatiletiya. *Izd. Nauka, Moskva*. pp. 213-233.

Piskunov, I. A., 1970. Materialy po biologii osetra i sevryugi Kaspiya v morskoi per iod zhizni. *Trudy TSNIORKH* 2: 74-85.

Probst, R.T. and E. L. Cooper, 1955. Age, growth, and production of the Lake sturgeon *(Acipenser fluvescens)* in the lake Winnebago region, Wisconsin. *Trans. Amer. Fish. Soc*. 84: 207-227.

Putilina, L. A., 1981. Qualitative structure of the spawning part of the Persian Sturgeon population of the Volga. Rational principles of Sturgeon Farming (in Russian). Volgograd. pp. 209-210.

Putilina, L. A., 1983a. Kolichestvennaya i kachestvennaya otsenka nerestovol pop ulyatsii persidskogo osetra v r. Volge. In: Kompleksnoe ispol'zovanie biolo gicheskikh resursov Kaspilskogo I Azovskogo morei. *Izd. VNIRO*, Moskva. pp. 71-72.

Pycha, R. L. 1956: Progress report on White Sturgeon studies. *Calif. Fish Game,* 42 (1): 23-49.

Randal, K. Buddington' & Jay, P. Christofferson , 1985. Digestive and feeding characteristics of chondrosteans. *Env. Biol. Fish.* 14: 31-41.

Raspopov, V. M. 1987. Fecundity of Beluga Sturgeon, *Huso huso*, of the Caspian Sea. *Vopr Ichthyol.* 2: 254-263.

Raspopov, V. M. and Putilina. L. A. 1989. The winter spawning migration of Beluga, *Huso huso,* and Russian Sturgeon, *Acipenser guldenstadti,* in the Volga River. *Vopr Ichthyol.* 4: 596-600.

Raspopov , V. M. 1992. Age structure and population dynamics of the Beluga, migrating into the Volga. *Vopr Ichthyol.* 32 (6), 74-80.

Raspopov. V. M. 1993. Growth rate of Caspian Sea Beluga. *Vopr Ichthyol.* 33 (3), 417-426.

Rezvani. S. 1989. Sex proportion of sturgeons in the Caspian Sea and the effect of monosexuality on the sturgeon population of the Caspian Sea (Published in International Conference, *The Rational utilisation of Caspian Sea resource, Iranian fisheries*. P. O. Box 14155-3789 Tehran Iran. (In Persian).

Rien, T. A., Beamesderfer. R. C., 1994. Accuracy and precision in age estimates of White Sturgeon using pectoral fin rays. *Trans. Amer. Fish. Soc.* 123: 255-265.

Ricker. W. E. 1973. Linear regressions in fishery research. *J. Fish. Res.Board. Can.*, 30: 409-34.

Rikhter. V. A. And Efanov. 1976. On one of the approaches to estimation of natural mortality of fish populations. ICNAF Res. Doc., 76/VI/8: 12 p.

Romanov, A. A. and Altuf 'ev. YU. V. 1985. Ecological characteristics of the reproduction of sturgeons under hatchery conditions in the Volga. *Vopr Ichthyol.* 25, 5: 783-793.

Rochard, E. Castelnaud, G, and Lepage. M. 1990. Sturgeons (Pisces: Acipenseridae); threats and prospects. *J. Fish Biol.* 37 (Supplement A), 123-132.

Romanycheva, O. D. 1976. *The modern condition of the development of the marine sturgeon for commercial purposes and its perspectives* (All-Union Reseach Institute of Marine Fisheries and Oceanography (VNIRO), 17 Krasnoselskaya, Moscow B-140, USSR.

Rostami, I. 1961. Biologie et exploitation des Esturgeons (*Acipenseridae*) Caspiens. Paris Narle-Duc (Meuse).

Roussow, G. 1959. Some considerations concerning sturgeon spawning periodicity. *J. Fish. Res. Board Can.* 14:553-572.

Royce, W. F. 1984. Biology of aquatic resource organisms. In: *Introduction to the practice of Fishery Science* pp. 132-179. Academic Press, Inc., Chichester.

Rudin, Z. N., 1966. K voprosu o sovremennom razvitii rybnogo khozyaistva iran skogo Kaspiya. In: *Problemy ekonomiki i istorii stran Blizhnego Vostoka. Izd. Nauka, Moskva.* pp. 139-149 (In Russian).

Russell, E. S. 1931. Some theoretical considerations on the 'overfishing' problem. *J. Cons. Int. Explor. Mer*, 6: 3-20.

Saheli. H. M. 1989: Fishing of the Persian, Russian and Cheap Stureons in the southern Caspian. (Published in: International Conference, *The rational utilisation of Caspian Sea resource, Iranian fisheries.* P. O. Box 14155-3789 Tehran Iran. (In Persian).

Sal'nikov, N. I., and Malyatskii. S. M., 1934. K sistematika belugi Azovsko-Chernomorskogo basseina. Trudy nauchnol rybokhozyaistvennoi i biologocheskoi stantsii Gruzii 1. 31-50. "cited in" *Freshwater Fishes of Europe*, vol. 1. ed. J. Holcik, 1989. AULA Verlag. Wiesbaden, Germany.

Sandilands, A. P. 1987. Biology of Lake Sturgeon (*Acipenser fulvescens*) in the Kenogami River, Ontario. pp. 33-46. In: C.H. oliver (ed) Proceedings of a workshop on the lake sturgeon (*Acipenser fulvescens*), *Ont. Fish. Tech. Rep. Ser.* No. 23.

Saville. A (ed.). 1977. Survey methods of appraising fisheries resources. *FAO Fish. Tech. Pap.*, (171): 76p.

Schaefer. M. B. 1954. Some aspects of the dynamics of populations important to the managment of the commercial marine fisheries. *Inter-Amer. Trop. Tuna., Bull.*, 1 (2): 26-56.

Schneberger, E and Woodbury. L. A. 1944. The Lake Sturgeon (*Acipenser fulvescens* Rafinesque) in Lake Winnebago, Wisconsin. *Transactions of the Wisconsin Academy of Sciences, Arts and Letters* 36: 131.140.

Scote, W. B. and Crossman, E. J. 1973. Freshwater fishes of Canada. *Bull. Fish. Res. Board Can.* 184. 966 pp.

Semakula, S. and P. Larkin. 1968. Age, growth, food and yield of White Sturgeon (*Acipenser transmontanus*) of the Fraser River, British Colombia. *J. Fish. Res. Bd. Can.* 25(12): 2589-2602.

Severtsov, N. A. 1863. Zhizn, krasnoi ryby v ural skikh vodakhi i ee znachenie dlya poryadka uralskikh rybolovstv. Zhurnal Ministerstva gosudarstvennogo imushchestva 83. 94. "cited in" *Freshwater Fishes of Europe*, vol. 1. ed. J. Holcik, 1989. AULA Verlag. Wiesbaden, Germany.

Sewertzoff, A. N. 1923. The place of cartilaginous ganoids in the system and the evolution of the Osteichthyes. *J. Morph.*, 38, pp.105-145

Shorygin, A. A. 1952. Pitanie i pishchevye vzaimootnosheniya ryb Kaspiiskogo morya. Pishchepromizdat, Moskva. In *Freshwater Fishes of Europe*, vol. 1. ed. J. Holcik, 1989. AULA. Verlag. Wiesbaden, Germany.

Shubina, T.N., 1967a. Analiz vozrastnoi struktury nerestovoi populyatsii volzhskoi sevryugi *Acipenserstellatus* Pallas. *Trudy TSNIORKH* 1: 65-77.

Shubina, T. N. 1967b. The characteristics of the spawning runs and descents of the Stellate Sturgeon in the Volga and the composition of their schools in 1962-1963. *Tr. Azerb.otd. Tsentr. NII osetr. ryb. khoz-va*, 6, 44-52.

Silvka, A. P. 1971. A description of the Volga sturgeon population. In: *Aktual'nyye voprosy osetrovogo khozyaystva* (Topical questions of sturgeon fisheries). Astrakhan. pp. 101.

Silvka, A. P.and Pavlov. A. V. 1981. The biological bases for changing sturgeon (Acipenseridae) fishery regulations in the Volga Delta (Central Sturgeon Fisheries Reseach Institute (TSNIORKH), Astrakhan).

Skriptunov, A. N. 1970. Seaonal changes in Caspian Sea levels. *Trudi Gos. Okean. Inst.* Issue 98, pp 95-106.

Slivka, A. P. and Dovgopol. G. F., 1979. Qualitative characteristices and biological peculiarities of rational utilization of reserves. In: *Biological basis of developing sturgeon farming in the waterbodies of the USSR* (in Russian). Nauka press, Moscow, pp. 188-200.

Smith, T. I. J., Marchette. D. E., and Ulrich. G. F. 1984. The Atlantic sturgeon fishery in South Carolina. *N. Amer. J. Fish. Man.* 4: 164-176.

Smith, T. I. J. 1985. The fishery biology, and management of Atlantic Sturgeon (*Acipenser oxyrhynchus*), in North America. pp 61-72. In: F. P. Binkowski and Doroshov. S. I. (ed) *North American sturgeons: biology and aquaculture potential*, Dr. W. Junk Publishers, Dordrecht.

Smith, T. I. J. 1990. Culture of North American sturgeons for fishery enhancement. *National Marine Fisheries Service Tech. Rep.* 85: 19-27.

Sokal, R. R and Rohlf. F. J., 1995. *Biometry: the principles and practice of statistics in biological research.* W. H. Freeman and Company.

Sokolov, L. I. and Tessler. E. A., 1969. The Sevryuga, *Acipenser stellatus* Pallas, in the middle and late Holocene Sea. *Vopr Ichthyol.* 9, No. 4, pp.587-598.

Sokolov, V. I and N. V. Akimova. 1976. Age determination of the Lena River sturgeon, *Acipenser baeri. Vopr Ichthyol.* 16, pp. 773-778.

Sparre, P., Urisin, E., and Venema, S. C. 1989. Introduction to tropical fish stock assessment. Part 1. *Manual. FAO Fish Tech. Pap,* 306/1. pp. 333. Rome, Italy.

Stevens, D. E,. and Miller. L. W. 1970. Distribution of sturgeon larvae in the Sacramento-Sanjoaquin River system. *Calif. Fish Game* 56 (2):80-86.

Svetovidov, A. N. 1964. Ryby Chernogo morya. Izd. Nauka, Moskova - Leningrad. "cited in" *Freshwater fishes of Europe*, vol. 1. ed. J. Holcik, 1989. AULA Verlag. Wiesbaden, Germany.

Tanaka. S. 1960. Studies on the dynamics and the management of fish populations. *Bull. Tokai. Reg. Fish. Res. Lab.* 28: 1-200 (In Japanese).

Tarverdieva, M. l. 1967. Sutochnyi khod pitaniya osetra i sevryugi (po materialam iz zapadnogo raiona Severnogo Kaspiya za leto 1963 g.). *Trudy Azer-baidzhanskogo otd. TSNIORKH* 6: 53-66.

Tarverdieva, M. 1. 1968. Pastbishcha osetra i sevryugi v Kaspiiskom more v 1962 g. i mnogoletnie izmeneniya v pitanii kaspiiskikh osetrovykh. In: *Tezisy dokladov na otchetnoi sessii TSNIORKH*. Baku. pp. 87-89.

Taylor, C. C. 1985. Cod growth and temperature. *J. Cons. int. Explor. Mer.* 23: 366-70.

Taylor. C. C. 1960. Temperature, growth and mortality- the pacific cockle. *J. Cons. int. Explor. Mer.* 26: 117-24.

Tereshchenko, K. K. 1917. Bream (*Abramis brama* L) of the Caspian-Volga region, fishery and biology. *Tr. Astrakhan. Ikhtiol. Lob.*, 4 (2), 1-159.

Threader, R. W., and Brousseau, C. S. 1986. Biology and management of the lake sturgeon in the Moose River, Ontario. *N. Amer. J. Fish. Man.* 6:383-390.

Tsepkin, E. A. and Sokolov, L. I. 1970. Russkii osetr *Acipenser guldenstadti* Brandt v srednem i pozdnem golotsene Sea. *Vopr Ichthyol.* 10: 24-36. (in Russian).

Tsepkin, E. A., and Sokolov, L. I. 1971. Beluga *Huso huso* (L) v pozdnem golotsene. *Nauchnye doklady Vysshei shkoly, biologicheskie nauki* 5. 11-16.

Ursin, E. 1967. A mathematical model of some aspects of fish growth, respiration and mortality. *J. Fish. Res. Bd Can.* 24, 23355-453.

Vasnetsov, V. V. 1934. Comparative analysis of growth of cyprinids. *Zool. Zhurn.*, 13: 54-583.

Vasnetsov, V. V. 1974. Growth of fish as an adaptation. *Byul. MOIP. Otd. Biol.*, 52 (1), 23-34.

Veshchev, P. V. 1978. Composition of the spawning population of the sturgeon, *Acipenser guldenstadti* and *Acipenser stellatus*, in the spawning grounds of Akhtuba River. Central Sturgeon Fisheries Research Institute (TSNIORKH), Astrakhan, pp.151-155.

Veshchev, P. A. 1979. Composition of the spawning population of the sturgeon, *Acipenser guldenstadti* and *Acipenser stellatus*, in the spawning grounds of Akhtuba River.*Vopr Ichthyol.* 19: 362-365.

Veshchev, A. N. and A. S. Novikova. 1983. Reproduction of Sevruyga, *Acipenser stellatus* (Acipenseridae), under conditions of variable flow of Volga.*Vopr Ichthyol.* 23: 766-773.

Veshchev, P.V. and Novikova, A. S. 1986. Biological characterristics of sevryuga, *Acipencer stellatus*, on the spawning grounds of the lower Volga. *Vopr Ichthyol.* 5: 771- 778.

Veshchev , P. V. and Novikova , A. S. 1987. Reproduction of *Acipenser stellatus*, in the lower Volga. *Vopr Ichthyol*, 5: 801-808.

Veshchev, P. V. 1991. Effectiveness of natural production in the Stellate Sturgeon (*Acipenser stellatus*) under conditions of regulated flow in the Volga. *Vopr Ichthyol* 30: 76-83.

Vinberge, G. G. 1971. Length and body weight of animals. *Zhurn. Obshch. Biol.*, 32: 714-722.

Vlasenko, A. D. 1986. Formirovanie promyslovykh zapasov osetrovykh pod vliya niem estestvennogo i iskusstvennogo Vosproizvodstva. In: *Formirovanie zapasov osetrovykh v usloviyakh kompleksnogo ispol'zovaniya vodnykh resursov. Izd. Volgogradskaya pravda*, Volgograd. pp. 55-57.

Vlasenko, A. D.1994. The present status and conservation of sturgeons (Acipenseridae) in the Caspian Sea. The international Confererance on Sturgeon Biodiversity and Conservation. The American Museum of Natural History (July28-30, 1994), pp, 1-7.

Vosogh, A. A. 1989. The unique management for the Iranian fishery company and the problems of dividing in to a different cooperative. (Published in International Conference, *The rational utilisation of Caspian Sea resource*, Iranian fisheries. P. O. Box 14155-3789 Tehran Iran. (In Persian).

Votinov, N. P., and Kas'yanov. V. P. 1979. The ecology and reproductive efficiency of the Siberian Sturgeon (*Acipenser baeri*) in the Ob as affected by hydraulic engineering works.*Vopr Ichthyol.* 18: 20-29.

Walford, L. A. 1946 A new graphic method of describing the growth of animals. *Biol. Bull. mar. Biol. Lab.*, Woods Hole 90: 41-7.

Wilson, N. C. 1987. Age determination of lake sturgeon (*Acipenser fulvescens*) by use of the marginal pectoral fin ray. pp. 77-83. In: C. H. Oliver (ed) Proceedings of a work shop on the lake sturgeon (*Acipenser fulvescens*), *Ont. Fish. Tech. Rep. Ser.* No. 23.

Yegelskiy, Ye.I. 1970. Growth of Siberian sturgeon juveniles under extreme and natural conditions. *Tr. Tsentr. NII Osetr. Khoz.*, 2: 191-196.

Yelizarov, G. A. 1968. The condition of the overwintering stock of sturgeons in the lower reaches of the Volga. *Vopr Ichthyol.* 8: 50

Zakharov, S. S., 1975. Sovremennoe sostoyanie chislennosti osetrovykh v Severnom Kaspii. Trudy VNIRO 108: 99-108. "cited in" *Freshwater fishes of Europe*, vol. 1. ed. J. Holcik, 1989. AULA Verlag. Wiesbaden, Germany.

Zakharyan, G. B. 1972. Materialy k izucheniyu uslovii razmnozheniya kurinskikh osetrovykh (in Russian). *Trudy TSNIORKH* 4: 67-77.

Zenkevitch, L. 1963. *Biology of the Seas of the USSR*. Translated by: S. Botcharskaya. pp. 538-646. George Allen & Unwin Ltd, London.

Zheltenkova, M. V. 1964. Pitanie osetrovykh yuzhnykh morei (in Russian). Trudy VNIRO 54: 9-48. "cited in" *Freshwater fishes of Europe*, vol. 1. ed. J. Holcik, 1989. AULA Verlag. Wiesbaden, Germany.