INTRODUCTION

Migration of animal species is one of the most complicated and interesting biological phenomena, and fish migration is no exception. Fish migration may vary significantly, depending on the length of migration, as well as its direction and form, i.e., passive or active migration. Spawning (reproductive), feeding, and wintering fish migrations altogether form a migration cycle that is considered to be an inseparable part of the entire fish life cycle.

As a rule, fish migration is closely connected with the systems of water currents in the areas where individual fish populations are distributed. Specifically, upstream (contranatant) fish migration usually alternates with downstream (denatant) migration (Meek, 1916; Scheuring, 1929; Shmidt, 1947; Harden Jones, 1968; Northcote, 1978; Pavlov, 1979; Thorpe, 1982; and others). Downstream migration is an important part of the freshwater fish migration cycle. It is especially typical for their early ontogenetic periods, being the first and fairly important part of their migration cycle, affecting the scope of further migration and many aspects of the fish ecology.

Downstream migration is also important because it affects fish distribution and feeding modes (Pavlov, 1979; Pavlov et al., 1981). This migration is characteristic of diadromous, amphidromous, and resident fishes. Until recently, the detailed study of downstream migration has been performed for rivers and streams. Reviews of these studies have been provided in a number of publications (Harden Jones, 1968; Pavlov, 1979; Pavlov et al., 1994, and others). However, this type of migration can be observed in both rivers and reservoirs with slow water exchange, i.e., lakes and manmade reservoirs where, regardless of the suppression of the water exchange, some currents are always present.

The construction of hydroelectric power plants (HPPs) worldwide has resulted in generation of regulated water flows in most rivers with significant fish resources. The creation of manmade water reservoirs has drastically changed the modes of currents, thereby violating well-established ecological relationships and, consequently, conditions for fish migration, including downstream migration.

Downstream migration has been well known and well described in literature. In some cases, downstream migration is called ”drift” migration or “escape” migration to emphasize an accidental or forced way of the fish movement (Cada et al., 1997). However, it does not seem to be quite precise. Fish downstream migrations are considered to be downstream migrations, regardless of whether they are forced by external circumstances or occur naturally. Fish transition with a flow of water from a lake or a manmade reservoir is practically the same phenomenon. Therefore, so called drift or escape of the fish from the reservoir through the dam, as a rule, should be considered to be fish downstream migration under modified hydrological conditions.

In Russia and other countries of the former Soviet Union, such migrations have been described for the following manmade reservoirs: Vazuzsky, Vyshnevolotsky, Mingechaursky, Mozhajsky, Ruzsky and Ozerninsky (Pavlov et al., 1985a), Verkhnevolzhsky (Pavlov et al., 1980), Veselovsky (Schetinina, 1959; Nusenbaum, 1961), Volgogradsky (Shilov, 1966; Batychkov, 1967; Gajduk et al., 1970; Degtyarev et al., 1990), Ivan'kovsky (Pavlov et al., 1984, 1991b), Volkhovsky (Tikhij, 1939), Kajrakumsky (Rezanov, 1969), Kapchagajsky (Nezdoliy, 1974; Orlov, 1980; Pavlov et al., 1981), Kujbyshevsky (Chikova, 1968; Sharonov, 1972), Leninsky (Mel'nikov, 1957), Novoseletsky and Otkaznensky (Pavlov et al., 1985a, Nezdoly, Resin, 1988), Nureksky (Pavlov et al., 1992), Rybinsky (Volodin, 1958; Rybinsky Reservoir….., 1972; Pavlov, Nezdoly, 1981), Sergeevsky (Lebedev, Shipilov, 1985), Sengilevsky and Novotroitsky (Popova, 1962), Tulomsky (Golovkov, Kozhin, 1939), Uglichsky (Pavlov et al., 1985b), Ust'Khantajsky (Pavlov et al., 1994a), Tsimlyansky and Ust'Manychsky (Dryagin, 1953; Potekhina, 1956; Syrovatsky, 1957; Mokryak, 1958; Zdanova, 1963; Verzin, 1978; Gorodnichij, 1978), Chardar'insky (Eretchenko, 1971, 1972; Kuznetsova, 1980), Sheksninsky (Kostin et al., 1986). In other countries, fish downstream migration from manmade reservoirs is also well known (Hamilton, 1955; Clay, 1961, 1995; Elder, 1965; Durkin et al., 1970; Trefethen, 1972; Vostradovsky et al., 1973; Ebel, 1975; Hadderingh, 1978, 1979; Vasilyev, 1986; Pavlov et al., 1987; Pavlov et al., 1988 and many other publications.)

Unlike the Russian publications, the publications by foreign authors mostly focus on downstream migration of diadromous fishes of the family Salmonidae, and their injuries and losses during passage through the turbines (Clay, 1961, 1995; Trefethen, 1972; Monten, 1985; Davies, 1988; Cada, 1990, Cada et al., 1997). Though fish downstream migration is, on the whole, fairly well studied, most of these publications only acknowledge the downstream migration phenomenon and indicate its potential consequences. As a rule, the data given in those publications are based on occasional observations. There are very few studies that have been based on systematic evaluations, let alone year-round observations, which would have been crucial for complete understanding of this phenomenon. For the most part, the publications are oriented to specific needs, i.e., environmental research or fisheries needs. There has been a lack of fundamental research that would have been oriented towards patterns, causes and mechanisms of fish downstream migration.

Our research division called Laboratory for Studies on Behavior of Primary Vertebrates of the A.N. Severtsov Institute of Ecology and Evolution of the Russian Academy of Science (SIEE RAS) has been doing research on fish downstream migration from reservoirs with slow water exchange since 1965 as follow up to studies made on fish migration and behavior in the rivers. The major goals of those studies were to identify patterns and leading primary factors, as well as causes and mechanisms of downstream migration for resident fishes. Currently, information has been accumulated on fish migration from 45 manmade reservoirs and lakes (Pavlov et al., 1980, 1981, 1984, 1985a, b, 1988, 1991a, b, and other publications).

Originally, the research strategy was to perform initial comprehensive reviews to identify and compare various major patterns of fish downstream migration from man-made reservoirs and lakes with slow water exchange. Those studies were completed in

1979 – 1984, and they resulted from occasional or small-scale observations. Their major results have been described in D.S. Pavlov's publications (1985a) that show that some of the patterns of downstream fish migration depend on water intake conditions and the morphology of the reservoir bed.

The next stage of the studies was aimed at identifying the primary factors of fish downstream migration. These studies were completed in 1982 – 1985, and they resulted from year-round comparative observations and studies of two pairs of reservoirs, different in the water intake conditions, i.e., Mostiste reservoir and Vestonitse reservoir (Pavlov et al., 1987), as well as Sheksninskoe reservoir and Lozsko-Azatsky lake (Pavlov et al., 1991a). These studies have shown that the patterns of fish downstream migration depend on environmental conditions and distribution of the specific kinds of fish, as well as on such factors as the velocity of currents, water exchange intensity, light, and conditions for nutrition and water intake. However, those studies have created new questions, specifically: Why, even with the water exchange of over ten times a year, there may still be fish in the reservoir that will not be exposed to downstream migration? Why some of the fishes that enter the HPP water intake region do not migrate into the HPP tailwaters? Why can littoral fish be found in the water intake region located in the pelagic zone? What is the significance of the downstream migration for the size of the population of some specific types of fish? And many other questions.

This book answers some of these questions. The major accomplishment of this publication is that it has summarized and reviewed all the data on fish downstream migration that have been accumulated during years of studies, thereby making it possible to provide the quantitative description of processes and mechanisms associated with this phenomenon.

This book goes beyond identifying individual factors that affect downstream migration and makes an attempt to develop the hierarchy and provide quantitative estimations of the reviewed factors, making it possible to both explain the obtained results and predict the future downstream migrations. Starting from individual mechanisms, we have attempted to perform a systematic evaluation of various processes affecting fish downstream migration. The quantitative approach to identifying the contributions of the individual mechanisms and factors into the final result has made it possible to develop the first model of downstream migration for juvenile fishes from the reservoirs. The model has been successfully tested, which has confirmed the adequacy of our understanding regarding cause and effect relationships in downstream fish migration.

The quantitative approach towards fish downstream migration makes it possible to evaluate its role in the size of the populations of fishes in the reservoirs. This role significantly varies for natural and manmade reservoirs. At passage through the turbines, some of the fish are lost, and, beyond that, in most cases the downstream migration is irreversible. It may decrease the sizes of the fish populations. Based on quantitative estimations, we have identified some methods for evaluating irreversible fish losses and changes in the size of the fish populations.

The goal of this book is to define the major factors and mechanisms of fish downstream migration from reservoirs with slow water exchange and provide a quantitative description of these factors and mechanisms. It has been made possible due to the development of the year-round observations data base that includes data collected since 1972. For the most part, the individual data have already been published. However, the comparative analysis of the data is presented here for the first time. The following specific tasks have been implemented:

- major patterns of fish distribution in reservoirs with slow water exchange have been evaluated;
- major factors, causes and mechanisms that form fish downstream migration have been identified;
- the model for fish downstream migration from reservoirs has been developed; scope and factors contributing to fish losses in the HPP turbines have been evaluated.

The book includes an introduction, six chapters and a conclusion. The first chapter describes methods for studying fish downstream migration. The second chapter introduces the concept of an ecological zone of the water intake and provides classification of the reservoirs based on this concept. The third chapter presents the analysis of the major patterns for downstream fish migration from reservoirs, proving that the ecological zone of the water intake affects many of these patterns. The fourth chapter describes causes and mechanisms of fish downstream migration and the model for this migration. The fifth chapter provides data on fish injuries resulting from passage through the HPP turbines and gives a detailed description of the factors causing fish losses. The sixth chapter discusses how fish downstream migration affects the available fish resources in the reservoirs.

The book has used the data for nine HPP reservoirs, obtained on a year-round basis with application of identical methods and procedures. However, realistically, the book has resulted from over 30-years of studies performed at the SEEI RAS Division for Studies on Behavior of Primary Vertebrates for forty-five water reservoirs (manmade reservoirs and lakes).

Many scientists, graduate and postgraduate students have been involved in these studies during this time. Our foreign counterparts from the Czech Republic and Bulgaria have also made extremely significant contributions to the research. The authors would like to thank all those who have participated in the research.

Our special thanks are to those who have helped in collecting and evaluating the data on the major reservoirs: V.K.Nezdoliya (Kapchagajskoe, Ivan'kovskoe, Nurekskoe and Mostiste reservoirs), V.N. Mikheev (Alexander Stambolijsky reservoir[1]), V. Barusha and J. Gaudushek (Mostiste reservoir), M.P. Ostrovsky (Sheksninskoe and Nurekskoe reservoirs), M.V. Vasileva and L.Z. Pekhlivanova (Al. Stambolijski), V.P. Khaladzhieva and V.S. V'uchnova (Volgogradskoe reservoir), A.I. P'yanova (Nurekskoe), A.M. Boldyreva, G.I. Ol'khovskya and A.I. Lokhamatikova (Ivan'kovskoe), N.I. Gorshkova

[1] Further on referred to as Al. Stambolijski.

and V.Yu. Lobankov (Ozerninskoe). We would also like to thank the organizations that assisted in performing the studies, specifically: Glavrybvod and its field offices; HPP management where the studies have been performed; Institute of Zoology of Czech Academy of Science (1982 – 1983 studies); Institute of Zoology of Bulgarian Academy of Science; Institute of Zoology of Turkmenistan; Gydroproekt Institute and its Volgograd Division; State University of Kazakh Republic and other organizations. The publication of the book has been made possible with the assistance of the company "Ecology of Russia."

Chapter 1 REGIONS OF RESEARCH, MATERIAL AND METHODS

This chapter presents general characteristics of the studied reservoirs, major hydroelectric facilities and hydroelectric power plants (HPPs). It describes methods for studies of fish migration from the reservoirs and fish distribution in the HPP dam areas.

1.1 Brief Description of Studied Reservoirs

The studies have been performed for nine reservoirs. Five of them, i.e., Ivan'kovskoe, Volgogradskoe, Sheksninskoe, Ozerninskoe and Ust'-Khantajskoe, are located in Russia, while the other four are located in other republics of the Former Soviet Union or other countries, specifically: Kapchagajskoe in Kazakhstan, Nurekskoe in Tadjikistan, Mostiste in Czech Republic and Al. Stambolijski in Bulgaria. Most Russian reservoirs are located in the European part of Russia, two of them (Kapchagajskoe and Nurekskoe) are located in the south, and Ust'-Khantajskoe reservoir is located in the northern part of the Asian part of the Former Soviet Union (Fig. 1.1).

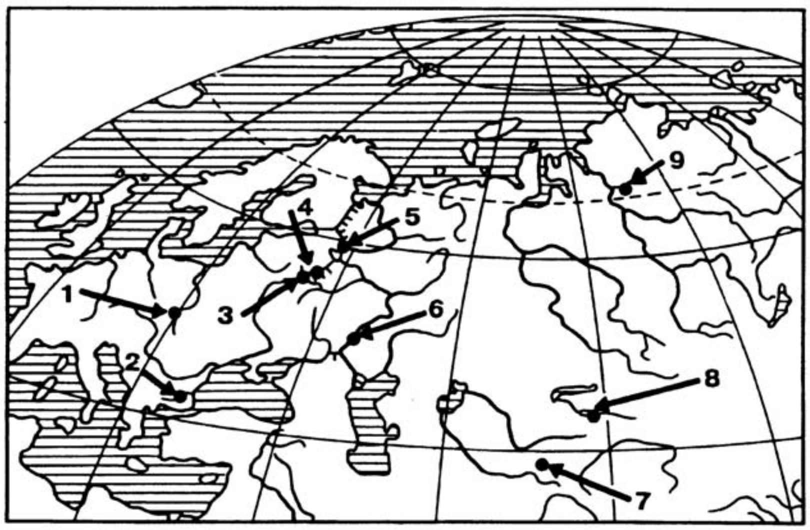

Figure 1.1 Schematic of locations of studied reservoirs.

1 – Mostiste, Czech Republic; 2 – Al. Stambolijski. Bulgaria; 3 – Ozerninskoe, Russia; 4 – Ivan'kovskoe, Russia; 5 – Sheksninskoe, Russia; 6 – Volgogradskoe, Russia; 7 – Nurekskoe, Tadjekistan; 8 – Kaphagajskoe, Kazakhstan; 9 – Ust'-Khantajskoe, Russia

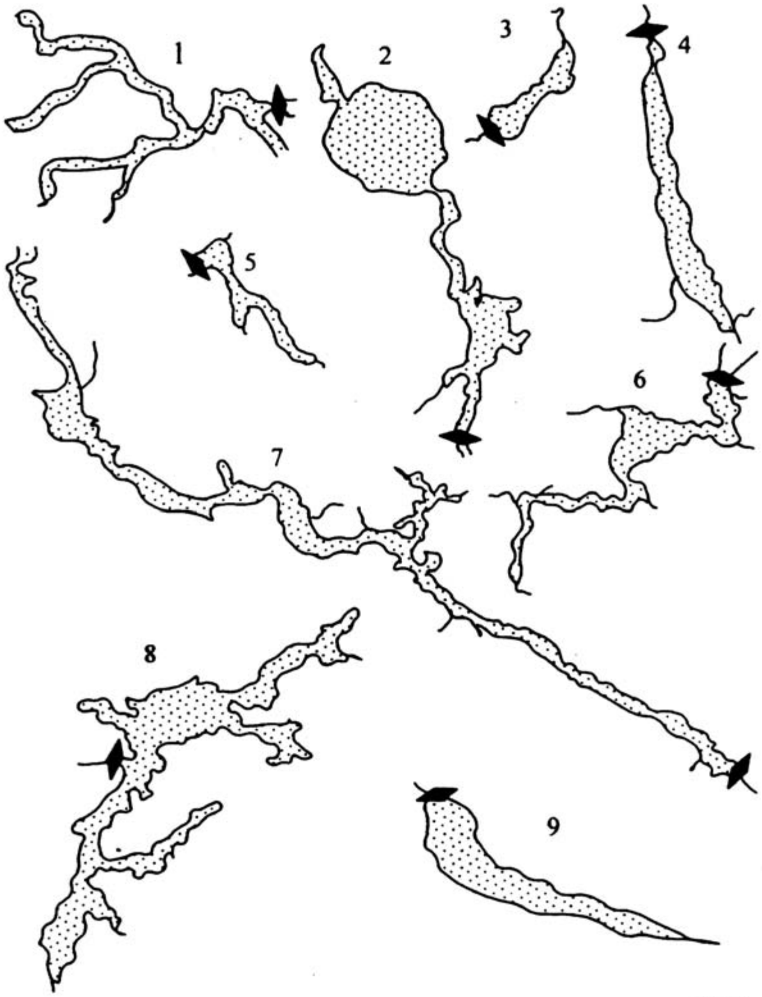

Figure 1.2 Schematic presentations of studied reservoirs (ref.: Isaev, Karpova, 1989).

1 - Ivan'kovskoe; 2 – Sheksninskoe; 3 – Ozerninskoe; 4 – Kapchagajskoe; 5 – Mostiste;
6 – Al. Stambolijski; 7 – Volgogradskoe; 8 – Ust'-Khantajskoe; 9 – Nurekskoe;
◆ - dam

The studied reservoirs are considered to be river-type reservoirs. However, some of them (Ust'-Khantajskoe, Ivan'kovskoe and Sheksninskoe) also have a lake-shaped part, not just a waterway (Fig. 1.2.). The reservoirs vary in their areas (0.86 - 3,287 km^2), volume (0.01 – 31.45 km^3), length (5.5 – 540 km) and average depth (3.4 – 107 m). The annual water exchange coefficient has been the highest in Ivan'kovskoe reservoir (13.0) and the lowest in Sheksninskoe reservoir (0.73). Therefore, the studied reservoirs significantly vary in their morphological and hydrological properties (Table 1-1). 76 fish species from 16 families can be found in those reservoirs (Table 1-2.). The fish differ by types and quantity. Some of the fishes, like roach and common perch, have been found in eight out of nine reservoirs.

Table 1-1 Major morphological and hydrological properties of studied reservoirs

Characteristic	Sheksninskoe	Ivan'kovskoe	Ozerninskoe	Volgogradskoe	Ust'-Khantajskoe
Area, km^2	1,665.0	3278.0	23.0	3117.0	2120.0
Capacity, km^3	6.52	1.12	0.14	31.45	23.5
Annual flow volume, km^3	5.07	14.5	0.24	251.0	19.5
Length, km	262.0	133.0	30.0	540.0	160.0
Maximum width, km	9.0	8.0	3.0	4.6	27.0
Average depth, m	3.9	3.4	6.3	10.1	27.0
Maximum depth, m	25.0	20.0	20.5	40.0	50.0
Annual water exchange coefficient	0.73	13.0	1.66	8.0	1.3

Characteristic	Kapchagajskoe	Mostiste	Al. Stambolijski	Nurekskoe
Area, km^2	1,847.0	0.86	10.86	98.0
Capacity, km^3	2.81	0.01	0.22	10.5
Annual flow volume, km^3	5.63	0.05	0.35	34.2
Length, km	118.0	5.5	19.0	70.0
Maximum width, km	22.0	2.5	2.0	6.5
Average depth, m	15.0	12.1	20.3	107.1
Maximum depth, m	40.0	30.0	46.0	300.0
Annual water exchange coefficient	2.0	5.0	1.6	3.3

Table 1-2 Fish species in studied reservoirs

Species	S	I	O	V	K	U	A	M	N
Caspian lamprey - *Caspiomyzon wagneri (Kessler)*	-	-	-	+	-	-	-	-	-
Russian sturgeon - *Acipenser gulgenstadtii* (Brandt)	-		-	-	+	-	-	-	-
Fringebarbel sturgeon - *Acipenser nudiventris* (Lovetsky)	-	-	-	-	+	-	-	-	-
Sterlet - *Acipenser ruthenus* (Linnaeus)	+	-	-	+	-	-	-	-	-
Sturgeon - *Acipenser stellatus* (Pallas)	-	-	-	+	-	-	-	-	-
Beluga - *Huso huso* (Linnaeus)	-	-	-	+	-	-	-	-	-
Caspian anadromous shad - *Alosa kessleri* (Grimm)	-	-	-	+	-	-	-	-	-
Black sea sprat - *Clupeonella cultriventris* (Nordmann)	-	-	-	+	-	-	-	-	-
Taimen - *Hucho taimen* (Pallas)	-	-	-	-	-	+	-	-	-
Rainbow trout – *Parasalmo mykiss* (Walbaum)	-	-	-	-	-	-	-	-	+
Charr - *Salvelinus alpinus* (Linnaeus)	-	-	-	-	-	+	-	-	-
Vendace - *Coregonus albula* (Linnaeus)	+	-	-	-	-	-	-	-	-
Humpback whitefish - *Coregonus lavaretus pidschian* (Gmelin)	-	-	-	-	-	+	-	-	-
Common whitefish - *Coregonus lavaretus lavaretus* (Linnaeus)	+	-	-	-	-	-	-	+	-
Broad whitefish - *Coregonus nasus* (Pallas)	-	-	-	-	-	+	-	-	-
Peled - *Coregonus peled* (Gmelin)	+	-	-	-	-	+	-	-	-
Sardine cisco - *Coregonus sardinella* (Valenciennes)	-	-	-	-	-	+	-	-	-
Round whitefish - *Prosopium cylindraceum* (Pallas)	-	-	-	-	-	+	-	-	-
Connie - *Stenodus leucichthys* (Guildenstadt)	-	-	-	+	-	-	-	-	-
Grayling - *Thymallus arcticus* (Pallas)	-	-	-	-	-	+	-	-	-
European smelt - *Osmerus eperlanus eperlanus* (Linnaeus)	+	+	+	-	-	-	-	-	-
Northern pike - *Esox lucius* (Linnaeus)	+	+	+	+	-	+	+	+	-
European eel - *Anguilla anguilla* (Linnaeus)	+	+	+	-	-	-	-	+	-
Blue bream - *Abramis ballerus* (Linnaeus)	+	+	-	+	-	-	-	-	-
Carp bream - *Abramis brama* (Linnaeus)	+	+	+	+	+	-	-	+	-
Southwest white eye - *Abramis sapa* (Pallas)	+	-	-	-	-	-	-	-	-
Spirlin - *Alburnoides bipunctatus* (Bloch)	-	-	-	-	-	-	-	-	+
Bleak - *Alburnus alburnus* (Linnaeus)	+	+	+	+	--	-	+	+	-
Bighead carp **-** *Aristichthys nobilis* (Richardson)	-	-	-	+	-	-	-	-	-
Asp - *Aspius aspius* (Linnaeus)	+	+	+	+	+	-	-	+	-
Silver bream - *Blicca bjoerkna* (Linnaeus)	+	+	+	+	-	-	-	-	-
Nase - *Chondrostoma variabile* (Jakowlew)	-	-	-	+	-	-	-	-	+
Silver carp - *Hypophthalmichthys molitrix* (Valencinnes)	+	+	+	-	-	-	-	-	-
Moderlieschen - *Leucaspius delineatus* (Heckel)	+	+	+	-	-	-	-	-	-
Chub - *Leuciscus cephalus* (Linnaeus)	+	+	+	+	-	-	+	+	-
Ide - *Leuciscus idus* (Linnaeus)	+	+	+	+	-	+	-	-	-
Dace - *Leuciscus leuciscus* (Linnaeus)	+	+	+	+	+	+	-	-	-
Ziege - *Pelecus cultratus* (Linnaeus)	+	+	-	+	-	-	-	-	-
Eurasian minnow - *Phoxinis phoxinis* (Linnaeus)	-	-	-	-	-	+	-	-	-
Roach - *Rutilus rutilus* (Linnaeus)	+	+	+	+	+	+	-	+	+
Rudd - *Scardinius erythrophthalmus* (Linnaeus)	+	+	-	+	-	-	+	+	-
Morrunash - *Vimba vimba* (Linnaeus)	-	-	-	-	-	-	+	-	-
Sharpbelly - *Hemiculter leucisculus* (Basilewsky)	-	-	-	-	+	-	-	-	-
Bitterling - *Phodeus seroceus* (Pallas)	-	-	-	-	-	-	+	-	-
Amur false gudgeon - *Abbottina rivularis* (Basilewsky)	-	-	-	-	+	-	-	-	-
Gudgeon - *Gobio gobio* (Linnaeus)	+	+	-	-	-	-	-	+	-
Topmouth minnow - *Pseudorasbora parva* (Temmick et	-	-	-	-	+	-	+	-	-

Species	S	I	O	V	K	U	A	M	N
Schlegel)									
Barbel - *Barbus brachycephalus* (Kessler)	-	-	-	-	+	-	-	-	-
Grass carp - *Ctenopharyngodon idella* (Valenciennes)	-	-	-	+	+	-	-	-	-
Black carp - *Mylopharyngodon piceus* (Richardson)	-	-	-	+	-	-	-	-	-
Goldfish - *Carassius auratus* (Linnaeus)	-	+	+	+	+	+	-	-	-
Crucian carp - *Carassius carassius* (Linnaeus)	+	-	-	-	-	-	-	-	-
Carp - *Cyprinus carpio* (Linnaeus)	-	+	-	+	+	-	+	+	+
Tench - *Tinca tinca* (Linnaeus)	+	+	+	+	-	-	-	+	-
Snowtrout - *Schizothorax intermedius* (McClelland)	-	-	-	-	-	-	-	-	+
Snowtrout - *Schizothorax pseudaksaiensis* (Herzenstein)	-	-	-	-	+	-	-	-	-
Transcaucasian barb - *Varocorhinus capoeta* (Guldenstadt)	-	-	-	-	-	-	-	-	+
Stream loach - *Barbatula barbatula* (Linnaeus)	+	-	-	-	+	-	-	-	-
Loaches - Cobitidae sp.	-	-	-	-	-	-	-	-	+
Spined Loach - *Cobitis taenia* (Linnaeus)	+	-	-	-	-	-	+	-	-
Wels catfish - *Silurus glanis* (Linnaeus)	-	+	-	+	+	-	+	-	-
Ricefish - *Oryzias latipes* (Temminck et Schlegel)	-	-	-	-	+	-	-	-	-
Burbot - *Lota lota* (Linnaeus)	+	+	+	+	-	+	-	-	-
Ten-spined stickleback - *Pungitius pungitius* (Linnaeus)	-	-	-	-	-	+	-	-	-
Pumpkinseed sunfish - *Lepomis gibbosus* (Linnaeus)	-	-	-	-	-	-	+	-	-
Ruffe - *Gymnocephalus cernuus* (Linnaeus)	+	+	+	+	-	-	+	+	-
European perch - *Perca fluviatilis* (Linnaeus)	+	+	+	+	-	+	-	+	-
Schrenkii balkhash perch - *Perca screnki* (Kessler)	-	-	-	-	+	-	-	-	-
Pikeperch - *Stizostedion lucioperca* (Linnaeus)	+	+	+	+	+	-	+	+	-
Volga pikeperch – *Stizostedion volgense* (Gmelin)	+	+	+	+	-	-	-	-	-
Gobies - Gobiidae sp.	-	-	-	+	-	-	-	-	-
Yoshinobori - *Rhinogobius brunneus* (Temmink et Scheleger)	-	-	-	-	+	-	-	-	-
Bullhead - *Cottus gobio* (Linnaeus)	+	+	-	-	-	-	-	-	-

Note: Reservoirs: **S** – Sheksninskoe, **I** – Ivan'kovskoe, **O** – Ozerninskoe, **V** – Volgogradskoe, **K** - Kapchagarskoe, **U** – Ust'-Khantajskoe, **A** – Al. Stambolijski, **M** – Mostiste, **N** – Nurekskoe. Plus (+) - species present,minus (-) - species not found. The names are given as in: *Summarized Catalog*....., 1998.

Table 1-3 Geometrical characteristics of locations of water collectors for HPP water intakes

HPP	Average depth at HPP dam, m	Water intake collector depth, m		Water intake width, m	Distance to the shore, m	
		Upper	Lower		Left	Right
Sheksninskaya	26.0	13.0	25.0	60.0	340	800
Ivan'kovskaya	20.0	9.5	19.5	60.0	216	350
Ozerninskaya	20.5	16.0	20.0	4.0	600	400
Volzhskaya	42.7	17.2	28.2	736.0	1400	1000
Ust'-Khantajskaya	31.0	13.0	28.2	736.0	1400	1000
Kapchagajskaya	26.0	26.0	26.0	70.0	60	0
Mostiste	29.0	27.0	28.0	1.0	40	760
Al. Stambolijski	30.0	26.0	29.0	3.2	250	250
Nurekskaya	300.0	50.0	60.0	120.0	1000	0

1.2 Characteristics of Studied HPP Dams

The hydroelectric facilities usually consist of a dead-end dam, spillway, and an HPP dam. To produce electrical energy, the major water flow of the reservoirs goes through the turbines, and the remaining water goes through the spillway.

In hydroelectrical engineering, the HPP dams are usually classified depending on the location of the HPP building relative to the major structures of the hydroelectrical facility (Grishin, 1962). There are two location-related dam types, i.e., central and littoral. With the central type, the HPP structures are located in the central part of the hydroelectric facility. The littoral type means that the HPP structures are adjacent to the shore line of the reservoir. Beyond that, these two types imply three possible ways of locating the HPP water intakes: front, "dipping" and canal. For the front location, the HPP gatewells are located directly in the water reservoir. For the "dipping" location, the gatewells are located in a special area ("dipping" zone) that is connected with the reservoir by a wide canal. The canal type is implemented when the HPP is located far from the head front and the gatewell antechamber is connected with the reservoir by a special canal. In accordance with the vertical configuration, depending on the depth of the gatewells, there are the following types for feeding the water into the gatewell: bottom type, deep-seated and surface type.

Based on the geometry of the gatewells for the studied HPPs (Table 1-3) and the vertical cross sections of the turbine channels (Fig. 1.3), the studied HPP water intakes have been classified according to their location and types (Table 1-4). Taking into account the fact that fish downstream migration often causes fish injuries and losses, which is mostly associated with the turbine parameters, we have found it necessary to describe the major parameters for a number of the studied HPP dams (Table 1-5).

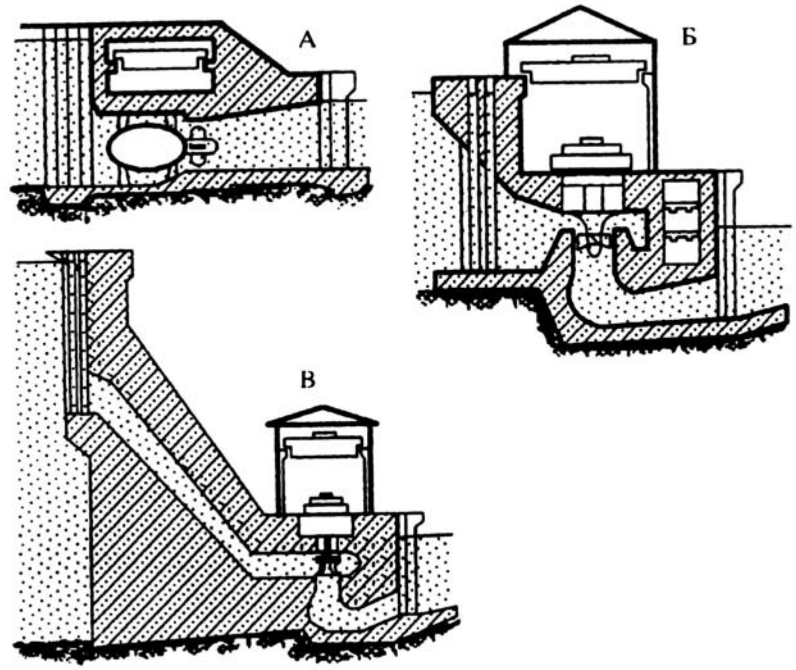

Figure 1.3 Schematic presentations of cross sections for studied HPPs

А – Ozerninskaya, Б – Ivan'kovskaya, Sheksninskaya, Volzhskaya, Mostiste and Al. Stambolijski; В – Chagajskaya, Ust'-Khantajskaya and Nurekskaya.

Table 1-4 HPP water intake geometry, location and type of water intake for studied reservoirs

HPP	Type of HPP location	Type of gatewell location	Type of water intake feeding
Sheksninskaya	Central	Front	Bottom
Ivan'kovskaya	Central	Front	Bottom
Ozerninsakya	Central	Front	Bottom
Volzhskaya	Central	Canal	Deep-seated
Ust'-Khantajskaya	Littoral	Canal	Deep-seated
Kapchagajskaya	Littoral	Canal	Bottom
Mostiste	Littoral	Front	Bottom
Al. Stambolijski	Central	Front	Bottom
Nurekskaya	Littoral	Front	Bottom

Table 1-5 type and other parameters of turbines

HPP	Type of turbine	Head, m	Flow rate, m^3/s	Rotation velocity, rpm	Power, kW
Sheksninskaya	Kaplan	13.0	200.0	-	21,000
Ivan'kovskaya	Kaplan	14.5	135.0	-	26,000
Volzhskaya	Kaplan	14.0 – 30.0	713.0	68.2	108,500 – 126,000
Ust'-Khantajskaya	Kaplan	48.0 – 56.5	165.0	187.5	65,000
Kapchagajskaya*	Kaplan	35.0 – 42.7	348.0	107.1	110,000 – 130,000
Nurekskaya	Francis	156.0 – 206.0	155.0	-	310,000

Note. Asterisk (*) means that HPP has double runner blades; Minus (-) means that there are no available data.

Therefore, both the studied reservoirs themselves and their HPP dams differ significantly in most of their parameters. It makes it possible to transfer the obtained results to a wide range of existing reservoirs and HPPs.

1.3 Methods for the Study of Downstream Migration and Fish Distribution

Methods for Catching Downstream Fish Migrants

As a rule, downstream migrating fish are collected by means of passive fishing tools, i.e., cone-shaped nets. Much attention has been given to the development and improvement of these nets (Pakhorukov, 1980; 1982; Turin, Dyagtyareva 1981a,b; Pavlov et al., 1993). Therefore, the sizes and design of these nets are very different. In our opinion, when applying cone-shaped nets for catching fish migrants at HPP dams, the following three requirements have to be met.

First, catching fish migrants in the HPP tailwaters needs to be avoided. In order to avoid this, all fishing should be performed with the inlets of the nets overlapping the outlets of the draft tube of the turbine (Cramer, Oligher, 1964; Travade et al., 1987). Unfortunately, catching all fish will only be possible at small HPPs with a low flow rate. To avoid undesirable catching with relatively small fishing nets, they have to be installed in the central stream of the turbine discharge flow, or in the headwaters flow in the vicinity of the HPP gatewell.

Second, it is necessary to be aware of the fact that the efficiency of the nets, especially that of ichthyoplanktonic cone-shaped nets (ICSN) can be reduced due to their plugging with debris and small organisms. We have evaluated the filtration capacity as a function of time of application of the nets (Fig. 1.4.) We have found that even at high (typical for summer) concentrations of plankton (≈ 10 g/ℓ), the ICSN filtration capacity with an orifice area of 0.2 m^2 has not worsened within 20 minutes. To make sure that the ICSN remains efficient, it needs to be installed in a highly turbulent flow with an average current speed of no less than 0.7 m/sec.

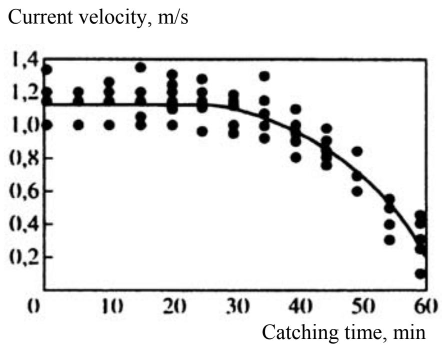

Figure 1.4 Flow velocity in the orifice (ICSN-0.2 m^2) as a function of time of its operation in the tailwaters of Sheksninskaya HPP

Third, these nets may damage fins and scales of the young and adult fish. This fact needs to be taken into account while analyzing fish injuries in the HPP turbines. While catching ichthyoplankton, the nets both kill and grind the larvae. Therefore, the hold time for those traps should not exceed 20 minutes.

All data provided in this book have been collected using the identical methods with application of the standard fishing tools and with compliance with the above-mentioned requirements.

Cone-shaped nets were used for catching fish. Larvae and young fish were caught using ICSN with an orifice area of 0.2 to 0.5 m^2, made of N 9-11 material. For catching one-year-old fish and adult fish, cone-shaped nets (cells 4 – 8 mm) with an orifice of 0.5 to 1.2 m^2 were used. The nets were installed in the HPP spillway with a current velocity of 0.7 – 1.2 m/sec (Fig. 1.5). The only exception was Volgogradskaya HPP (Volgogradskoe reservoir), where the nets were installed on the three depth levels 50 meters away from the gatewell in the area of the trash rack (Khaladzhiev et al., 1990). The hold time for the nets was usually 15 minutes for catching larvae and young fish (but never exceeded 20 minutes) and 2 hours for catching the adult fish.

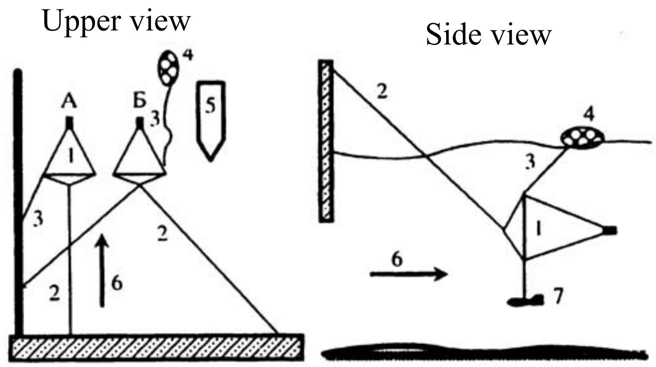

Figure 1.5 Installation of nets in the HPP tailwaters

А – littoral, Б – central; 1 – net, 2 – major puller; 3 – tension puller; 4 – float; 5 – boat; 6 – direction of current; 7 – hydrodynamic load

Fish downstream migration in rivers and from reservoirs depends on the time of day and the season. The time needs to be taken into account for the quantitative estimation of the migration. The sampling needs to be performed on a daily and annual basis. As a rule, we have been taking 12 samples a day. In some reservoirs, i.e., Ivan'kovskoe and Kapchagajskoe, samples occasionally have been taken on an hourly basis (24 samples a day). Catching young and adult fish has been performed daily with 5 to 10-minute breaks for removing the catch.

Catching Fish for Studies of Its Distribution

Because downstream migration of fish through HPP dams is related to their distribution in the reservoirs, the fish distribution in the area adjacent to the dam has been studied for the five reservoirs.

Sampling was performed in various ecological zones by daytime and night surveys. Active fishing was performed in pelagic and sublittoral areas by means of trawling from motor boats at the speed of 0.9 – 1.5 m/s. The same nets as for the HPP tailwaters have been used. Beyond that, a high-speed ichtyoplanktonic trawler has been used in the Sheksninskoe reservoir (Pakhorukov, 1982). In the littoral area, tuck nets have been used for ichtyoplankton and young fish. Only hydroacoustic methods have been used for studies of the fish distribution in the Nurekskoe reservoir (Pavlov et al., 1992).

From June to September 1992, the dynamics of the fish distribution in the various ecological zones of the Ivan'kovskoe reservoir in the mouth of the Soz' river were studied. Trawling was used in the pelagic and sublittoral zones at night. The trawling depths were 0.1 – 0.8 and 4 – 5 meters for the pelagic zone, and 0.1 – 0.8 meters for the sublittoral zone. The trawling speed was monitored and maintained at 1.3 m/s. The ichtyoplanktonic nets made of N 11 with an orifice area of 0.5 m^2 (for young fish less than 30 – 35 mm long) or cone-shaped nets with 4-mm cells and an orifice area of 1.0 m^2 (for fish over 30 - 35 mm long) were used for trawling.

In the littoral zone, fish were caught in 1-meter-deep water. The fish larvae were caught by an N 11 hand net equipped with an electric narcotizer, and the young fish were caught by tuck nets with 4-mm cells with the wing span of 2.5 meters. In stagnated water, fish were caught in the closed areas with mud bottom and rich vegetation. In flowing water, the fish were caught in the areas with vegetation and sandy or mud bottom, while, in the reservoirs, open littoral areas were used with sandy or rocky bottoms and poor vegetation.

Data Processing and Calculations

The standard sample processing was used (identification of species, stage of development and length) (Koblitskaya, 1981).

For the qualitative characteristics of fish downstream migration and young fish distribution, the following equation has been used to calculate the *fish concentration*:

$$C_p = \frac{N}{W} = \frac{N}{V \cdot t \cdot S},$$

where: C_p is the fish concentration in the sample, no./m^3; N is the fish quantity (number) in the net, by species; W is the water volume filtered by the net, m^3; V is the velocity of current in the net orifice, m/sec; t is the sampling time for the net (sec); and, S is the area in the net orifice, m^2.

The current velocity was measured by a hydrometric rotator (GR-21 and GR-99).

The fish concentration values have been used for calculating average daily and then average annual fish concentration values, taking into account seasonal fish concentration changes.

Fish quantity (N) in the HPP dam per year has been calculated by the following equation:

$$N = \Sigma N_I = \Sigma(C_I W_I),$$

where: N is the annual fish quantity; N_I is the fish quantity in the HPP dam during the period of time for which C_I is extrapolated; C_I is the average daily concentration of the i-species of fish in an i-daily survey, no./1,000m^3; W_I is the water discharge volume during the time, for which C_I is extrapolated.

The diel variation coefficient (K_c) has been used in calculations to take into account diel (day to night) variations in the fish migration from various reservoirs. The following equation has been used to calculate this coefficient:

$$K_c = (C_n - C_d)/(C_n + C_d),$$

where: C_n and C_d are average concentration values for the fish migrants at night and in the daytime, respectively.

This coefficient may vary from –1.0, with the fish migrating in the daytime only, to + 1.0 with the fish migrating only at night. With the homogenous migration, the coefficient will be 0. To create charts for illustrating daily dynamics of fish downstream migration for various age groups, the results have been averaged from different daily surveys.

The correlation between a number of the fish migrants and resident fish of the reservoirs has been estimated by the *migration index* (M_I). The migration index shows a capability of migration for a certain species relative to other species in the same reservoir. It is a difference (D) between the quantity of the migrants versus the quantity of the resident fish on a unified scale of 0 – 1. The migration index has been calculated by the following equation:

$M_I = (D_I – D_{min})/(D_{max} – D_{min})$,

where: M_I is the migration index for i-species; D_I is difference in the quantity of i-species; D_{min}, D_{max} – minimum and maximum difference in all D_i.

The migrant versus resident quantity difference is determined in the following way:

$D_I = RP_I - RO_I$,

where: RP_I is the quantity of migrant i-species; RO_I is the quantity of resident i-species..

The biological interpretation of the migration index is that the quantity of the species calculated using this index corresponds to the percentage of the migrants for this species taken from the total quantity of the fish of this particular species in this reservoir. If the migration index of a certain species equals 1, this species has the maximum amount of migrants, and, if the migration index is 0, this species has the minimum amount of migrants.

Table 1-6 overall downstream fish migration data collected for various HPP dams

HPP	Period of studies	Number of daily stations (surveys)	Number of samples	Fish caught, specimen
Fish downstream migration				
Sheksninskya	1982 – 1983	38	613	8452
Ivan'kovskaya	1979 – 1980	36	1442	1596
	1989 – 1990	45	924	3044
Ozerninskaya	1981 – 1982	10	176	501
Volzhskaya	1990 – 1991	7	933	30,000
Ust'-Khantajskaya	1991 – 1992	16	384	980
Kapchagajskaya	1973 – 1974	6	221	17,000
Mostiste	1982 – 1983	30	1,095	1,039
Al. Stambolijski	1983 – 1985	38	1,010	6,260
Nurekskaya	1986 – 1987	12	144	0
Fish distribution prior to passing through the dam				
Sheksninskaya	1982 – 1983	68	420	8242
Ivan'kovskaya	1979 – 1980	12	131	13,000
	1989 – 1990	9	81	403
	1992	16	493	199,966
Ust'-Khantajskaya	1991		11	50
Kapchagajskaya	1972 – 1975	12	453	3,000
Mostiste	1982 – 1983	15	563	4,016
Al. Stambolijski	1983 – 1985	7	830	17,860
Nurekskaya	1986 – 1987	-	10*	-

Note. Asterisk (*) is the amount of cross sections for echo sounding surveys.

Statistical and graphic processing of the data has been performed by *REBUS* software, software packages CSS, Statgraf, HGRUS and the specifically designed software (Kostin, 1989), using standard statistical procedures (Lapkin, 1990).

1.4 Scope of Collected Material

Research presented in this book dates back to 1972 – 1992 (Table 1-6). It should be noted that more detailed reviews of the performed studies for all HPPs, with the exception of Nurekskaya and Volzhskaya NPPs, have been provided in earlier publications (Pavlov et al., 1981, 1984, 1985a, 1988, 1991a, b, 1994a; Pavlov et al., 1987, and other publications). Both our colleagues (V.K. Nezdoly, V.N. Mikheev, M.P. Ostrovsky and others) and our foreign counterparts from Czech Republic (V. Barush and J. Gakdushek) and from Bulgaria (M.V. Vasilev and L.Z. Pekhlivanov) have participated in the studies. Studies at the Volzhskaya HPP have been performed under our supervision by the *Hydroproekt* Science Division (Khaladzhiev et al., 1990). But the goal of this book is not to publish those data again, but perform a comparative quantitative analysis.

In total, 238 daily surveys have been performed for studying fish downstream migration, 6,942 samples have been taken, and about 70 thousand specimens of fish have been caught. For studying the fish distribution, 139 surveys have been performed, 2,992 samples were taken, and over 66 thousand specimens of young fish have been caught.

* * *

Therefore, the book contains data for various reservoirs and HPP dams collected with the use of identical methods and procedures. The studied reservoirs and HPP dams differ in most of the parameters, thereby making it possible to apply the obtained results to a wide range of the existing reservoirs with slow water exchange.

Chapter 2 FISH DISTRIBUTION AND ECOLOGICAL ZONES OF WATER INTAKE

Reservoirs with slow water exchange have distinctive water intake currents associated with the withdrawal of water for power production. Adjacent to this intake, there is an area where the velocity of current exceeds the average current velocity in the reservoir itself. We define this area as a water intake zone. For manmade reservoirs, this area is synonymous with the water intake influence zone.

An obligatory condition for fish downstream migration is the location of the fish in the water flow. Applied to fish downstream migration from the reservoirs, it means its presence in the HPP water intake influence zone. As it has been shown earlier (Pavlov et al., 1985a, 1991a), the presence of fish in that zone can only be assured if the fish distribution area coincides (overlaps) with the water intake area. The goal of this chapter is to evaluate when and where this overlap is likely to happen. The fish distribution and locations of the water intake zones will be described. Since that description is related to the ecological zones of the reservoirs, first we need to give a more detailed description of the concept of the ecological zones.

2.1 Ecological Zones of Reservoirs with Slow Water Exchange

Reservoirs have various zones that are characterized by a number of abiotic and biotic conditions, and various living organisms inhabit those zones. Classifications of ecological zones for limnic reservoirs (lakes, reservoirs and ponds) differ from author to author (Zernov, 1949; Ruthener, 1962; Poddubny, 1971, 1990; Odum, 1975; Timm, Timm, 1986; Batkanov, 1990 et al.) and, to some extent, they are even contradictory. Those classifications even differ for lakes and manmade reservoirs because some authors do not consider it acceptable to transfer the terms associated with lake classifications to manmade reservoir classifications. In our opinion, differences in the scale of the water body (sea, lake or manmade reservoir) does not exclude applications of the same terminology for describing the macrostructure of their ecological zones. It is primarily related to the terms “limnion” versus “pelagic zone” and “profoundal” versus “bathyal zone.” Such oppositions of the terms do not appear to be justified, nor is the claimed similarity of terms “littoral” and “sublittoral” in marine and fresh water hydrobiology justified. Therefore, we think that the terminology and, to some extent, classifications regarding marine systems and fresh water reservoirs of a limnic type, especially lakes and manmade reservoirs, do not have any significant differences and need to be unified. Since we are trying to perform a comparative analysis of fish distribution and migration in both lakes and manmade reservoirs, we have to make an attempt to unify the terms.

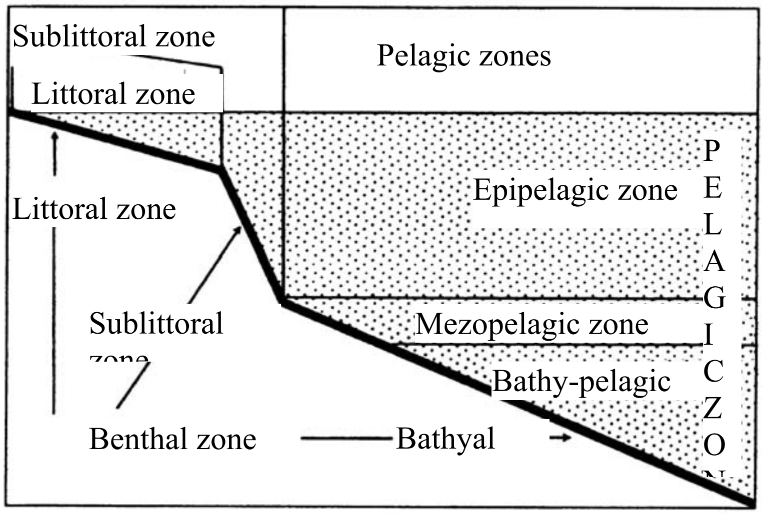

Figure 2.1 Ecological zones in reservoirs with slow water exchange

The bottom of the reservoir is associated with so called benthal zone (Fig. 2.1) that is divided into littoral, sublittoral (depth pile[1]) and bathyal (profundal) zones. The water mass, i.e., pelagic zone, is divided into: epipelagic zone (epilimnion), located above sublittoral and bathyal; mezo- (metalimnion) and bathy-pelagic zone (hypolimnion) located above the bathyal zone. Therefore, three major ecological zones of the reservoirs can be identified, i.e., littoral, epipelagic and bathy-pelagic, and two transition zones, i.e., sublittoral and mezopelagic zones.

Littoral zone is associated with shallow water near the shores where macrophytes, if available, reach the water surface. The littoral zone in the Russian reservoirs usually comprises the water depth of 1.5 – 3 meters. The prevailing currents there are tide cracks and shore longitudinal. As a rule, there are no transit or water intake currents present in this zone or these currents are very insignificant.

Epipelagic zone is the water mass located above the benthal zone from the surface down to the depth of the effective sunlight penetration (approximately 1% of the solar energy). The temperature in the epipelagic zone varies significantly from day to day and from season to season, and it is the area most exposed to winds, causing waves and water mass mixing. Usually, the epipelagic zones in the Russian reservoirs are 6 – 10 meters deep, and, in deeper reservoirs, they have no contact with either the bottom or the littoral vegetation.

Bathy-pelagic zone is the bottom and the water mass without sunlight penetration, photosynthesis, waves, and with insignificant seasonal temperature changes.

Sublittoral zone is located below the littoral zone down to the depth of the effective sunlight penetration. This is the zone where the epipelagic zone contacts the bottom of the reservoir. As the upper pelagic zone, it is exposed to winds and drastic seasonal temperature changes.

[1] Terms used by different authors are given in brackets.

Mesopelagic zone is a layer of rapid temperature drop with depth, located between the epi- and bathy-pelagic zones.

It is clear that the proposed terminology is practically identical to the terminology used in the marine hydrobiology. Since this terminology is widely used in publications on manmade reservoirs and large lakes, we feel comfortable about the selected approach.

2.2 Fish Distribution in Reservoirs

Fish downstream migration can only occur when the spatial structure of the fish distribution matches the structure of the water intake current. To estimate this match, the major patterns of fish distribution in the reservoirs with slow water exchange will have to be considered. There is a great number of publications on this issue. However, as a rule, they describe some specific reservoirs and only a few periods of development of young fish. Hardly any general species-specific patterns of the fish distribution for all the stages of their ontogenesis have ever been described in literature (Pavlov, Pakhorukov, 1983). Therefore, we have structured this section in the following way. It first describes data taken from the literature and the information obtained by the authors of this book on the distribution of young fish typical for most of the studied reservoirs (see Table 2-1.).

Table 2-1 Most frequent fish species in studied reservoirs

Species	S	I	O	V	K	U	A	M	N	Frequency of occurence, %
European smelt	+	+	+	+	-	-	-	-	-	44.4
Northern pike	+	+	+	+	-	+	+	+	-	77.8
Carp bream	+	+	+	+	+	-	-	+	-	66.7
Bleak	+	+	+	+	-	-	-	-	-	66.7
Silver bream	+	+	+	+	-	-	-	-	-	44.4
Roach	+	+	+	+	+	+	-	+	-	77.8
Rudd	+	+	-	+	-	-	+	+	-	55.6
Ruffe	+	+	+	+	-	-	+	+	-	66.7
European perch	+	+	+	+	+	+	-	+	-	77.8
Pikeperch	+	+	+	+	+	-	+	+	-	77.8

Note. See legend in Table 1-2

Then the described data are discussed in regards to their applicability for further analysis of the relationship between the fish distribution and the downstream fish migration. Further on, the data on the distribution of different ontogenetic stages of young fish are summarized, and a classification is provided for fish distribution in the ecological zones of reservoirs with slow water exchange.

Distribution of Various Fish Species in Lakes and Reservoirs

Pikeperch (*Stizostedion lucioperca*)

Spawning occurs in May – June at water temperatures of 7 - 20°C. Eggs are laid 0.5 – 20 meters deep in areas with a weak current on the plant roots, old grass, or rocky bottom (Syrovatsky, 1940; Konstantinov, 1949; Ambroz, 1956; Vladimirov et al., 1963; Bely, 1968; Kovalev, 1976; Kuznetsov, 1978, and other authors).

Prolarvae are 4.6 – 5.7 mm long, and they are sustained by a large "oil globule". They have a positive phototaxis, and, during the first four days, they tend to go up to the surface, making short-distance, vertical (so called "candle"-type) movements. The average speed of ascent to the surface is 5 cm/min. Reaching the water surface, they stay there, and the currents may take them around throughout the pelagic zone of the reservoirs (Bocharnikova, 1952; Kryzhanovsky et al., 1953; Vasnetsov, et al., 1957; Baburina, 1972). Their presence in the pelagic zone has been confirmed by our data on young fish distribution in the Sheksninskoe reservoir (Table 2-2).

Table 2-2 Frequency of various stages of fish species collected in epipelagic and bathy-pelagic zones of the Sheksninskoe Reservoir. For a given species, the number represents the % of individuals collected that were in that life stage (ref.: Pavlov et al., 1991).

Species	Eggs	Early larvae	Late larvae	Fry	Over 12 months
Smelt	0.0	4.2	95.2		0.6
Roach	0.0	74.5	25.2	0.2	0.1
Bleak	0.6	22.0	74.6		2.8
Carp bream	1.6	97.3	0.8	0.0	0.3
Silver bream	1.6	97.4	1.0	0.0	0.0
Rudd	0.5	98.8	0.7	0.0	0.0
Pikeperch	28.2	63.4	8.4		0.0
European perch	1.8	45.8	52.4		0.0
Ruffe	65.7	23.8	10.5	0.0	0.0

The *larvae* switch to external feeding when they are 6.2 – 8.2 mm long and, before the end of that ontogenetic phase, they feed on zooplankton (Konstantinov, 1957; Kuznetsov, 1970, 1975; Kovalev, 1965, 1976). They primarily inhabit the epipelagic zone of the open area of the reservoir. At that period, the number of pikeperch larvae in the littoral areas is decreasing. In the deep water areas, the larvae can be found from the surface down to 15 meters, although, for the most part, they are not likely to be found deeper than 5 – 6 meters down (Gorodnichij, 1962;

Kuznetsov, 1973; Konobeeva, 1983a; Gorin, 1985). After switching to external feeding, the pikeperch starts daily vertical movements. Various directions of these movements have been indicated for various reservoirs. In some reservoirs, the pikeperch larvae have primarily been observed near the surface in the daytime and closer to the bottom at night (Sheksninskoe, Ivan'kovskoe and Mostiste reservoirs); while, in other reservoirs, the situation is just the reverse, i.e., the larvae are located deeper in the daytime than at night (Al. Stambolijski reservoir). It can be assumed that, for the latter case, the pikeperch larvae follow their major feeding targets. With the growth and development of the larvae, the range of their daily vertical movements tends to expand (Bojtsov, 1980; Bojtsov et al., 1980; Pavlov et al., 1981, 1984, 1985a, 1988).

With the beginning of the *fry* stage (body length is 21 – 36 mm), when scales are being formed, the pikeperch feeds on young fish and larvae of chironomids. The pikeperch fry (larger than 36 mm) primarily feed on large necto-benthonic crustaceans and young fish. In that period (August), they descend to the bottom of the pelagic zone and can be found in the littoral zone (Bojtsov, 1980; Bojtsov et al., 1980; Pavlov et al., 1984, 1985a).

However, such distribution and behavior of the pikeperch fry can change with a lack of nutrition. For example, pikeperch has been observed to accumulate as loose conglomerations in the littoral area of the Al. Stambolijski reservoir. On accumulating, those conglomerations converted into dense mobile schools moving along the shore. They moved both in the daytime and at night. In a couple of weeks, the mobile schools would disintegrate and the fry would go to the pelagic zones of the reservoir. At that time, its concentration in the vicinity of the HPP water intake was significantly higher than away from it (Pavlov et al., 1988). Similar behavior has also been observed in other reservoirs (Syrovatsky, 1953; Potekhina, 1956; Gorodnichij, 1962, 1978; et al.).

At the age of *12 months and older*, the pikeperch becomes a solitary predator. In most of the reservoirs, two peaks of its productive activity have been observed, i.e., in the morning and in the twilight. In the fattening period, the pikeperch usually inhabits the area near the bottom. They mostly feed on young fish and mature small fish. The pikeperch hibernates in deep areas of the reservoir, i.e., flooded river beds and deep pools, etc.

European perch (*Perca fluviatilis*)

Spawning usually takes place at 7 – 15°C in the littoral zone, but it may also take place in the deep areas. Its adhesive eggs are laid on various substrates (Iyudina, 1951; Zakharova, 1955; Ginzburg, 1958; Popova, 1965; et al.).

As soon as the prolarvae are formed, they ascend to the water surface (Konstantinov, 1957). At the end of the prolarvae period, they can be seen throughout the reservoir (Kryzhanovsky et al, 1953). The range of their dispersal depends on the direction and force of the currents (Konobeeva er al, 1980; Konobeeva, 1983б). The concentration of prolarvae in the pelagic zone is lower than in the littoral zone, but the larvae are bigger in size in pelagic zone (Gorin, 1985).

The major location of the early larvae is the pelagic zone (see Table 2-2; Disler, 1960; Kuznetsov, 1970, 1975; Konobeeva, 1983б; Pavlov et al., 1981; et al.) It should be noted that their concentration in the open area of the reservoir is usually lower than that in the littoral zone. In the pelagic zone, the European perch early larvae perform daily vertical movements. Their direction varies from reservoir to reservoir. When the late larvae start forming, the European perch population can be divided into two ecological groups, littoral and pelagic. Some of the larvae (primarily, large specimens) can be found in the littoral zone, while others continue to inhabit the pelagic zone and move into deeper areas when they grow bigger (Disler, 1960; Kuznetsov, 1970; Bojtsov, 1980; Pavlov et al., 1980, 1984). The quantity of European perch in the pelagic versus littoral zone depends on the specific environmental conditions. For example, Rybinskoe reservoir has many more European perch juvenile fish in the pelagic zone than in the littoral zone, while the situation in Pletcheevo lake is just the reverse (Poddubny, 1998).

Reaching the *fry* period, the European perch population is no longer divided into location groups. By late summer – early fall, some of the fry appear to descend to deeper areas of the reservoir (Kuznetsov, 1970; Boldyrev, 1985; Coles, 1981).

At *12 months old and older*, there are two groups of the species, i.e., small and slow-growing, plankton-eating forms that become mature during the second – fourth year of their life, and large forms, acquiring the "carnivorous way of life", that get mature during the fifth – seventh year of their life (Poddubny, Malinin, 1988). Smaller individuals inhabit the epipelagic zone, while the predators inhabit the sublittoral zone and the adjacent bathy-pelagic zone.

Ruffe (*Gymnocephalus cernuus*)

Ruffe lay eggs away from the shore, by portions, on various substrates, with the water temperatures of 6 - 20°C (Pyatkova, 1962; Pisanko, 1969; Poddubny, 1971; Pikhu, Pikhu, 1974; Pavlov et al., 1988).

Prolarvae, after the quiet period of 2 –3 days, can be found in the pelagic zone (Table 2-2), resulting from their short-distance, vertical movements. During that time, wind and water intake currents can transfer them throughout the reservoir (Kryzhanovsky et al, 1953; Kovalev, 1975).

Upon switching to the external type of feeding, the *larvae* tend to stay closer to the bottom. They can hardly be found in the pelagic zone (see Table 2-2). The *fry* stay near the bottom all the time. They can be found in the bathyal, as well as in sublittoral and littoral zones (Mosiyash, 1980; Gorin, 1985). At later stages of life, ruffe continue living near the bottom.

Roach (*Rutilus rutilus*)

Roach start accumulating prior to spawning during the freeze-up period. Its spawning occurs at the water temperatures of 8 - 12°C. The roach is phytophilous, it spawns in the littoral zone, one meter deep, in the underwater grass. In manmade reservoirs, it sometimes spawns 6 - 8 meters deep (Zakharova, 1955; Lange, 1960; et al.).

Prolarvae (5.0 – 6.7 mm) attach themselves to the vegetation right after hatching, occasionally they get loose but then attach themselves to the vegetation again. During stage B, they finally separate from the vegetation and form large conglomerations in the littoral zone. In the daytime, the prolarvae are located right near the surface, while, at night, they go deeper.

The roach *larvae* (6.5 – 20 mm) primarily feed on zooplankton and form groups in the littoral zone, in the areas protected from the wind (Ponedelko, 1958a, б; Kozhina, 1966). Larger larvae tend to leave their shelters more often than the smaller ones (Kuznetsova, 1980). Since they tend to leave the shelter and they are not very good swimmers, certain currents can take some of the early fry to the epipelagic zone. In the pelagic zone, early larvae can be found near the surface, and at night some of them go deeper (Eloranta, Eloranta, 1980; Pavlov et al., 1984, 1985a, б). By the end of the larvae period, there are hardly any larvae left that migrate to the pelagic zone from the littoral zone (see Table 2-2). By the end of the larvae period and during the fry period, roach can primarily be found in the littoral zone (Kuznetsov, 1973; Pavlov et al., 1985a).

In the protected littoral zone, the *fry* perform horizontal daily migrations: they inhabit the littoral area in the daytime, and leave the littoral area at night (Kuznetsova, 1980; Pavlov et al., 1985a). In the end of summer and in the fall, roach start permanently leaving the littoral zone, inhabiting the deeper areas of the reservoirs (Bojtsov, 1980; Bojtsov et al., 1980; Boldyrev, 1985; Pavlov et al., 1984, 1985б).

At 12 months old and older, roach primarily feed on vegetation, detritus and benthos. Its "fattening" migrations are usually limited by the littoral and sublittoral zones where there are the optimal conditions for nutrition and protection from predators. After spawning, large molluscivorous individuals perform relatively long migrations and go into the open pools of the reservoirs. In the end of the "fattening" period (September – October), roach go closer to the shoreline and hibernate in the floodplain area.

Carp bream (*Abramis brama*)

Carp bream are phytophilous. They spawn at water temperatures of 12 - 20°C. Eggs are laid on the vegetation, usually one meter deep (littoral zone), but can also be laid 20 meters deep in the reservoirs (Bely, 1956, 1970; Vasnetsov et al., 1957).

Prolarvae (4.6 – 6.0 mm) attach themselves to the vegetation after hatching. At stage B, they set free and start inhabiting the littoral zone (Ginzburg, 1958; Ponedelko, 1958a).

Larvae (6 – 23 mm) primarily feed on the most numerous groups of zooplankton. In the littoral zone, in the vicinity of their hatching, they migrate for approximately 20 – 50 meters. In the daytime, they can be found in the 10 – 20 cm deep littoral shallow water areas, and, at night, they go closer to the bottom farther away from the shore. With the wind currents, some early larvae can be washed out from the littoral zone into the sublittoral zone and the epipelagic zone (see Table 2-2), and their nightly migration to the deeper areas make it even more probable (Ponedelko, 1985б; Poddubny, 1971; Ozinovskaya, 1973; Danilov, 1975). From the deep-water spawning areas, the carp bream larvae go up to the surface and can be transferred throughout the reservoir by the water intake and wind currents. In the pelagic zone of the reservoirs, they perform vertical daily movements, i.e., they stay near the surface in the daytime and descend to the deeper areas at night (Pavlov et al., 1984, 1985a, 1991a, б). With growth and development, a quantity of the carp bream larvae in the pelagic zone drastically decreases (Pavlov et al., 1984, 1985a).

Fry (20 – 23 mm) gradually switch over to feeding on benthonic organisms. Trying to find more food, they descend to the deeper areas of the reservoir. At that time, they can be found in the bottom layers of the bathy-pelagic zone (Bojtsov, 1980; Bojtsov et al., 1980; Boldyrev, 1985), above the muddy and sandy bottoms and, more seldom, above the muddy bottoms (Konobeeva, 1983б).

Temperature drop in October and November causes fish mass migration from the littoral and sublittoral zones into the open area of the reservoir where they settle for winter hibernation.

At *12 months and older*, carp bream primarily feed on benthos and inhabit the bottom of the reservoir. For fattening, bream go to the deep-water areas of the reservoirs, as well as to the littoral zone. There will be especially high fish density in the mud accumulation areas. Bream hibernate in the deep-water areas of the floodplain and in the river beds.

Bleak (*Alburnus alburnus*)

The bleak is phytophilous, and spawns and lays eggs at water temperatures of 15 – 16°C in the littoral zone with a weak current.

Prolarvae attach themselves to the plants or hide there. In the end of the prolarvae period, when their swim bladders fill up, the photoreaction changes from negative to positive and the juveniles go up to the water surface (Kryzhanovsky, 1958; Koblitskaya, 1958).

Early *larvae* keep schools in the currents in the littoral and sublittoral zones, showing rheotaxis. Since they are poor swimmers, they are dragged to the pelagic zone by the wind and water intake currents (see Table 2-2). Most publications indicate that bleak can be primarily found in the upper levels of the pelagic zones in the daytime, while at night some can also be found in the deeper areas (Pushkina, 1980; Lesnikova, Kharitonova, 1979; Pavlov et al., 1984; 1985a).

Fry have well-defined horizontal migrations, i.e., at night they leave the closed littoral areas and go to the areas with poor vegetation or into the sublittoral zone. From mid-summer or the fall, more bleak species come to the deep-water area of some reservoirs. However, there have been some indications that, even in the fall, bleak are not likely to be found outside the sublittoral zone (Ponedelko, 1985б; Pavlov et al., 1984; 1985a; and other authors).

Silver bream (*Blicca bjoerkna*)

Silver bream is a typical representative of phytophilous species. It spawns and lays eggs at water temperatures of 16 - 17°C in the shallow littoral water, but it also spawns down to 10 meters deep.

Prolarvae attach themselves to the plants and get released in the end of the prolarvae period. When they get loose, they may be taken to the pelagic zone by the currents where they stay close to the surface (Kryzhanovsky, 1948; Delitsin, 1971; Dorozhkina, 1972; Bratsenok, 1974).

Larvae primarily inhabit the littoral zone. When they switch to the external feeding, they become more mobile. In the daytime, they tend to leave the vegetation areas, which may cause them to be washed away from the littoral to the pelagic zone (Pavlov et al., 1984, 1985a, б; 1991б, see Table 2-2).

The major habitat for the *fry*, as well as for specimens of the previous age groups, is the littoral zone. There are usually very few bleak species beyond the littoral zone, but there may be more by the end of summer and early fall (Bojtsov et al., 1980; Pavlov et al., 1984, 1985a, б, 1991a).

Rudd (*Scardinius erythrophthalmus*)

The rudd is phytophilous, and it spawns and lays eggs in the littoral zone with water temperatures of 19 – 23°C (Kryzhanovsky, 1948; Koblitskaya, 1958). The juvenile species can be found in the littoral zone all summer. Sometimes their larvae (stages B – C_1) can be found in the vicinity of large water intakes (Bojtsov et al., 1980; Pavlov et al., 1991a, see Table 2-2). Adult fishes are primarily phytophagous and they avoid areas with strong currents.

European smelt (*Osmerus eperlanus eperlanus*)

European smelt spawns at water temperatures of 4 - 9°C but it lays eggs on the solid sand and rocky bottom in the littoral areas of the lakes and reservoirs, or in their tributaries (Domrachev, Pravdin, 1926; Lapin, 1955).

Prolarvae can be found in the water, continuously moving up and down. When they reach the water surface, they stay put for a while and then slowly go down. They move more intensely in the daytime than at night. Due to this mode of behavior, they are easily taken throughout the entire reservoir by the currents. Their distribution depends on the existing currents (Petrov, 1940; Ivanova, Polovkova, 1972; Polovkova, Permitin, 1981; Ivanova, 1982).

Early *larvae* can be found not only in the pelagic zone, but also on the sand bars. Late larvae can mostly be found in the open part of the reservoir, i.e., in the pelagic zone (see Table 2-2). During summer, young species can be transferred by the currents, but they hardly ever leave the deep-water areas. Their daily vertical movements can go in various directions. It has been observed that, in the beginning of summer, the European smelt stay in the deep water mass in the morning, ascend to the water surface in the evening and scatter all over the water mass at night (Chumaevskaya-Svetovidova, 1945; Ivanova et al., 1970a, б). The European smelt early larvae have been found deeper in the daytime than at night in the dam pool of the Sheksninskoe reservoir (Pavlov et al., 1991a).

The *fry* continue to stay in the pelagic zone. Their major conglomerations can be found in the deep-water areas of the reservoirs, i.e., in river beds, manmade reservoirs and central parts of the lakes. Upon further growth and development, they descend deeper and deeper (Lapin, 1955; Ivanova et al., 1970a, б; Polovkova, 1970; Permitin et al., 1971).

At *12 months old and older*, European smelt inhabit the pelagic zone of the reservoirs, feeding on zooplankton.

Northern pike (*Esox lucius*)

The Northern pike is a typical phytophilous species. Its spawning occurs at water temperatures of 5 - 10°C in the littoral zone, usually 10 - 20 cm deep (Kryzhanovsky, 1949; Ponedelko, 1958a, б).

Prolarvae attach themselves to the vegetation. After they become active swimmers, they stay in the littoral vegetation. They become carnivorous 1–2 months later (Ponedelko, 1958 a, б). The Northern pike stays in the littoral zone for practically its entire life. The adult Northern pike can very seldom be found in the pelagic zone (Poddubny, Malinin, 1988).

The literature is known to have a lot of data on fish distribution. Unfortunately, the data have been collected by different methods and in different modes. The following tools have been used for collecting the data: trawling of various designs and sweep nets for the pelagic zone, and sweep nets and tuck nets for the littoral zone. The catching results are mostly given in the following units: specimens (caught for the sweep nets and tuck nets) and specimens per minute (for trawling). There are few data on the fish density (no./m^2) and even fewer data on the fish concentration (no./m^3). More often than not, the studies on fish distribution in the pelagic zone do not contain data on its presence in the littoral zone and vice versa. For collecting the information, one to two surveys have been conducted during the season or a few samples per day, but all this has been done within a short period of ontogenesis. Undoubtedly, a wide range of the applied methods has been justified by various goals of the studies because each goal requires a specific method and means for catching fish. On the whole, from the standpoint of fish distribution patterns, this information is mostly of qualitative character.

In this book, the data on the fish distribution are applied to estimate overlapping between the spatial structure of fish distribution and the water intake area. To obtain such an estimate, not only qualitative, but also quantitative data on fish distribution are required. The information presented is available for some fish species only. These are the species that mostly inhabit one of the ecological zones. For example, Northern pike and rudd inhabit the littoral zone, European smelt and pikeperch inhabit the pelagic zone, and ruffe inhabit the bathyal zone. However, roach, carp bream, silver bream, and European perch, as well as some other fish species, can be found in various ecological zones. To study these species, more detailed information, especially qualitative data on their distribution, will be required. Their downstream migration can mostly be observed during the first year of life in summer and fall. Our many years' experience shows that, to detect all significant changes in the concentration of the fish migrants, observations need to be conducted every 5 – 10 days. Consequently, to reach the goals identified for this book, adequate data on the fish distribution will have to be obtained. Since we have not found the required information on the fish distribution in any of the available publications, in 1992 we performed special studies on the fish distribution in the ecological zones of the reservoir.

Fish Distribution in Ecological Zones of the Reservoir as Influenced by Ontogenesis

The studies have been performed in Ivan'kovskoe reservoir in the mouth of the Soz' river. The selected test site included three typical areas: open water area, a bay with water circulation formed by flooding the Soz' river bed, and a bay without water circulation. The test site in the bay with circulation was 2 km long, 100 – 3000 meters wide and up to 10 meters deep. The current velocity there did not exceed 10 cm/s. The bay without circulation was 300 meters long, and it was a bay of the second order connected to the bay with circulation. It was 15 – 40 meters wide and up to 4 meters deep. The ecological zones have been identified for all the areas of the test site: littoral zone (up to 2 meters deep), sublittoral zone (2 – 3 meters deep), and the pelagic zone (3 – 17 meters deep) (Fig. 2.2).

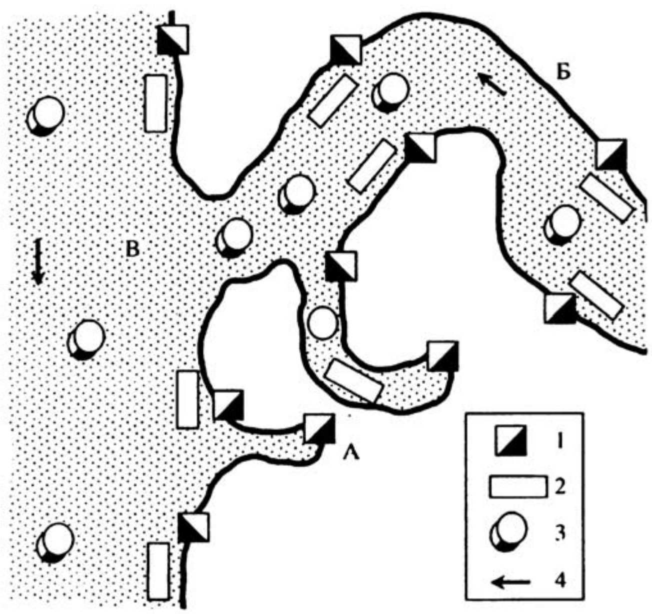

Figure 2.2 Schematic of experimental test site in Ivan'kovskoe reservoir

А – bay without water circulation; Б – bay with water circulation; В - open water area of the reservoir; fishing locations in littoral (1), sublittoral (2) and pelagic (3) zones; 4 – direction of current

The most frequently found species in the test site area were as follows: bleak (8,011 specimens have been caught), roach (6,714 specimens), silver bream (1,495 specimens), pikeperch (1,282 specimens), rudd (980 specimens), and common perch (301 specimens). There were very few Northern pikes and ruffes.

Pikeperch have not been found in the littoral zone; the young pikeperch have only been caught in the pelagic and sublittoral zones (Fig. 2.3), A). Practically, their concentrations have always been higher in the pelagic zone than in the sublittoral zone. The distribution of pikeperch juveniles in the test site areas changed in the ontogenesis process. In June, the pikeperch larvae were caught in the bay with water circulation and in the open water area of the reservoir. In July and early August, they were caught in the bay with water circulation only, and, starting mid-August, in the open water area of the reservoir. No juvenile pikeperch have ever been caught in the bay without water circulation.

European perch have been found in all ecological zones of the reservoir. They have been caught more often and in higher concentrations in the littoral zone (Fig. 2.3, E). However, two periods have been indicated for the mass presence of European perch in the pelagic zone: the first period was from June 10 to July 10, and the second period was from August 15 to September 5. At the same time, its quantity in the littoral zone during these periods was significantly lower, resulting from migration of the European perch juveniles to the pelagic zone. From June through the beginning of September, European perch were found in all the areas of the test site. At the end of September, European perch were primarily found in the bay with water circulation.

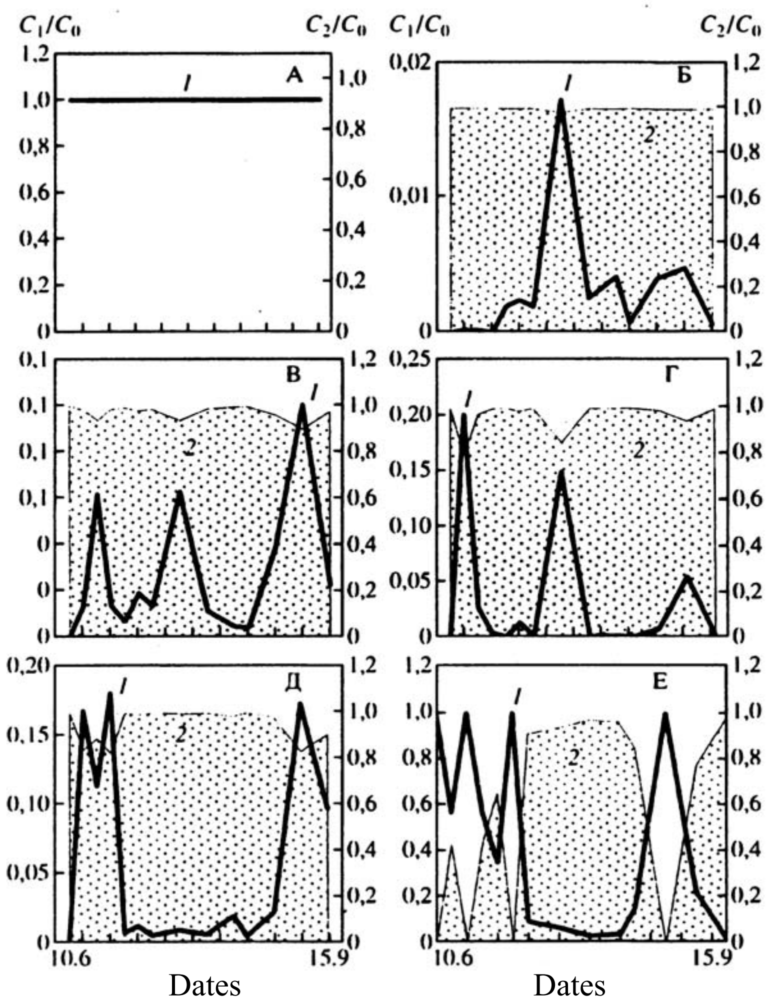

Figure 2.3 Dynamics of distribution of young fishes in ecological zones of the Ivan'kovskoe reservoir in 1992.

А – Pikeperch; Б – Roach; В –Carp bream; Г – Silver bream; Д – Bleak; Е – European perch; C_1 – average concentration in sublittoral and pelagic zones (1), C_2 – average concentration of the given species in littoral zones, c_o - average daily concentrations of the given species in all ecological zones.

The young *roach* concentration in the littoral zone has always been higher than in other ecological zones (Fig. 2.3, Б). Since July, roach were always caught in the sublittoral zone, but always in small quantities. Some increase in the roach concentration in the pelagic zone was observed on July 20, and in the period of August 26 - September 5. During those periods, the roach concentration in the pelagic zone was higher than in the sublittoral zone. In June, the roach larvae were primarily found in the bay without water circulation. The roach fry were mostly found in the bay with water circulation after the beginning of July, and, at the end of July they were found in the littoral zone of the open area of the reservoir. From the end of August to mid-September, the maximum roach concentration was observed in the open area of the reservoir. In late September, over 90% of the entire young population of roach were caught in the bays with circulation. The largest specimens (over 45 mm) were observed at depths of 9 – 11 meters in the open water area of the reservoir.

Bleak have been found in practically all ecological zones of the test site. Its concentration in the littoral zone has always been higher than in the pelagic and sublittoral zones (Fig. 2.3, Д). It should be noted that two periods of high concentration of the young bleak in the sublittoral and pelagic zones have been observed: June and late August through September. From June to mid-July, bleak were observed in all the areas of the test sites. The fry have mostly been found in the bays, with their concentrations in the open water area of the reservoir drastically decreasing.

The concentration of juvenile *carp bream* in the littoral zone was higher than in other ecological zones by one or two orders of magnitude (Fig. 2.3, В). Some increase in the carp bream quantity in the sublittoral and pelagic zone has been observed three times, i.e., June 15, July 20 and from the third decade of August through mid-September. It should be noted that in August – September the largest juveniles left the littoral zone. For example, on August 26 and on September 5, the carp bream specimens of up to 45 mm long were found in the littoral zone, while the specimens from 47 to 60 mm long were found in the pelagic and sublittoral zones (differences are valid at a probability of error, $P< 0.05$). In June, the carp bream fry were found in all the areas of the test site. In July, they were primarily found in the bay with water circulation, and, from late July through late August, they were again found in all the areas of the test site. In September, the major locations for the carp bream were the bay with circulation and the open area of the reservoir.

The concentration of young *silver bream*, as well as other Cyprinidae species, was always an order of magnitude higher in the littoral zone (Fig. 2.3, Г). Three periods of increasing concentration have been observed for silver bream in the sublittoral and pelagic zones: June 15, July 20 and September 5. Until September, the juvenile fishes inhabited all the areas of the test site with the maximum concentration in the first week of August in the bay without circulation. In September, its highest concentration was observed in the bay with circulation.

Rudd have practically been found only in the littoral zones of the bays.

Table 2-3 Period of locations of juvenile fishes in sublittoral and pelagic zones of the Ivan'kovskoe reservoir

Species	Stage or length, mm	Beginning		End	
		Ten-day period of month	Month	Ten-day perioid of month	Month
Pikeperch	10 - 65	1	VI	3	VIII
European perch	12 – 27	1	VI	1	VII
	> 60	2	VIII	1	IX
Bream	$C_1 – D_1$	2	VI	3	VI
	F and > F	2	VII	3	VII
	> F	2	VIII	3	IX
Roach	> F	2	VI	3	VI
	> F	3	VIII	1	IX
Silver bream	$C_1 – D_1$	2	VI	3	VI
	C_2 - E	2	VII	2	VII
	> F	1	IX	1	IX

Note. > F means fry older than Stage F.

Qualitatively, the data obtained for the studied fish species do not contradict the data found in the available literature. Quantitatively, these data give much more specific details. The descriptions provided make it possible to draw a conclusion that some of the fish species migrate to the pelagic zones of the reservoir; we have been able to give quantitative estimation of these migrations as well (Table 2-3). The interpretation of the existing and obtained data shows that many fish species have similar features of their distribution in the ecological zones, thereby making it possible to develop a classification of fish species, depending on their distribution.

Classification of Distribution of Young Fishes in Ecological Zones

For the classification of the distribution of the juvenile fishes in ecological zones of the reservoirs, we have not taken into account the location of immobile eggs and prolarvae attached to the substrates. Neither did we take into account the presence of the species in some ecological zones during migration of the juvenile fishes from the spawning locations.

Our results and the literature data have indicated that five types of fish distribution in the ecological zones can be identified that will comprise the following two groups: monozonal and polyzonal. The monozonal group represents three types of fish distribution. Those types include species whose juveniles mostly inhabit a single zone, either the littoral zone, or the pelagic zone, or the benthal zone. The polyzonal group includes two subgroups, i.e., permanent (species can be permanently found in all ecological zones), or temporary (species temporarily leave their permanent habitat for other ecological zones).

First Type of Distribution – Monozonal Pelagic Distribution

This type consists of pikeperch, European smelt, sprat, Caspian anadromous shad, peled, vendace, and ziege. Those species spawn in various ecological zones. The pikeperch lays eggs 0.5 – 20 meters deep, i.e., in the littoral and bathyal zones. European smelt, vendace and peled lay eggs on the solid bottom in the littoral zone (Domrachev, Pravdin, 1926). Sprat, Caspian anadromous shad, and ziege prefer the pelagic zone and, consequently, they mostly spawn in the pelagic zones of the bays or in the upper parts of the reservoirs.

The prolarvae of all those species inhabit the pelagic zones, primarily closer to the water surface, and a few days after their hatching, they tend to go deeper. Their concentration in the bays is usually higher than in the channel-type areas of the reservoirs (Ponedelko, 1958a, б; Kryzhanovsky, 1948, 1956; Kryzhanovsky et al., 1953; Poddubny, 1958). Some larvae, but very few, can be temporarily sustained in the littoral zone for a short period of time.

The larvae are not found in the littoral zone. They start daily vertical movements in the pelagic zone, and the direction of those movements will depend on the fish species, specific reservoir and the time of observations. Upon growth and development, the larvae go to the deeper areas of the pelagic zones, thereby increasing the amplitude of their vertical migrations.

The fry of those species continue residing in the pelagic zone of the reservoirs. Pikeperch stay closer to the bottom, while ziege stay closer to the surface. European smelt, peled and Caspian anadromous shad inhabit both epipelagic and bathy-pelagic zones. Their highest concentrations can be observed in lake areas and in the bays of the reservoirs. At the end of summer, some pike perch fry have been found in the sublittoral zone of some reservoirs.

On the whole, the fishes with the pelagic type of distribution inhabit the pelagic zone even during the larval stage (sublittoral, epi-, mezo- and bathy-pelagic zones). Only very few of them can be found in the littoral zone. By the end of summer and in the fall, their maximum concentrations have been observed in the pelagic zones of the bays and lake-type parts of the reservoirs.

Second Type of Distribution – Monozonal Littoral Distribution

Such species as Northern pike, rudd, tench, Crucian carp, and ide belong to this type. These species are phytophilous and they spawn in the littoral zone. Their eggs and prolarvae attach themselves to the substrate (Kryzhanovsky, 1948), and they can be found in the pelagic zone only occasionally, i.e., if, for example, the eggs or prolarvae get accidentally disconnected from the substrate. When the larvae become active, some of them, for example the rudd larvae, can be found in the pelagic zone, but only for a short time and only few of the larvae. They can be found near the water surface there. From stage C_2, these fish species can only be found in the littoral zone where they prefer to inhabit the closed areas. Only very few specimens can still be found in the pelagic zone.

On the whole, the species with the littoral type of distribution tend to stay in the littoral zone for the entire vegetation period. Only when they become active swimmers can they be found in the pelagic zone, but for short periods of time.

Third Type of Distribution – Monozonal Benthal Distribution

Such species as ruffe, sterlet, burbot and Wels catfish belong to this type. They spawn under different conditions. Ruffe lay eggs relatively far away from the shore, by portions, on various substrates. Burbot and sterlet are lithophilous and European catfish are phytophilous (Kryzhanovsky, 1949; Pavlov et al., 1981; Pavlov et al., 1988; Poddubny, 1971).

The prolarvae can be found in the pelagic zone either right after hatching (burbot and sterlet) or two – three days after the "quiet" period (ruffe). It results from their "candle"-type vertical movements or temporary upward migrations. During that period, they can be transferred throughout the entire reservoir by the wind and water intake currents. The Wels catfish differ from three other species because its prolarvae have a well-defined negative photoreaction and they stay near the bottom in sheltered areas (Kryzhanovsky, 1949; Kryzhanovsky et al., 1953; Kovalev, 1975; Pavlov et al., 1981).

Switching to external feeding, the migrations from the bottom become shorter both in time and distance. The species with this type of distribution cannot be as frequently found in the pelagic zone as before because they stay near the bottom. They inhabit various areas of the reservoir, i.e., sterlet prefer the bathyal zone, while the other species of this type stay in the sublittoral and even in the littoral zone (Soin, 1947; Alyvdina, 1951; Kurilov, 1951; Petkevich, 1952; Volodin, Ivanova, 1968; Polyaninova, Khodorevskaya, 1976).

The fry stay near the bottom. Upon growth and development, they tend to go to the benthal zone of the reservoir. They can hardly ever be found in the pelagic zone at that time.

On the whole, the fish with the benthal type of distribution can be found near the bottom of the reservoirs, apart from the very early prolarvae and larvae stages of development. Wels catfish can hardly ever be found in the pelagic zone, while ruffe and sterlet can always be found there for a short time in the early juvenile period.

Fourth Type of Distribution – Polyzonal Permanent Distribution

The literature data make it possible to determine which species belong to the polyzonal group. However, only detailed quantitative studies allow us to determine the specific types of this group. Therefore, only the studies performed in the Ivan'kovskoe reservoir have helped us identify the representatives of the IVth and Vth types.

European perch and bleak belong to the IVth type. They usually spawn near the shore and their eggs get attached to the substrates.

Right after hatching, the European perch prolarvae ascend to the water surface from where they can be transferred throughout the reservoir by the currents. The bleak larvae can get attached to the vegetation and hide there. At the end of the prolarvae period, the fry go up to the water surface. The range of habitat of these species depends on the direction and force of the currents. By the end of the prolarvae period, European perch are already transferred throughout the entire reservoir. The density of prolarvae is lower in the pelagic zone than in the littoral zone, but the fish are larger in the pelagic zone.

During the larval period, bleak can mainly be found in the littoral zone, in schools in the currents. Because they are poor swimmers, the water intake and wind currents move some of them to the pelagic zone. The pelagic zone is the major habitat for European perch larvae. In the pelagic zone, the early larvae of European perch and bleak perform daily vertical movements. Their directions may vary from reservoir to reservoir.

Upon growth and development of the larvae, the European perch population can be divided into two ecological groups, i.e., littoral and pelagic. Some of the larvae (primarily, the largest specimens) can be found in the littoral zone, while the remainder stay in the pelagic zone, going deeper and deeper upon growth.

The fry of these species mostly inhabit the littoral zone. At the same time, both European perch and bleak can always be found throughout the pelagic zone. In late summer – early fall, some juvenile species leave the littoral area for the deeper areas of the reservoir.

On the whole, the species with a permanent polyzonal distribution type can be found in all ecological zones of the reservoirs after they become active swimmers. Some species, e.g., European perch, can be divided into groups, depending on the major zone of the habitat. However, even for this type of distribution, some species that inhabit the littoral zone occasionally migrate to the pelagic zone.

Table 2-4 Distribution of young fish in ecological zones of manmade water reservoirs and lakes

<table>
<tr><th>Type of distribution</th><th>Species</th><th>Eggs</th><th>Prolarvae</th><th>Early larvae</th><th>Late larvae</th><th>Young fishes</th></tr>
<tr><td rowspan="7">I</td><td>Peled</td><td rowspan="3">Littoral zone</td><td rowspan="7" colspan="3">Pelagic zones</td><td rowspan="6">Pelagic zone</td></tr>
<tr><td>Sardine cisco</td></tr>
<tr><td>European smelt</td></tr>
<tr><td>Caspian anadromous shad</td><td rowspan="3">Pelagic zone</td></tr>
<tr><td>Sprat</td></tr>
<tr><td>Ziege</td></tr>
<tr><td>Pikeperch</td><td>Sublittoral, bathyal, and littoral zones</td><td>Bathy-pelagic zone</td></tr>
<tr><td rowspan="5">II</td><td>Northern pike</td><td rowspan="5" colspan="2">Littoral zone</td><td rowspan="3">Littoral zone</td><td rowspan="5" colspan="2">Littoral zone</td></tr>
<tr><td>Tench</td></tr>
<tr><td>Crucian carp</td></tr>
<tr><td>Ide</td><td rowspan="2">Littoral zone, some species go to the pelagic zone for a short period of time</td></tr>
<tr><td>Rudd</td></tr>
<tr><td rowspan="4">III</td><td>Wels catfish</td><td>Littoral zone</td><td>Benthal zone</td><td rowspan="2">Bathyal zone</td><td rowspan="2">Bathyal zone</td><td rowspan="2">Bathyal zone</td></tr>
<tr><td>Sterlet</td><td rowspan="2">Littoral zone</td><td rowspan="3">Benthal zone, perform “candle”-type migrations</td></tr>
<tr><td>Burbot</td><td rowspan="2">Benthal zone and some in the pelagic zone</td><td rowspan="2">Benthal zone</td><td rowspan="2">Benthal zone</td></tr>
<tr><td>Ruffe</td><td>Sublittoral zone</td></tr>
<tr><td rowspan="2">IV</td><td>Bleak</td><td rowspan="2">Littoral zone</td><td>Littoral zone</td><td colspan="3">All zones, except benthal zone</td></tr>
<tr><td>Perch</td><td>All zones, except benthal zone</td><td colspan="2">All zones, except benthal zone</td><td>All zones</td></tr>
<tr><td rowspan="3">V</td><td>Silver bream</td><td rowspan="3">Littoral zone</td><td rowspan="3">Littoral zone</td><td rowspan="2" colspan="2">Littoral zone and goes to pelagic zone</td><td rowspan="3">Littoral zone and goes to pelagic zone</td></tr>
<tr><td>Carp bream</td></tr>
<tr><td>Roach</td><td colspan="2">Littoral zone</td></tr>
</table>

Fifth Type of Distribution – Polyzonal Temporary Distribution

Such species as carp bream, roach and silver bream belong to this type. According to our observations, these species perform temporary migrations from the littoral zone to the pelagic zone. They spawn in the littoral zone and lay eggs in the underwater vegetation; their eggs and the prolarvae are sticky and, therefore, attach themselves to the vegetation.

The larvae feed on zooplankton, and they can be found in conglomerations located in the areas protected from the winds. Larger larvae tend to leave the shelters more often than smaller ones and, with the appropriate wind directions and water intake currents, they may migrate to the pelagic zone. In the pelagic zone, the larvae stay near the water surface in the daytime, and at night some of them go deeper.

The roach fry remain in the littoral zone, while the fry of silver bream and carp bream also inhabit the sublittoral zone. In mid-summer and early fall, the fry leave the littoral zone and start migrating along the shoreline. These migrations correspond to the presence of the fish in the pelagic zone. The older the fish becomes, the deeper it can be found.

On the whole, the fish with this distribution type mainly inhabit the littoral zone of the reservoirs during the first 12 months of their life. In summer and fall, some of those species tend to migrate to the pelagic zone of the reservoirs. While they can be found in the pelagic zone, their migrations between various areas of the reservoir may also occur.

The information obtained shows the location of the studied fish species in various ecological zones during various stages of their development. This information is summarized in Table 2-4 that provides a detailed presentation of the juvenile fish distribution in the reservoirs. Additional input to the classification may be acquired with further studies of other fish species that have not been mentioned in the table.

2.3 Procedure for Estimating the Ecological Zones of Water Intake

As has been mentioned before, one of the crucial conditions that makes fish downstream migration possible is the presence of the water intake in the area. The fish distribution is also closely connected with the ecological zones of the reservoir. Consequently, downstream migration will depend on how much the ecological zones overlap with the water intake zones. It is especially important for the reservoirs with a slow water exchange (Pavlov et al., 1991a). Depending on how the water intake affects various ecological zones, the fish distribution structure will match the water intake structure or differ from it.

For example, if the water intake is located in the bathy-pelagic zone, drifting of pike perch late larvae and fry will occur through the water intake, and, if the water intake is located in the surface (epi-pelagic) zone, early Cyprinidae larvae will drift through the water intake (Pavlov et al., 1991a).

At many HPPs, the water is taken from several ecological zones, thereby affecting these zones in different ways. It is only natural that if the water intake current affects the epi-pelagic zone more than the littoral zone, the migration of the fish from the epipelagic zone will be more intense than that from the littoral zone.

To provide quantitative estimation of the influence of the water intake on the ecological zones of the reservoir, we have introduced the term "ecological zone of water intake" (EZWI). The degree of influence of water intake (P_i) on the i^{th}-ecological zone of the reservoir can be expressed in a mathematical equation as the water volume W_i taken from the i^{th}-ecological zone as part of the total water intake W_c during a certain period of time, or:

$$P_i = W_i/W_c \qquad (2.1)$$

It is obvious that we need to have data on the sizes of the ecological zones and the water intake zone. The borderlines of the ecological zones can be determined from the bottom contours of the reservoir and the depth values of the reservoir (see Section 2.1). The length and the width of the ecological zones can be estimated for each specific area, taking into account its morphological characteristics.

It is more difficult to estimate the size of the water intake zone because it usually has a more complicated geometry. Therefore, we have made an assumption that the borders of the water intake zone are rectilinear and its volume is that of a truncated pyramid, thereby converting it from the three-dimensional to one-dimensional space. For these conditions, the equation (2.1) will be as follows:

$$P_i = S_i/S_c, \qquad (2.2)$$

Where: S_i is the area of the horizontal projection of the figure formed by intersection of the water intake zone and the ecological zone of the reservoir; S_c is the area of the horizontal projection of the water intake zone.

Quantitatively, the characteristics of the ecological zone of water intake will include five values that will describe the influence of the water intake zone on the littoral (P_l), sublittoral (P_s), epi-pelagic (P_e), bathy-pelagic (P_b) and bathyal (P_d) zones of the reservoir.

The assumption on the rectilinear borderlines of the water intake zone makes it possible to determine the size of the water intake zone. Taking into account the equation on the flow continuity:

$$Q = V \cdot F, \qquad (2.3)$$

and, with the known values of the water flow rate Q through the HPP water intake, and the average current velocity value in the water intake flow, we can find the F value for the area of the cross section of the water intake zone located at the X distance from the gatewell. However, the current velocity along the axis of the flow and along the breadth of the water intake front does not change linearly, thereby making the calculations more difficult. Our studies on the Ivan'kovskoe reservoir have made it possible to identify the patterns in changes of the current velocities along the axis of the water intake flow. Taking into account these patterns, we have measured the angle of the water intake pyramid planes, with which there is no significant difference between the actual and the calculated values. This angle is: A = 26°.

Table 2-5 Comparison of actual values (V_f) and calculated values (V_r) for the average current velocity in the Ivan'kovskya HPP water intake influence zone

Distance from gatewell, m	V_f, m/s	V_r, m/s
10	0.39	0.42
20	0.31	0.26
30	0.21	0.18
40	0.16	0.15
50	0.12	0.13
60	0.10	0.11
70	0.09	0.10

Taking into account the correlation between the actual and the calculated values and the fact that the farther we go from the gatewell, the more equalized the current velocities will be in the horizontal cross section of the water intake flow, the area of the horizontal cross section (F) could be roughly calculated by the following equation:

$$F = (3b \cdot L \cdot tgA \cdot \cos 45) \cdot (2h \cdot L \cdot tgA \cdot \cos 45°) - f,$$

or:

$$F = 4b \cdot h(L \cdot tgA \cdot \cos 45°)^2 - f, \quad (2.4)$$

where b and h are breadth and height of the gatewell; f is the area of the cross section of the water intake beyond the water media; A – the recommended pyramid angle (assumed 26°).

This equation is based on the law on the pyramidal constriction of the flow down to the water intake cross section area (Fig. 2.4).

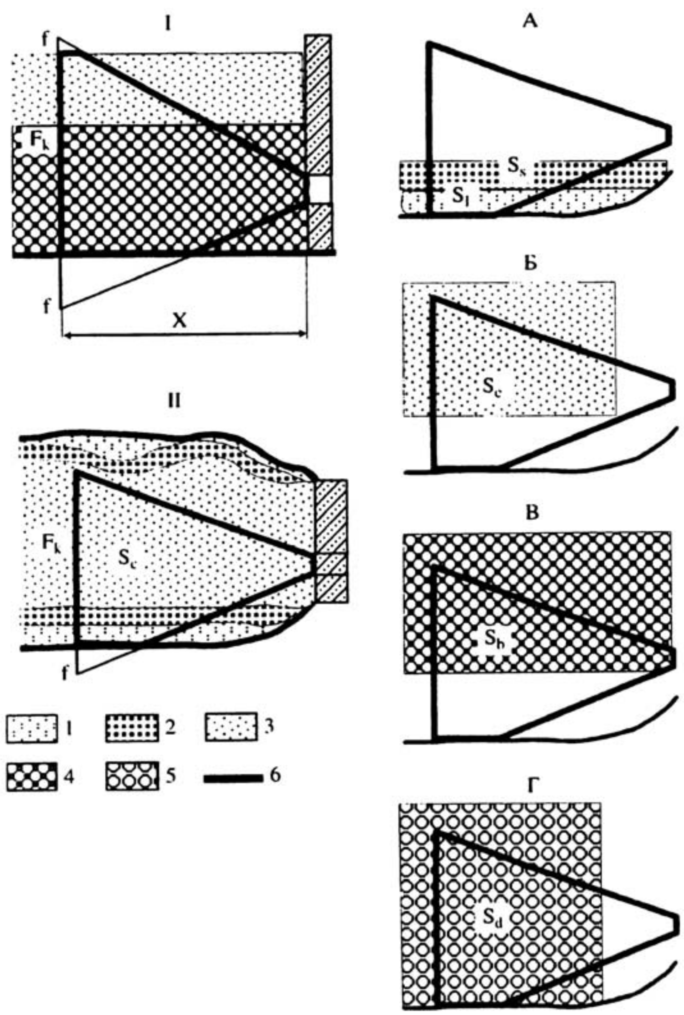

Figure 2.4 Water intake flow affecting the ecological zones of the reservoir

I – cross section; II – planar view; water intake current affecting: A – littoral (1) and sublittoral (2) ecological zones; Б – epi-pelagic zone (3), В – bathy-pelagic zone (4); Г – bathyal zone (5); 6 – border of the area of the water intake influence. See other symbols in the text.

With equations (2.3) and (2.4), the water intake area length X can easily be calculated. In order to do that, we need to assume that V equals the average current velocity in the reservoir; while the F_k value of the water intake area cross section in the final section needs to be calculated using equation (2.3). Further on, if we set the right part of equation (2.4) equal to the F_k value, we'll find the X_k value.

To determine the quantitative characteristics of the ecological zones of the water intake, the borders of the water intake zone need to be found. Then, by calculations or using the plotting board of the HPP dam area where the ecological zones are shown, the area S_i and the parameters P_i can be found.

2.4 Estimation of Ecological Zones of Water Intake Based on Studied HPP Intakes

To estimate the ecological zones of the water intake, their parameters have been found as described in Section 2.3. For those calculations, the average velocity of current in the reservoir has been calculated in relationship to its average cross section (F_s) in the equation:

$$V_S = \frac{Q}{F_s} = \frac{Q}{B_s \cdot H_S}, \qquad (2.5)$$

where: Q is the water intake flow rate; and B_s and H_s are the average breadth and depth of the reservoir.

The data on the current velocities in the gatewell V_o, average current velocity in the reservoir V_s, and length of the water intake area (water intake influence area) X_k are given in Table 2-6 for the average flow rates of the studied HPPs. These data have made it possible to estimate the borders of the water intake influence areas and the qualitative characteristics of the ecological zones of the water intake for the studied HPPS, taking into account the morphological parameters of their dams (Table 2-7). It should be noted that Table 2-7 displays the HPPs in order from a stronger to a weaker influence of the water intake currents on the ecological zones. The total water intake influence for the five zones can be interpreted as its approximate average value.

Table 2-6 Hydraulic characteristics of the water intake area and water intake length

HPP	Water flow rate, m^3/sec	Velocity of current, cm/sec		Length of water intake area influence (X_k), m
		Water intake (V_o)	Average in the reservoir (V_s)	
Sheksninskaya	343	143	3.0	670
Ivan'kovskaya	135	84	1.0	1,050
Ozerninskaya	20	125	0.4	390
Volzhskaya	1,500	12	2.1	2,490
Ust'-Khantajskaya	500	36	0.1	3,200
Kapchagajskaya	525	23	0.3	3,180
Mostiste	1.5	150	0.5	35
Al. Stambolijski	10	98	0.2	350
Nurekskaya	465	58	0.1	3,200

Table 2-7 HPP ecological zones of water intake

HPP	Degree of influence of water intake current to ecological zones					
	Littoral, P_l	Sublittoral, P_s	Epi-pelagic, P_e	Bathy-pelagic, P_b	Bathyal, P_d	Total, Σ_p
Sheksninskaya	0.00	0.500	0.97	1.00	0.99	3.46
Ivan'kovskaya	0.00	0.400	0.97	1.00	0.99	3.36
Ozerninskaya	0.00	0.390	0.66	1.00	1.00	3.05
Volzhskaya	0.00	0.012	1.00	1.00	1.00	3.01
Kapchagajskaya	0.00	0.011	1.00	1.00	1.00	3.01
Ust'-Khantajskaya	0.00	0.010	1.00	1.00	0.86	2.96
Al. Stambolijski	0.00	0.00	0.00	1.00	0.97	1.97
Mostiste	0.00	0.00	0.00	1.00	0.86	1.86
Nurekskaya	0.00	0.00	0.00	1.00	0.00	1.00

The parameters of the ecological zones of the water intake (P_l through P_d) show that the studied water intake areas can be divided into four groups. The first group is the HPP water intake with a strong influence on the sublittoral zone. These are water intakes of Sheksninskaya, Ivan'kovskaya, and Ozerninskaya HPPs. The second group is the HPP water intake with an influence on the sublittoral zone that is an order of magnitude (over a factor of 30) less than in the first group. Those water intakes are ranked as follows: Volzhskaya, Kapchagajskaya, and Ust'-Khantajskaya HPPs. It should be noted that all water intakes of the second group significantly affect the bathy-pelagic and epipelagic zones. The latter zone contains a lot of juvenile fishes. The third group includes the water intakes without any noticeable influence on the sublittoral or epi-pelagic zones. These are as follows: Al. Stambolijski and Mostiste HPPs. And, finally, the fourth group consists of the water intakes with the influence on the bathy-pelagic zone only. In our case, it is the Nurekskaya HPP water intake.

To verify the adequacy of the identified groups based on the P_l through P_d parameters, a cluster analysis has been performed (Table 2-8, Fig. 2.5). Its results have quantitatively confirmed the presence of these groups (Table 2-9) and, consequently, the feasibility of the provided classification.

Table 2-8 Similarities (Euclidean Distance) between HPP water intakes in EZWI groups

HPP	Ivan'kovskaya	Ozerninskaya	Volzhskaya	Kapchagajskaya	Ust'-Khantajskaya	Al. Stambolijski	Mostiste	Nurekskaya
Sheksninskya	0.10	0.33	0.49	0.49	0.51	1.09	1.10	1.47
Ivan'kovskaya	0	0.31	0.39	0.39	0.41	1.05	1,06	1.44
Ozerninskaya		0	0.51	0.51	0.53	0.77	0.78	1,26
Volzhskaya			0	0.00	0.14	1.00	1.01	1.41
Kapchagajskaya				0	0.14	1.00	1.01	1.41
Ust'-Khantajskaya					0	1.01	1.00	1.32
Al. Stambolijski						0	0.11	0.97
Mostiste							0	0.86

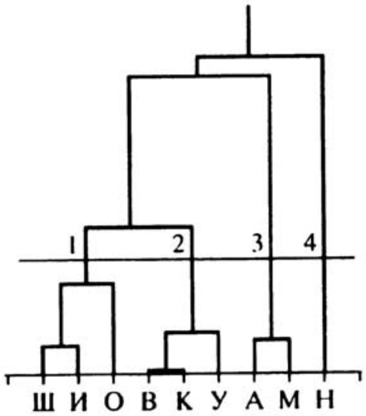

Figure 2.5 Schematic of gatewell locations relative to ecological zones of water intake

Ш – Sheksninskaya; И – Ivan'kovskaya; О – Ozerninskaya; В – Volzhskaya; К – Kapchagajskaya; У – Ust'-Khantajskaya; А – Al. Stambolijski; М – Mostiste; Н – Nurekskaya; 1 – 4 – groups of ecological zones of water intake

Table 2-9 Euclidean Distance between the HPP water intakes in EZWI groups

EZWI Group	HPPs in the EZWI Group	Euclidean Distance	
		Maximum between the water intakes of one EZWI group	Minimum between the water intake in one EZWI group and water intake in another EZWI Group
1	Sheksninskaya, Ivan'kovskaya, Ozerninskaya	0.33	0.39
2	Volzhskaya, Ust'-Khantajskaya, Kapchagajskaya	0.14	0.39
3	Al. Stambolijski Mostiste	0.11	0.77
4	Nurekskaya	0	0.86

2.5 Relationship between Downstream Migration and Fish Distribution

The ecological zone of water intake is considered to be one of the leading factors affecting fish downstream migration from the reservoirs. This factor, along with the data on fish distribution, enables us to predict the fish movement into the water intake influence area on a qualitatively new level, and, consequently, determine a probability of the downstream migration through the HPP dams. Also, this relationship allow us to describe some of the major parameters of fish downstream migration, such as identification of species and their age, as well as seasonal dynamics of the downstream migration.

Using the data on the fish distribution (Section 2.2) and the description of the ecological zones of the water intake (Table 2-7), the following can be assumed.

The fish species with the I^{st} – IV^{th} types of the distribution have a high probability of downstream migration (pikeperch, peled, sardine cisco, ziege, Caspian anadromous shad, sprat, European perch and bleak), since they always inhabit the pelagic zone.

The fish species with the V^{th} type of the distribution may also perform downstream migration (carp bream, silver bream and roach), when they are likely to be present in the pelagic zone (Table 2-3).

The species with the II^{nd} type of fish distribution are not subject to downstream migration (Northern pike, pumpkinseed sunfish, loach, and rudd) because the water intake area does not affect their habitat.

For all the studied reservoirs, with the exception of the Nurekskaya reservoir, the fish species with the III^{rd} type of distribution (ruffe, burbot, sterlet, and Wels catfish) may perform downstream migration since they inhabit the bathyal zone affected by the HPP water intake.

The water intake areas of the HPPs that belong to the 1^{st} group of the ecological zones of water intake affect most of the ecological zones of the reservoir, therefore they will have the greatest variety of migrant species. The HPPs of the 3^{rd} group would have a lesser variety of downstream migrants, while the HPPs of the 4^{th} group would have the least variety. Similar differences seem to be expected regarding the size and age of the migrant species. The validity of these assumptions will be evaluated in the next chapter where the patterns of fish downstream migration are described.

Chapter 3 PATTERNS OF FISH DOWNSTREAM MIGRATION THROUGH HPP DAMS

Fish downstream migration can be characterized by a number of parameters. Usually such parameters as kinds of species, age, size and the number of individuals are considered, as well as seasonal and daily dynamics of the downstream migration. The general patterns of downstream migration from the reservoirs are known and have already been published. The goal of this chapter is not to describe these patterns again, but to identify the key factors that will make these patterns appear. Special focus will be given to the ecological zones of the water intake that will determine most of the characteristics and patterns of fish downstream migration from a reservoir with a slow water exchange. It should be noted that some of the tables given in this chapter will not have the data on the Nurekskaya HPP because no downstream migration has been observed there.

3.1 Species-Specific Structure of Migrants

The species-specific structure of the fish migrants can be characterized by the following parameters: relative number of the species, index of the species similarity between the migrants and resident fishes, as well as the migration index.

The *relative number of the migrants* is a percentage of the fishes of the given species from the total number of the migrants. It has been determined for the species most frequently collected (Table 3-1).

Among the species found in practically all studied reservoirs, European perch and pikeperch are found to be the most numerous migrants, while roach is the least numerous.

To illustrate the differences in downstream migration of the species inhabiting the pelagic and littoral zones, we have grouped them according to their major habitat. The first group will consist of the species that mostly inhabit the pelagic zone (epipelagic and bathy-pelagic), i.e. European perch, Volga pikeperch, ruffe, European smelt, sprat, peled, sardine cisco, *Rhinogobius brunneus*, and burbot. The second group consists of the species that inhabit the littoral zone, i.e., roach, silver bream, pike, sharpbelly, and pumpkinseed sunfish. The remainder of the species have not been included in these groups, the reasons being as follows: some of them inhabit more than one ecological zone (perch, carp bream, and bleak), the distribution of others has not been thoroughly studied, and European eel is only a catadromous (transitory) species. The relative numbers of the migrants are given in Table 3-2.

In all cases, the percentage of migrants coming from inhabitants of the pelagic zone significantly exceeds the amount of the inhabitants of the littoral zone (the differences are significant with $p > 0.001$).

Table 3-1 Share (in %) of the common and frequently found fishes among the migrants from reservoirs

Species	Sheksninkoe	Ivan'kovskoe	Ozerninskoe	Volgogradskoe	Kapchagajskoe	Ust'-Khantajskoe	Al. Stambolijski	Mostiste
European perch	78	24	77	20	*	49	-	82
Pikeperch	9	7	12	29	64	-	82	*
Volga pikeperch	2	*	-	2	-	-	-	-
Ruffe	1	5	*	1	-	-	18	9
Roach	*	3	*	1	*	*	-	*
Carp bream	*	17	3	1	4	-	-	*
Bleak	1	32	*	1	--	-	-	*
Silver bream	*	*	7	1	-	-	-	-
Ide	*	*	-	1	-	*	-	-
Ziege	*	1	-	1	-	-	-	-
European smelt	8	4	*	-	-	-	-	-
Caspian anadromous shad	-	-	-	14	-	-	-	-
Sprat	-	-	-	14	-	-	-	-
Peled	*	-	-	-	-	24	-	-
Sardine cisco	*	-	-	-	-	26	-	-
Gobies	-	-	-	1	30	-	-	-
European eel	-	*	-	-	-	-	-	8
Others	1	7	1	5	2	1	-	1

Note. Asterisk (*) indicates the percentage of the migrants is less than 1%; together with the percentage of the species not mentioned in the table it is taken into account in the row "Others'; minus (-) means that species have not been observed among the migrants in that reservoir.

Table 3-2 Relative number (in %) of the migrant fish species inhabiting the pelagic and littoral zones of the reservoirs

Major habitat	Sheksninskoe	Ivan'kovskoe	Ozerninskoe	Volgogradskoe
Pelagic zone	99.0	74.5	62.3	97.2
Littoral zone	1.0	25.5	37.7	2.8

Major habitat	Kapchagajskoe	Ust'-Khantajskoe	Al. Stambolijski	Mostiste
Pelagic zone	98.9	99.7	100.0	99.0
Littoral zone	1.1	0.3	0.0	1.0

Table 3-3 Number of fish species, inhabitants and migrants in the reservoirs, and the index of the species similarity

Reservoir	Evaluation of EZWI varieties (Σ_p)	Number of species		Index of species similarity, %
		Inhabitants	Migrants	
Sheksninskoe	3.46	22	20	90.9
Ivan'kovskoe	3.36	33	20	60.6
Ozer'ninskoe	3.05	20	9	45.0
Volgogradskoe	3.01	50	20	40.0
Kapchagajskoe	3.01	28	11	39.3
Ust'-Khantajskoe	2.96	18	7	14.3
Al. Stambolijski	1.97	14	2	14.3
Mostiste	1.86	15	7	46.7
Nurekskoe	1.00	12	0	0.0

The correlation between the species, i.e., migrants and inhabitants, can be expressed by the *index of the similarity of species* (the ratio of the amount of the migrants to the amount of the inhabitants). The values of this index are given in Table 3-3, based on the data collected by the authors of this book (Pavlov et al., 1981, 1984, 1985a, 1988, 1991a, б, 1992; Pavlov et al., 1987) and the reference materials (Isaev, Karpova, 1989) for all the fish species found in the reservoirs.

With the exception of the Mostise reservoir the similarity index decreases with decreasing variety of the ecological zones of the water intake (the correlation coefficient is 0.75 with $p = 0.026$), i.e., the fewer zones the HPP water intake affects, the fewer species migrate from the reservoir.

The species-specific characteristic that reflects the correlation between the migrants and the resident fishes of the reservoir is the percentage of the migrants in the total number of fishes of the given species in the reservoir. However, it is very difficult and time-consuming to give a precise estimation of a quantity of fish in the reservoir, and we only have such data for the Ivan'kovskoe reservoir. Therefore, for our rough estimates, we use the *migration index* (see Section 1.3).

Table 3-4 shows the calculations of the migration index for the most common and frequently found fish species. This Table indicates that, for certain species, the migration index does not significantly differ from reservoir to reservoir. However, the value of the migration index appears to be greater for the pelagic species than for the littoral species (Table 3-5).

To determine how the ecological zones of the water intake affect the species-specific structure of the migrants (Table 3-6), the values for the applied parameters have been averaged for the HPPs according to the EZWI groups identified in Section 2.4. Table 3-6 indicates that, in groups 1 – 3, the percentage of the migrants from the pelagic zone increases, while the percentage of the migrants from the littoral zone decreases. The index of the similarity of species for the resident fishes and the migrants in those groups goes down. These values, according to the dispersion analysis, are connected with the ecological zones of the water intake ($p<0.05$). The differences in the migration index have not been found for various EZWI. However, it should be noted that the differences in the ecological zones of the water intake for the studied HPP water intakes are fairly small.

Table 3-4 Migration index for common and frequently found fishes in reservoirs

Species	Sheksninkoe	Ivan'kovskoe	Ozerninskoe	Volgogradskoe	Kapchagajskoe	Ust'-Khantajskoe	Al. Stambolijski	Mostiste
European perch	0.5	0.6	1.0	0.9	0.8	0.8	-	0.8
Pikeperch	1.0	1.0	0.4	0.9	1.0	-	1.0	0.7
Volga pikeperch	*	*	-	0.6	-	-	-	-
Ruffe	0.7	0.6	0.6	0.6	-	-	1.0	1.0
Roach	0.1	0.1	0.2	0.3	*	0.1	-	0
Carp bream	0.2	0.8	0	0	0.6	-	-	0.4
Bleak	0.3	1.0	0.2	0.3	-	-	-	*
Silver bream	0.5	0.5	*	0.2	-	-	-	-
European smelt	0.7	1.0	*	0.5	-	-	-	-
Caspian anadromous shad	-	-	-	1.0	-	-	-	-
Sprat	-	-	-	0.6	-	-	-	-
Peled	*	-	-	-	-	1.0	-	-
Sardine cisco	*	-	-	-	-	1.0	-	-
Gobies	-	-	-	*	0.5	-	-	-
European eel	-	*	-	-	-	-	-	1.0
Northern pike	0	0	0	0	-	0	-	*
Sharpbelly	-	-	-	-	0	-	-	-
Pumpkinseed sunfish	-	-	-	-	-	-	0	-
Carp	-	-	-	*	0.5	-	0	-
Burbot	*	*	*	-	-	1.0	-	-

Note. * - species not common in the reservoir; line - species not found.

Table 3-5 Migration index for most common and frequently found species in the pelagic and littoral zones

Major habitat	Sheksninskoe	Ivan'kovskoe	Ozerninskoe	Volgogradskoe
Pelagic zone	0.80	0.87	0.50	0.70
Littoral zone	0.20	0.20	0.10	0.17

Major habitat	Kapchagajskoe	Ust'-Khantajskoe	Al. Stambolijski	Mostiste
Pelagic zone	0.75	1.00	1.00	0.86
Littoral zone	0.00	0.05	0.00	0.00

Table 3-6 Species-specific structure as a function of ecological zones of water intake

Parameter	EZWI Groups			
	1	2	3	4
Percentage (%) among the migrants:				
Pelagic residents	78.6	98.6	99.5	0
Littoral residents	21.4	1.4	0.5	0
Index of similarity of species	65.5	39.4	30.5	0
Migration index:				
European perch	0.70	0.83	0.80	-
Pikeperch	0.80	0.95	0.80	-
Carp bream	0.33	0.30	0.40	-
Roach	0.13	0.15	0.00	-
Pelagic residents	0.72	0.83	0.93	-
Littoral residents	0.17	0.07	0.00	-

Note: Minus (-) – no migrants have been observed.

Detailed studies have been performed for three water intakes, i.e., HPP and sluice of the Sheksninskoe reservoir, as well as the dam of the Lozsko-Azatskoe lake. Fig.3.1. shows the similarities of these and some other water intakes. The water intake in the Lozsko-Azatskoe lake is from the littoral and sublittoral zones, in the Sheksninskoe sluice it is from the epipelagic, sublittoral and littoral zones, in the Sheksninskoe HPP it is from the bathy- and epipelagic zones and, only after that, from the sublittoral zone.

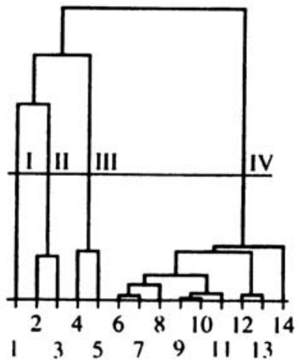

Figure 3.1 Schematic of water intake locations relative to EZWI

1 – hydroelectric unit in Nero Lake; 2 – Vestonitse HPP; 3 – the Veksa River outflow from Pletscheevo Lake; 4 – Lozsko-Azatsky dam; 5 – Sheksninskoe sluice; 6 – Ivan'kovskaya HPP; 7 – Sheksninskaya HPP; 8 – Ozerninskaya HPP; 9 – Volgogradskaya HPP; 10 – Kapchagajskaya HPP; 11 –Ust'- Khantajskaya HPP; 12 – Al. Stambolijski HPP; 13 – Mostiste HPP; 14 – Nurekskaya HPP; I – IV – EZWI types

The migration indexes for the fish species frequently collected in the manmade reservoir and the lake have been estimated with significant differences in the ecological zones of water intake. As an example, Table 3-7 gives the values of the migration indexes for the fish species with various distribution patterns. The coefficients of ranking correlation have been used to estimate the similarities (differences) in the migration. The values of the coefficients of ranking correlation (for the standardized species) have been as follows: - 0.8 for the HPP and sluice and + 0.5 for the sluice and the lake dam. The data show that the migration for all the fish species, as well as for individual fish species, will be similar for the sluice and the Lozsko-Azatskoe Lake dam water intakes, but it will be significantly different for the HPP water intake. It proves the fact that the fish migration index depends on the ecological zones of the water intake[1].

Therefore, we can conclude that the species-specific structure for fish migration through HPP dams depends on the fish distribution in the ecological zones of the reservoirs and the ecological zones of the water intake.

[1] For a pair of water intakes, i.e., sluice and HPP located in one reservoir, all the environmental factors that are not related to the EZWI have been identical. For the other pair of the water intakes, i.e., sluice and Lozsko-Azatskoe lake dam, only the EZWI related factors have been identical, while all other factors are significantly different because they are located in different reservoirs. Therefore, in accordance with the cluster analysis procedure, the EZWI produces a stronger influence on the downstream migration parameter (in our case, the migration index) than other environmental factors when its value for the sluice is closer to the similar value for the Lozsko-Azatskoe dam than for the HPP.

Table 3-7 Migration indexes for downstream migration of fish species from Sheksninksoe Reservoir (HPP and Sluice) and Lozsko-Azatskoe Lake (Dam)

Species	HPP	Sluice	Dam
Roach	0.11	0.19	0.22
Carp bream	0.42	0.60	0.56
Pikeperch	0.91	0.55	0.50

3.2 Age and Size Structure of Fish Migrants

The age structure of the migrants is usually characterized by the relative number (%) of fishes of various ages, and their size characteristics are usually associated with the average body length and its statistical distribution.

Taking into account significant differences in ecology, behavior and distribution of fishes in the first year of life versus older fishes, we have studied these age groups separately. The percentage of fishes in the age of 0+ for the common and frequently found fishes for the studied reservoirs is given in Table 3-8. This table shows that most of the given species migrate during the first year of life.

Fishes of the First year of Life

During the next stage of analysis, we have divided the fishes of the first year of life into two age groups, i.e., larvae and fry (Table 3-9). We found that the larvae are the most common migrants, i.e., they account for 38 – 95% of the total number of migrants in all reservoirs, with the exception of Al. Stambolijski reservoir. However, the situation is like this only due to the migration of a number of species, such as European perch, Volga pikeperch, peled, and sardine cisco. The greatest amount of the larvae, i.e., 76 – 95%, have been detected in Sheksninskoe, Ozerninskoe, Ust'-Khantajskoe and Mostiste reservoirs. In all cases, it was due to the pikeperch larvae migration because they inhabit almost all ecological zones of the reservoirs. Therefore, the study on how the ecological zones of water intake affect the identified groups does not seem to be reliable.

The greatest numbers of fry and fishes younger than one year old have been registered for Al. Stambolijski and Kapchagajskoe reservoirs, i.e., 93.3 and 31%, respectively. In both cases, it has resulted from the active migration of the pikeperch fry.

Table 3-8 Percentage (%) of fishes one year old and younger from the total number of fish migrants in reservoirs

Species	Sheksninskoe	Ivan'kovskoe	Ozerninskoe	Kapchagajskoe	Ust'-Khantajskoe	Al. Stambolijski	Mostiste	Average
Perch	100	45	99	-	96	-	97	88
Pikeperch	100	93	100	93	-	100	100	98
Volga pikeperch	100	-	-	-	-	-	-	100
Ruffe	46	20	35	-	-	47	10	32
Roach	96	20	42	24	96	-	0	46
Carp bream	98	66	100	32	-	-	100	79
Bleak	96	36	100	-	-	-	100	83
Silver bream	97	94	87	-	-	-	-	93
European smelt	96	20	100	-	-	-	-	72
Peled	0	-	-	-	94	-	-	94
Sardine cisco	0	-	-	-	86	-	-	86
Gobies	-	-	-	78	-	-	-	78
European eel	-	0	-	-	-		0	0
All species	99.7	49	89	79	92	97.4	85.3	-

Note. - Species not observed as migrants.

Table 3-10 gives more detailed analysis of the age structure of the migrants of the first year of life. The table shows that the prolarvae of the species studied have practically not been exposed to downstream migration. It can be explained by various reasons: attachment to the spawning substrate by the Cyprinidae prolarvae; long distances from the spawning areas to the HPPs for the European smelt; littoral and sublittoral spawning locations for European perch and pikeperch, as well as a short duration of this period. For most species, late larvae (except pikeperch and silver bream) tend to migrate more intensely than the early larvae. It results from their migration to the pelagic zone of the reservoir from the littoral zone and their drifting to the HPP water intake during those stages of development. Carp bream, roach, pikeperch and European smelt undergo the most intense migration as fry and, during this period of development, they inhabit the largest areas of the reservoir.

Table 3-9 Age structure of the migrants (%) for all fish species migrating from the reservoirs

Age group	Sheksninskoe	Ivan'kovskoe	Ozerninskoe	Ust'-Khantajskoe
Larvae	95.0	38.0	89.0	77.0
Fry	4.7	11.0	0	15.0
Total 0+	99.7	49.0	89.0	92.0
Older than 12 months	0.3	51.0	11.0	8.0

Age group	Kapchagajskoe	Al. Stambolijski	Mostiste
Larvae	48.0	4.1	76.0
Fry	31.0	93.3	9.3
Total 0+	79.0	2.6	14.7
Older than 12 months	21.0	2.6	14.7

The *size* of the migrants of the first year of life corresponds to the periods of their development. For downstream migration, the quantity of fishes with a longer body length (late larvae and fry) exceeds the quantity of fishes with a shorter body length (prolarvae and early larvae). It means that the concentration of the late larvae and fry in front of the HPP water intake is higher than that of younger fishes. Table 3-11 indicates that the swimming capability of the young fishes affects their downstream migration tendencies by showing that, in all cases, the average body length of the migrants appeared to be shorter than the average body length of the species caught in the headwaters of the HPP water intake.

Therefore, the major factor that affects the age and size structures of the migrants for fish 1 year old and younger is their distribution during various stages of development. Their swimming capability related to the body length only slightly modifies the concentration values for the migrants.

Table 3-10 Age structure and size of the fish migrants of one year old and younger (%) for Ivan'kovskoe, Sheksninskoe and Ozerninskoe Reservoirs

Species	Prolarvae		Early larvae		Late larvae		Fry and this year's brood	
	%	mm	%	mm	%	mm	%	mm
Bleak	0.0	-	31.0	7.3	41.0	11.7	28.0	15 – 16
Carp bream	0.1	6.8	20.4	7.9	22.5	13.0	57.0	16 – 67
European perch	0.1	5.7	34.0	8.5	51.4	12.5	14.5	15 – 65
Pikeperch	1.0	8.2	35.5	9.9	15.0	14.5	48.5	17 – 79
Roach	0.0	-	4.5	7.5	26.0	11.4	69.5	15 – 64
European smelt	0.0	-	0.2	14.6	6.4	20.0	93.4	24 – 84
Silver bream	2.5	5.2	54.0	7.3	5.0	12.0	38.5	14 – 58

Table 3-11 Average body length of migrants and resident fishes in the dam area of the Kapchagajskoe and Al. Stambolijski Reservoirs

Species	Reservoir	Month of observations	Average body length, mm	
			Headwaters	Downstream migrants
Rhinogobius brunneus	Kapchagajskoe	August	15.1	11.3
Pikeperch		June	19.5	9.6
Pikeperch	Al. Stambolijski	June	43.6	40.6
		July	46.6	42.5
		August	50.5	48.4

Table 3-12 Age structure of the fish migrants in Kapchagajskoe and Ivan'kovskoe Reservoirs, % of the total number of migrants older than 12 months

Species	Age, years						
	1+	2+	3+	4+	5+	6+	7+
			Kapchagajskoe reservoir				
Pikeperch	21.4	16.3	21.4	27.3	7.8	3.9	1.9
Carp bream	7.0	10.6	35.3	33.0	11.8	2.3	0
Asp	57.1	14.3	28.6	0	0	0	0
Roach	0	26.3	57.9	15.8	0	0	0
Crucian carp	0	0	10.0	30.0	55.0	5.0	0
Carp	0	0	0	0	64.3	28.6	7.1
			Ivan'kovskoe reservoir				
Pikeperch	68.8	18.8	6.2	6.2	0	0	0
European perch	41.2	35.4	20.2	1.9	1.3	0	0
Carp bream	35.5	33.1	26.1	4.9	0.4	0	0
Bleak	46.8	45.2	7.0	1.0	0	0	0
Roach	59.6	30.3	7.3	2.8	0	0	0
Silver bream	48.9	26.7	15.6	8.8	0	0	0

Fishes Older than 12 Months

The greatest number of fishes older than 12 months has been observed for Ivan'kovskoe and Kapchagajskoe reservoirs, i.e., 51 and 21%, respectively (see Table 3-8). The detailed analysis of the age structure for these fish species is given in Table 3-12.

For the fishes of the Ivan'kovskoe reservoir, there is a well-defined tendency for a decrease of the % of migrants with increasing age. For Kapchagajskoe reservoir, this tendency does not seem to be as well defined as for Ivan'kovskoe reservoir for the period of the most intense migration (November – December).

The decrease of the migration intensity with age may be explained by two reasons, specifically:

1) general decrease of the fish population in the reservoir due to natural mortality rate; and 2) an increase of the swimming capability and, consequently, the fish resistance to the water intake currents with age.

Table 3-13 Quantity of migrants (%) from Ivan'kovskoe Reservoir (1989 – 1990) as a function of body length

Body length, mm	European perch	Carp bream	Bleak	Roach	Pikeperch	Silver bream
< 10	7.87	8.71	13.04	0	27.34	8.66
10 – 29	**73.16**	1.63	**57.20**	23.05	**46.88**	14.45
30 – 49	1.03	**50.61**	3.26	**29.53**	18.21	**57.76**
50 – 69	0.81	22.45	3.35	0.82	3.50	2.89
70 – 89	1.92	2.31	3.85	2.47	2.93	2.89
90 – 109	**8.38**	5.05	**13.54**	**19.75**	0.16	5.05
110 – 129	5.64	**7.48**	4.53	11.12	**0.24**	**5.78**
130-149	0.68	0.54	1.00	8.23	0.08	1.08
150 – 169	0.13	0.27	0	1.23	0.16	0.36
170 – 189	0.13	0.27	0	1.23	0.16	0.36
190 – 209	0.09	0.14	0	1.23	0.16	0.36
210 – 229	0.04	0	0	0	0	0
230 - 249	0.04	0	0	0	0	0
250 – 269	0	0.07	0	0	0	0
270 – 289	0.04	0	0	0	0.08	0
310 – 329	0.04	0	0	0	0	0
330 – 349	0	0	0	0	0	0
350 – 369	0	0	0	0	0.08	0
>370	0	0	0	0	0.08	0
100%	659 specimens	705 specimens	796 specimens	131 specimens	233 specimens	81 specimens

Note. The local maximum concentration values are highlighted.

To identify the role of these factors in the intensity of the downstream migration, the sizes of the migrants need to be analyzed. Such detailed analysis has been performed for the Ivan'kovskoe reservoir migrants in 1989 – 1990 for the average annual concentrations (Table 3-13). The analysis shows that all the fish species had two local maximum concentration values for the migrants with certain body lengths (they are highlighted in Table 3-13). The *first* is for the size ranges: 10 – 29 or 30 – 49 mm, which corresponds to the first year of life and reflects the correlation between the migrants during various stages of ontogenesis given in Table 3-10. The *second* maximum is for the body length range of 90 – 169 mm, which corresponds to the fish body length of the age 1+ (the inhabitants of the reservoir). Though there are a lot of migrants in the age of 2+, 3+, and 4+ (see Table 3-12), no local maximum concentration values have been detected for those age groups. Detailed analysis of the fish ages with the body length that would correspond to the second local concentration maximum has shown that there are fishes there (for all species except pikeperch) in the age groups of 1+, 2+, and 3+ (Table 3-14). No studies for pikeperch have been performed because only 15 specimens of these age groups have been caught there.

Table 3-14 Percentage of migrants (in % of the total number of migrants) of the given age falling within a length class of the second local maximum

Species	Body length, mm	Age, years				
		1+	2+	3+	4+	5+
Perch	90 – 109	88.0	82.8	0.0	0.0	0.0
Bleak	90 – 109	98.7	43.9	50.0	0.0	0.0
Roach	90 – 109	50.0	48.0	0.0	0.0	0.0
Bream	110 – 129	13.2	100.0	87.8	0.0	0.0
Silver bream	110 – 129	25.0	77.8	67.0	0.0	0.0

Therefore, the intensity of the downstream migration for fishes greater than 12 months old is primarily connected with the size of the fish, but not with the stages of development. The reason for this connection is the swimming capability of the fishes that increases with their size, thereby increasing their resistance towards the water intake currents. For the Ivan'kovskoe reservoir, all fishes smaller than 130 mm seem to migrate. It is natural that the effect of body size on the intensity of downstream migration will vary for the studied reservoirs. For example, for the Ust'-Khantajskaya HPP, with a more powerful water intake, the typical size range of the downstream migrants will be up to about 350 mm.

The connection between the swimming capability of the fishes and their downstream migration provides information on the age of migrants for various species. Bigger fishes (pikeperch, Northern pike, carp bream, silver bream, and ide, etc.) migrate before they reach sexual maturity, primarily during the first year of life. The species that reach sexual maturity upon reaching the above mentioned size (bleak, roach, European perch, ruffe, and European smelt, etc.) also migrate at a greater age, including the reproductive age. The data obtained on the sizes of the migrants for other studied reservoirs do not contradict the patterns identified for the Ivan'kovskoe reservoir.

The maximum size of the migrants from the Ivan'kovskoe reservoir is 650 mm for pikeperch and 900 mm for European eel. The largest size of migrant fish for all the studied reservoirs, i.e., 950 mm long, has been detected in the Mostiste reservoir (European eel) and in Kapchagajskoe reservoir (some sturgeon specimens).

Ecological Zones of Water Intake Affecting Age and Size of the Fish Migrants

The comparison of the age and size of the fish migrants in the reservoirs with various types of ecological zones of the water intake shows that the correlation between them is not quite justifiable. In our opinion, it can be explained by the fact that the groups of the studied HPP water intakes have similar EZWI characteristics.

Table 3-15 Percentage (%) of roach, carp bream, and pikeperch migrants during various periods of ontogenesis in Sheksninskoe Reservoir and Lozsko-Azatskoe Lake

Species	Location for catching	Prolarvae	Early larvae	Late larvae	Fry	Fishes older than 12 months
Roach	HPP	0	14.4	59.6	21.7	4.3
	Sluice	1.2	61.7	16.0	19.3	1.8
	Lake Dam	0.6	62.5	1.0	34.7	1.2
Carp bream	HPP	0	38.4	41.3	19.0	1.3
	Sluice	17.0	79.2	2.5	1.3	0
	Lake Dam	44.5	1.3	5.7	42.7	5.8
Pikeperch	HPP	0.1	24.0	14.4	61.4	0.1
	Sluice	16.0	57.7	16.2	8.7	1.4
	Lake Dam	26.8	59.0	5.6	8.6	0

The analysis of fish downstream migration associated with a significant difference of the ecological zones of water intake shows that the age and size of the migrants depends on the type of the ecological zone. The studies have been performed for the Sheksninskoe reservoir and Lozsko-Azatskoe lake (Table 3-15) where the fish downstream migration through three water intakes has been evaluated. It should be emphasized that the species indicated in Table 3-15 have various distributions, specifically: roach inhabit the littoral zone, pikeperch inhabit the pelagic zone of the reservoirs, and the carp bream changes its habitat depending on the ontogenetic period. To determine the age of the fishes migrating through the water intakes of Lozsko-Azatskoe Lake dam, Sheksninskaya HPP and the sluice, the correlation coefficient has been used (Table 3-16). In all cases, the age of the migrants through the sluice is more similar to the age of the migrants from the lake than through the HPP.

Table 3-16 Correlation coefficients for ages of the migrants through water intakes of Sheksninskaya HPP and Sluice, as well as Lozsko-Azatsky dam

Species	Sluice – HPP	Sluice – Lake Dam
Roach	0.35	0.86
Pikeperch	0.33	0.82
Carp bream	0.17	0.91

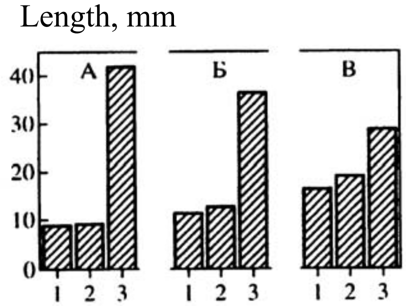

Figure 3.2 Average body length of migrants through the dam of Lozsko-Azatskoe Lake (1), Sheksninskaya sluice (2) and HPP (3)

A – Carp bream; Б – Perch; B – Roach

A similar situation has been observed for other common and frequently found fish species, i.e. this downstream migration parameter is closer for the water of different reservoirs with similar EZWI than for the water intakes of the same reservoir with different EZWI. It should be noted that the water flow rate through the sluice is pretty much the same as through the HPP, and the water intake through the lake dam is about two orders of magnitude lower.

The sizes of the fish migrants also appear to be affected by the ecological zones of water intake (Fig. 3.2). In all cases, the average body length of the HPP migrants is longer ($p < 0.05$) than that of the sluice or lake dam migrants. Comparing the sluice and dam, only roach have been observed to have a longer body length for the sluice migrants. The body size as an indicator for downstream migration is more comparable for the sluice and lake dam migration than for the HPP migration, thereby proving that the ecological zones of water intake affect the size of the migrants more significantly than any other environmental factors (see Footnote earlier in this chapter).

3.3 Quantitative Characteristics of Fish Downstream Migration

In this section we consider the following quantitative characteristics of fish downstream migration: fish concentration in the water flow (the number of fish per unit of water volume) and the intensity of downstream migration (the number of fish migrants per unit of time). The application of the intensity of the downstream migration for the analysis of the downstream migration dynamics does not seem to be appropriate because its value depends on the concentration of the fish migrants and the water flow rate through the HPP water intake or the fishing net. The studied reservoirs have various HPP water intake values, and a variety of fishing nets have been applied there for catching fish. Therefore, we have identified the concentration of the fish migrants as the major parameter of downstream migration, and the unit of measurement for this parameter is specimens per 1,000 m^3 (sp/m^3).

Such parameters as the maximum average daily and annual concentrations of the fish migrants (Table 3-17) give some general ideas about fish downstream migration. The greatest value for the average annual concentration of fish migrants has been observed for Volgogradskoe and Sheksninskoe reservoirs, and its smallest value has been observed for Nurekskoe and Mostiste reservoirs. The maximum average daily concentrations have exceeded the average annual values by one or two orders of magnitude, while the minimum average daily concentrations were, in all cases, equal or close to zero.

Table 3-17 Total concentration of fish migrants from reservoirs for all species

Reservoir	Concentration of fish migrants, no./1,000 m^3	
	Average annual	Maximum average daily
Volgogradskoe	347.82	2,580.00
Sheksninskoe	140.25	2,550.17
Al. Stambolijski	40.96	1,000.00
Kapchagajskoe	12.31	147.40
Ozerninskoe	11.74	62.60
Ivan'kovskoe	3.40	38.71
Ust-Khantajskoe	0.86	4.60
Mostiste	0.52	11.86
Nurekskoe	0	0

Estimating how *the ecological zones of water intake affect* the concentration of fish migrants, we have found a positive ranking correlation ($R_s = 0.76$, $p < 0.05$) of these factors. The concentration of fish migrants increases with the increase in the number of the ecological zones of the reservoir affected by the water intake currents. Another factor that is supposed to affect the concentration of fish migrants is the water intake flow rate. However, no reliable data on this correlation have been obtained ($R_s = 0.21$, $p > 0.05$). Nevertheless, the comparisons of the average concentration values for each group of the ecological zones of water intake and the average water flow rate through the HPP (Table 3-18) shows that the higher the water flow rate, the higher is the concentration of migrants.

Table 3-18 Average annual concentrations of fish migrants at HPPs for each EZWI group

EZWI group	Average annual concentration of fish migrants, no./1,000 m^3	HPP average flow rate, m^3/s
1	51.7	325
2	120.3	1,137
3	21.0	11
4	0	1,085

Table 3-19 Concentration of migrants and inhabitants of the HPP head dam areas of the reservoirs in June and July

Reservoir	Species	Concentration, no./1,000 m^3	
		Migrants	Pelagic residents
Ivan'kovskoe	European perch	8.30	32.00
	Bleak	6.90	444.00
	Pikeperch	0.45	1.75
	European smelt	0.15	0.70
	Roach	1.00	2.85
	Carp bream	0.64	50.90
	Perch	571.00	2,200.00
Sheksninskoe	Pikeperch	11.70	616.00
	European smelt	67.80	221.00
	Roach	1.56	247.00
	Carp bream	1.06	203.00
	Bleak	8.54	94.10
Kamskoe	European perch	73.90	1,025.00

The special analysis of how the *water flow rate affects* the concentration of the fish migrants for certain species has been performed with application of the association coefficient (R_a). It shows that, for the most common migrant species, there is always a reliable correlation between the water flow rate and the migrant fish concentration. This correlation works (at $p < 0.05$) for the pikeperch ($R_a = 0.68$) and ruffe ($R_a = 0.72$) in the Al. Stambolijski reservoir, as well as for the European perch larvae ($R_a = 0.71$) and the European smelt migrants in summer ($R_a = 0.69$) in Sheksninskoe reservoir. Beyond that, it has been observed for Al. Stambolijski reservoir that there are some minimum water flow rate values that will establish a limit for the downstream migration, i.e., there is no downstream migration if the water flow rate is lower than this value. For the pikeperch, this water flow rate value was 5 m^3/s, and for the ruffe it was 1 m^3/s (Pavlov et al., 1988).

It is obvious that one of the key factors for downstream migration is the fish concentration in the reservoirs and in the water intake area (HPP water intake influence zone). Unfortunately, we do not have these data available for all the studied reservoirs, but, when the data are available, we can see that the concentration of the migrants is much lower than the concentration of the residents in the HPP head dam area and in the HPP water intake influence area (Table 3-19).

Therefore, the key factors that provide quantitative characteristics of fish downstream migration are as follows: fish concentration in the dam area of the reservoir, ecological zones of water intake, and the water flow rate through the HPP.

3.4 Daily Dynamics of Fish Downstream Migration

The literature data have already provided a detailed description of daily dynamics of fish downstream migration in water flows (Pavlov, 1970, 1979; and other authors). The fish migration from the reservoirs through the HPP dams is likely to be of the same nature. The daily dynamics of the fish downstream migration from the reservoirs, to a large extent, reflects the fish interactions with the water intake currents in the HPP water intake influence zones and makes it possible to describe the mechanisms of those interactions for various species.

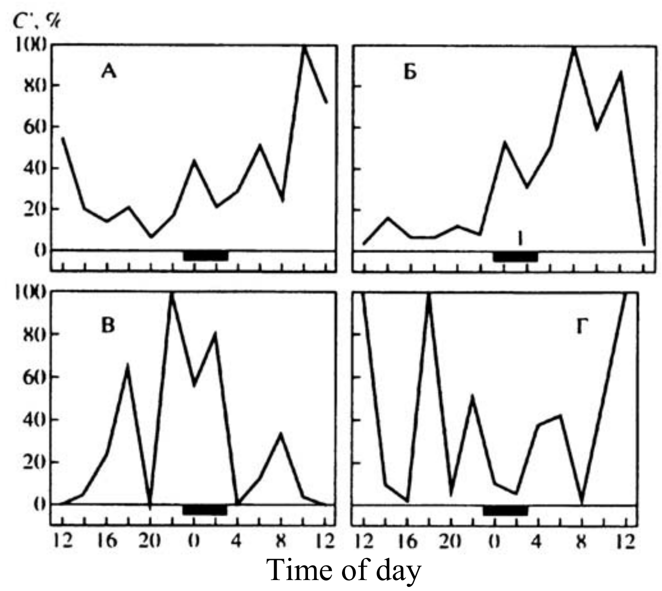

Figure 3.3 Daily dynamics of downstream migration for early larvae from Ivan'kovskoe and Sheksninskoe Reservoirs

A – European perch, 4,638 specimens; Б – Pikeperch, 369 specimens; В – Bleak, 272 specimens;
Г – European smelt, 186 specimens; 1 – night (light less than 1 lux), C` - relative concentration of the fish migrants (C/C_{max})

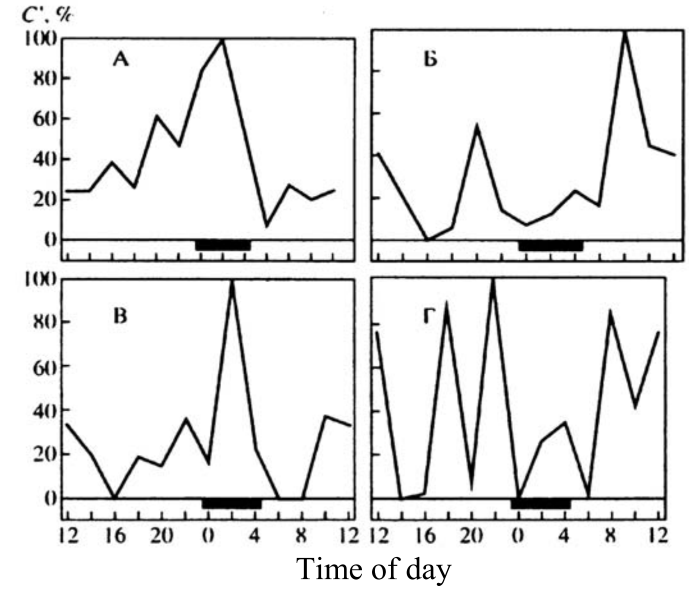

Figure 3.4 Daily dynamics of downstream migration for late larvae from Ivan'kovskoe and Sheksninskoe Reservoirs

A – European perch, 10,102 specimens; Б – Pikeperch, 213 specimens; B – Bleak, 348 specimens; Г – European smelt, 309 specimens; other: see Fig. 3.3.

For the analysis of the dynamics of fish downstream migration, we have used information on the migration of the species that can be found in practically all studied reservoirs, i.e., European perch, pikeperch, carp bream, roach, and bleak). Figures 3.3 –3.7 show the ratios of the concentrations of the migrants at a particular time of day to their maximum daily concentrations. To analyze how the patterns of the daily dynamics change as a function of various biotic and abiotic factors, the coefficient of daily variations (K_c) has been used (see Section 1.3).

Below are the data on the daily dynamics of downstream migration as a function of the kind of species, age, season and the latitude of the reservoir.

The daily dynamics of juvenile fish migration differ for various migrant species and change in the process of ontogenesis. We have collected most information on the downstream migration dynamics and have performed the longest observations for Ivan'kovskoe and Sheksninskoe reservoirs.

European perch *prolarvae* (45 specimens) primarily migrated in the daytime (K_c = -0.68), while pikeperch prolarvae (23 specimens) migrated both in the daytime and at night (K_c = -0.004). Due to a small number of prolarvae migrants, no figures of their migration dynamics have been provided.

Early larvae (stages C_1 – D_1). Perch migrated homogeneously within 24 hours' period (K_s = - 0.07) with a small peak at 10 am (Fig. 3.3). Pikeperch migrated in a similar way (K_s = 0.08) with a peak at 6 am. Bleak early larvae primarily migrated in the dark (K_s = 0.48), with the migration peak around 10 p.m.

Late Larvae (stages D_2 – E). Night migration prevailed for all the young fishes. European perch migrated (K_c = 0.53) in the dark with the peak at midnight (Fig. 3.4). Bleak migrated in a similar way (K_c = 0.68). Pikeperch did not intensify the night migration as much as perch or bleak (K_c = 0.17).

Table 3-20 Changes of the coefficients of daily variations for daily dynamics of downstream migration with ontogenesis (Stages C1 – E) for Sheksninskoe Reservoir

Species	C_1	C_2	D_1	D_2	E
Pikeperch	-1.00	0.20	0.38	0.14	0.22
European perch	-0.49	0.16	0.41	0.54	0.51
Bleak	-0.18	0.60	0.91	0.57	1.00

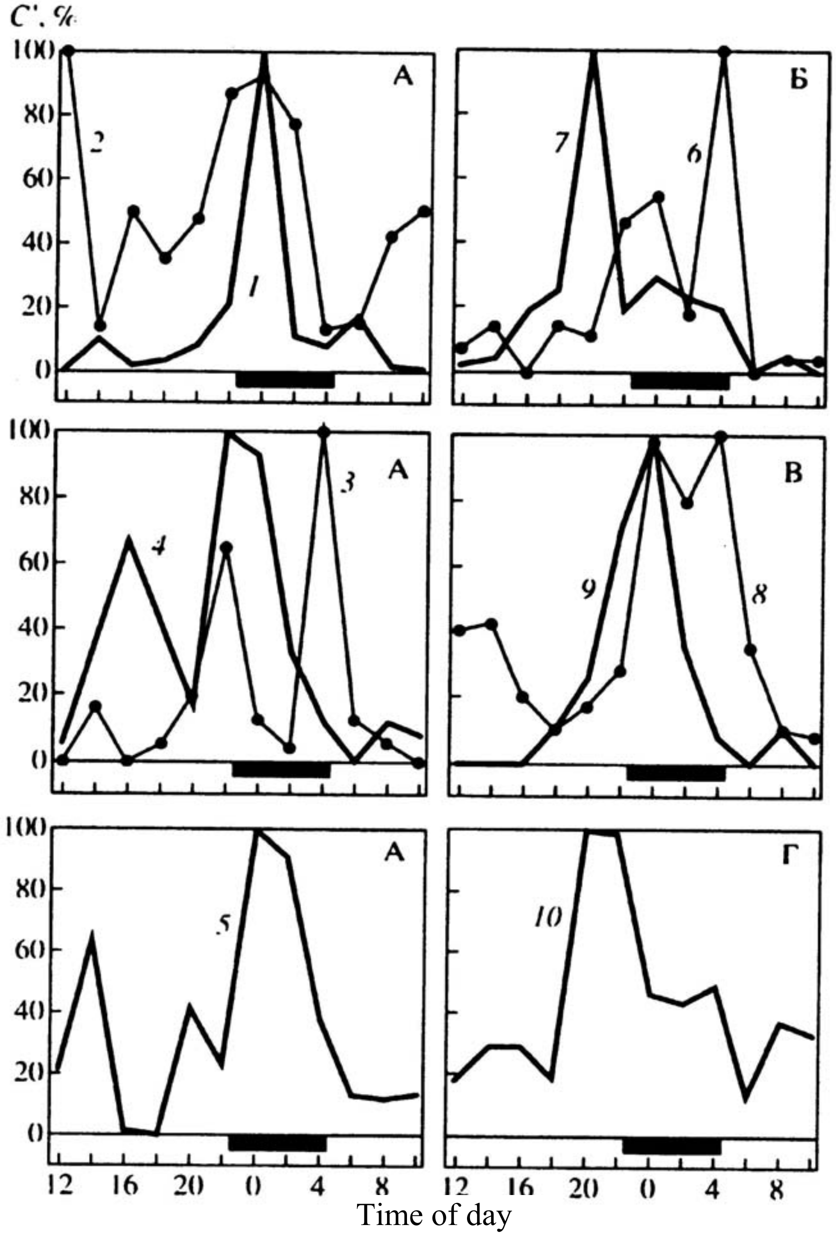

Figure 3.5 Daily dynamics of downstream migration for fry from Ivan'kovskoe and Sheksninskoe (A) Reservoirs, Volgogradskoe Reservoir (Б), Kapchagajskoe Reservoir (В), and Al. Stambolijski Reservoir (Г)

1 – European perch, 3,087 specimens; 2 – pikeperch, 1,109 specimens; 3 – bleak, 248 specimens; 4 – carp bream, 105 specimens; 5 –European smelt, 679 specimens; 6 – Caspian anadromous shad, 345 specimens; 7 – sprat, 568 specimens; 8 – carp bream, 67 specimens; 9 – pikeperch, 123 specimens; 10 – pikeperch, 11,210 specimens; other: see in Fig. 3.3

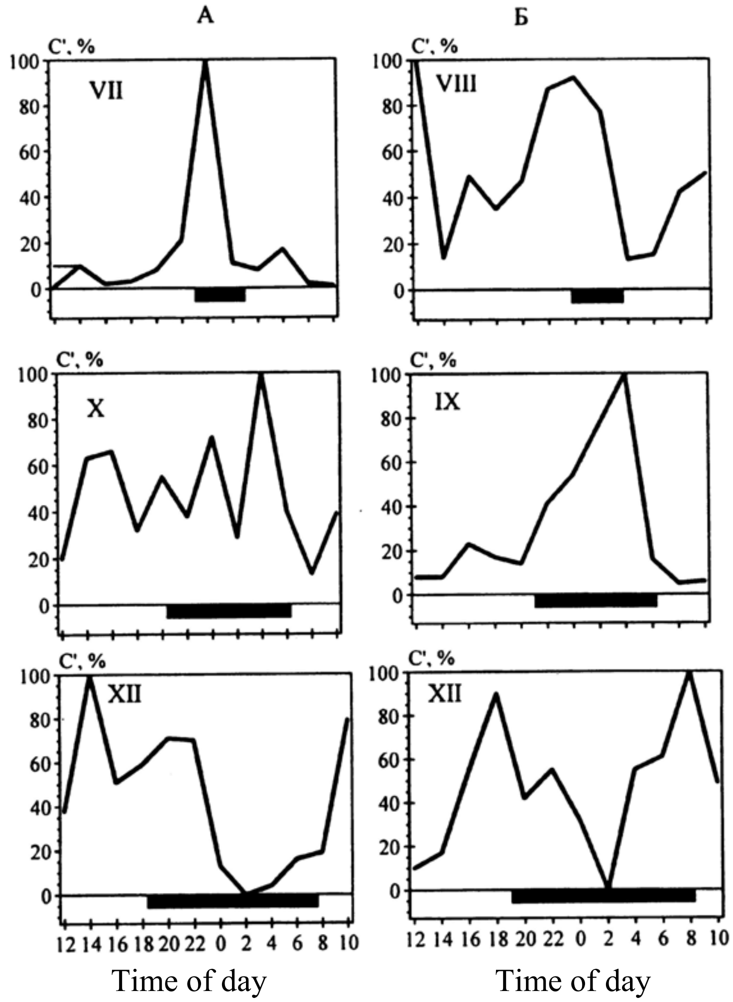

Figure 3.6 Daily dynamics of pikeperch fry migration from Ivan'kovskoe (A) and Sheksninkoe (Б) Reservoirs during different months (July (VII)- December (XII)) Other: see Fig. 3.3

The changes in the daily migration of the late larvae, in comparison with the early larvae, started during ontogenesis stages $C_1 - C_2$ (Table 3-20). Similar results have been obtained for the bleak migration from Vyshnevolotsky reservoir. For the latter, a drastic change in the daily dynamics of the downstream migration has been observed between stages C_2 and D_1.

Fry (Fig. 3.5). There is a tendency for intensifying migration at night in summer. The coefficients of daily variations for the fry were as follows: European perch +0.77, pikeperch + 0.43, and bleak + 0.72.

Table 3-21 Changes in coefficients of daily variations for daily dynamics of fry migration in different seasons for Ivan'kovskoe and Sheksninskoe Reservoirs

Species	Summer	Fall	Winter
European perch	0.77	0.18	-0.36
Pikeperch	0.30	0.94	0.25

Table 3-22 Coefficient of daily variations for downstream migration of perch larvae from HPP reservoirs

Species	Sheksninskoe	Ivan'kovskoe	Ozerninskoe	Volgogradskoe
European perch	0.44	0.14	0.39	-0.25
Pikeperch	0.10	0.56	0.97	0.17

Species	Kapchagajskoe	Ust'-Khantajskoe	Al. Stambolijski	Mostiste
European perch	-	0.26	-	0.50
Pikeperch	0.79	-	0.34	-

Note. – No migrants have been observed.

Taking into account a long period of development of fishes during the fry stage, their daily migrations depend on the season (Fig. 3.6). From summer to winter, significant changes in the daily mode of downstream migration have been observed. Specifically, there have been fewer pikeperch migrants at night in winter, and daytime migration prevailed. The maximum amount of pikeperch migrants at night has been observed only by fall. In winter, there were many fewer pikeperch migrants at night. Two peaks of downstream migration have also been observed, i.e., in the morning and early evening (Fig. 3.6).

At *12 months old and older*, bleak (54 specimens) migrated both in the daytime and at night (K_c = 0.04), pikeperch (98 specimens) mostly migrated in the daytime (K_c = -0.72), while other species did not migrate in sufficiently large quantities to draw any conclusions.

The study on how the ecological zones of water intake affect the daily mode of migration has been performed by comparing the migration modes for different reservoirs. For this comparison, we have used the coefficient of daily variation for the pikeperch larvae because the Percidae family was the most frequently found fish family (Table 3-22).

Table 3-23 Coefficients of daily variations for migration of perch family larvae in groups of ecological zones of water intake

EZWI group	European perch	Pikeperch	Percidae sp., total
1	0.32	0.54	0.43
2	0.05	0.48	0.27
3	0.50	0.34	0.42

Table 3-24 Coefficients of correlation of daily downstream migration of fishes through the sluice and HPP of Sheksninskoe Reservoir and Lozsko-Azatskoe Lake dam

Species	Sluice – HPP	Sluice – Lake Dam
Roach	0.15	0.38
Pikeperch	0.35	0.41
Carp bream	0.08	0.57

It should be noted that, with the available data, we have not been able to establish any well-defined correlation ($p < 0.05$) between the coefficient of daily variation of the perch family larvae migration and the ecological zones of water intake (Table 3-23).

As has been mentioned, the lack of correlation can be explained by insignificant differences in the ecological zones of water intake for the studied HPPs. When the ecological zones of water intake differ significantly, e.g., at the Sheksninskaya HPP and sluice, and the Lozsko-Azatsky Lake dam, the daily dynamics of the juvenile fish migration depend on the ecological zones of water intake (Table 3-24). This parameter is close for the sluice and the lake dam and different for the sluice and the HPP (see Footnote in Section 3.2).

How the *latitude of the reservoir location affects* the daily dynamics of downstream migration has been thoroughly studied for the European perch migration from Ivan'kovskoe, Sheksninskoe and Ust'-Khantajskoe reservoirs.

The maximum concentrations of the European perch early larvae migrants have been most often observed in the daytime, and, even on a polar day in the Ust'-Khantajskoe reservoir, their migration has been the most intense between 8 – 12 am. Regarding the late larvae migration from the Ust'-Khantajskoe reservoir (Arctic region), the migration occurs at night, i.e., during a polar night. Migration at night is typical for other reservoirs, too (Fig. 3.7).

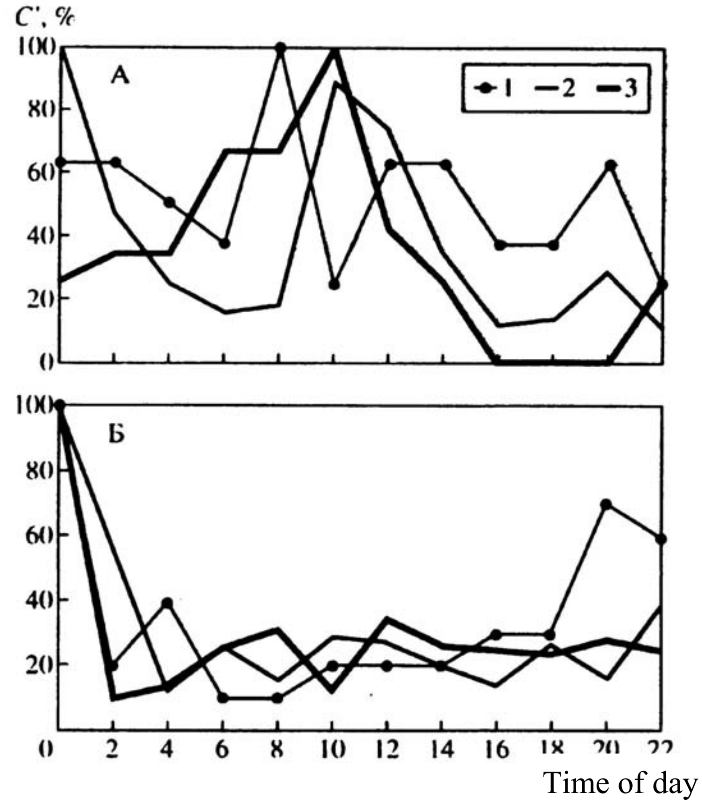

Figure 3.7 Daily dynamics of migration for perch early (a) and late (б) larvae from reservoirs located at various latitudes

1 – Ivan'kovskoe, 2 – Ust'-Khantajskoe, 3 – Sheksninskoe

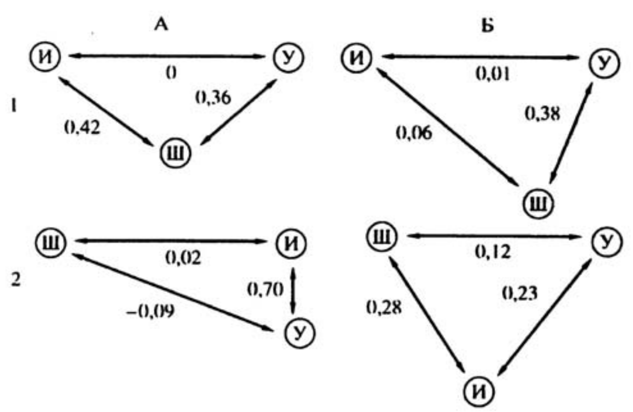

Figure 3.8 Similarities (Euclidean Distance) of daily downstream migration dynamics for perch early and late larvae from three reservoirs

И – Ivan'kovskoe; Ш – Sheksninskoe; У – Ust'-Khantajskoe; the numbers indicate the coefficients of ranking (A) and parametric (Б) correlation of daily dynamics of downstream migration

The comparison of the daily modes of European perch fry migration from various reservoirs has been performed with application of correlation analysis methods (Fig. 3.8).

The parametric correlation coefficients show that the daily dynamics of the European perch downstream migration from Ust'-Khantajskoe reservoir do not differ from the downstream migration dynamics from Sheksninskoe and Ivan'kovskoe reservoirs. However, the ranking correlation coefficients indicate just the reverse situation. The coefficients of daily variation do not show any connection between the daily migration dynamics and the latitude of the reservoir.

Therefore, two methods out of three have not shown any correlation between the daily dynamics of the downstream migration and the latitude of the reservoir. Consequently, the daily dynamics of the European perch juvenile fish downstream migration mostly depend on the environmental factors that are not associated with the geographical latitude of the reservoir.

It should be noted that the presence of light does not seem to significantly affect the migration dynamics either. For example, in June, in the Ust'-Khantajskoe area (polar day) the sun never sets, but the dynamics of perch early larvae migration were pretty much the same as in other reservoirs.

For all the studied reservoirs, the correlation has been performed between the coefficients of daily variation and the geographical latitude of the reservoir. The values of these coefficients were – 0.66 (p = 0.16) for European perch and + 0.26 (p = 0.62) for pikeperch. Uncertainty of the results suggests no connection between the downstream migration daily dynamics and the reservoir geographical latitude (that affects the presence of light in the area).

3.5 Seasonal Dynamics of Fish Downstream Migration

Data on the downstream migration for all the fish species depending on the month of a year are summarized in Table 3-25. Taking into account the fact that the studied reservoirs are located at various latitudes, the seasons there may start at different times and have different lengths. The following criteria have been taken into account for defining the seasons: beginning of freeze-up and ice melting period, analysis of the temperature modes of the reservoirs (Isaev, Karpova, 1989) and the time when the first larvae appear.

Table 3-25 shows that all the studied reservoirs have the maximum concentrations of the migrants in summer. There is shifting of the maximum values from the southern reservoirs to the northern reservoirs from May – June in Kapchagajskoe to August in Ust'-Khantajskoe reservoir. All the maximums are due to the fish larvae migration, with the sole exception of Al. Stambolijski reservoir, where the maximum values are associated with the migration of fry. The shifting of the larvae migration period to later dates in the northern reservoirs can be explained by the fact that the period favorable for their spawning starts there later than in the southern reservoirs.

Table 3-25 Average monthly concentrations of migrants (no./1,000 m^3) from reservoirs

Month	Sheksninskoe	Ivan'kovskoe	Ozerninskoe	Volgogradskoe	Kapchagajskoe	Ust'-Khantajskoe	Al. Stamoblijski	Mostiste
January	2.00	0.15	-	0.8	3.17	-	0.00	0.12
February	0.87	0.16	-	0.7	0.53	-	-	0.11
March	0.74	0.16	-	**0.7**	**8.00**	-	-	**0.04**
April	**0.48**	**1.86**	**1.00**	**0.7**	**1.33**	0.08	**0.30**	**0.17**
May	**0.88**	**1.88**	-	1,173.6	56.30	1.83	9.70	4.32
June	781.19	18.79	62.60	2,063.3	24.37	0.86	10.77	0.06
July	702.97	6.32	-	493.3	12.80	0.36	386.33	0.17
August	69.02	3.06	0.81	39.3	14.50	2.46	0.87	0.16
September	**79.81**	**3.61**	**3.42**	54.7	4.63	**0.14**	0.00	**0.46**
October	**9.13**	**2.77**	**1.02**	**273.3**	**1.07**	0.27	**1.52**	**0.01**
November	**3.50**	**1.27**	**1.62**	**43.3**	**7.63**	-	**0.09**	**0.41**
December	32.42	0.71	-	30.0	16.40	-	0.00	0.20

Note. The values for the spring and fall seasons are highlighted; a minus (–) means that no data are available

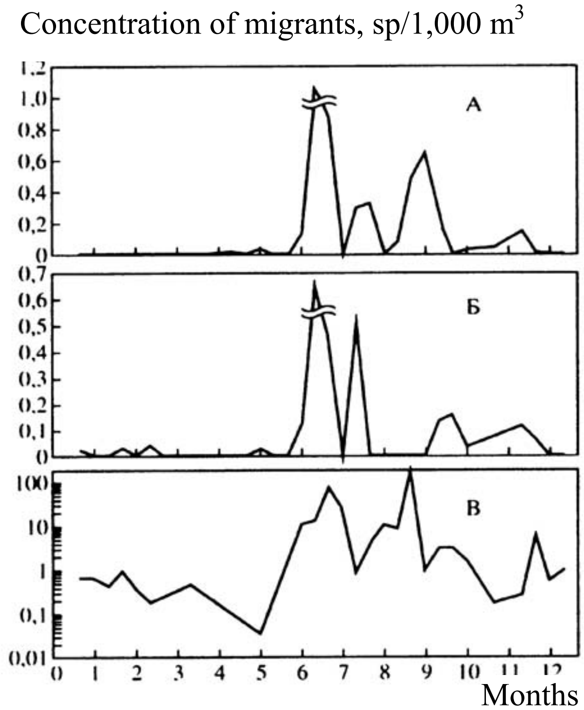

Figure 3.9 Seasonal dynamics of downstream migration for fishes of 1 year old and older from Sheksninskoe reservoir

A – Roach, Б – Carp bream, B – Pikeperch

More detailed analysis of the downstream migration seasonal dynamics shows that, within a year, there are two peaks of the downstream migration of the brood (0+), i.e., in summer with the larvae migration and in the fall with the fry migration (Fig. 3.9). The beginning of the fall migration coincides with the mass exodus of the brood from the littoral zone.

Fishes one year old and older have three migration periods, i.e., spring, summer and fall (Fig. 3.10). The spring migration is associated with post-spawning migration, while the fall migration is associated with the winter hibernation. It is obvious that different species and different reservoirs would have different time and length of those periods, e.g., sardine cisco and peled migrate from Ust'-Khantajskoe reservoir in early October (Fig. 3.11) due to the fall spawning of these species.

Therefore, both juvenile and adult fishes experience intense migration during the periods of mass transitions of fish in the reservoirs.

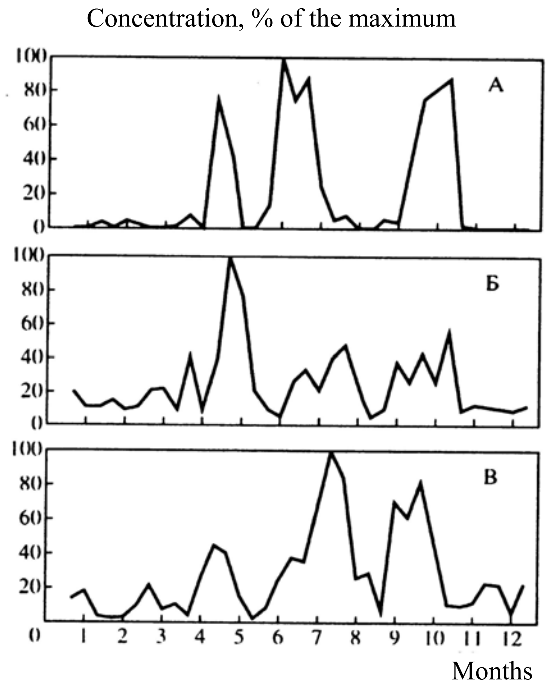

Figure 3.10 Seasonal dynamics of downstream migration for fish 12 months old and older from Ivan'kovskoe and Sheksninskoe reservoirs

А – Bleak, Б – European perch, В – Ruffe

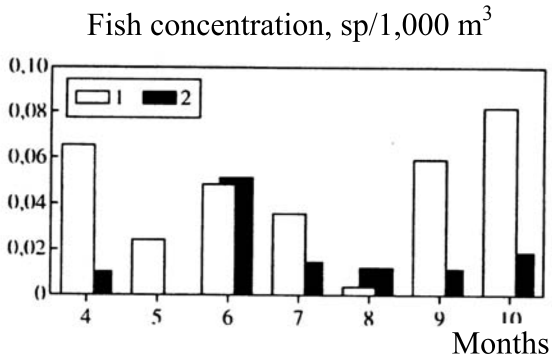

Figure 3.11 Seasonal dynamics of downstream migration of *Coregonus* species older than 12 Months old from Ust'-Khantajskoe reservoir

1 – Sardine cisco, 2 – Peled

Table 3-26 Correlation coefficients for dynamics of fish downstream migration

Reservoir	Ivan'kovskoe	Ozerninskoe	Ust'-Khantajskoe	Kapchagajskoe	Mostiste
Sheksninskoe	0.76	0.60	0.25	0.25	0.08
Ivan'kovskoe		0.49	0.25	0.16	0.13
Ozerninskoe			-1.00	0.37	0.14
Ust'-Khantajskoe				0.50	-0.05
Kapchagajskoe					0.38

Table 3-27 Correlation coefficients for fish downstream migration in EZWI groups and between EZWI groups

EZWI group	1	2	3
1	0.62	0.05	0.12
2		0.50	0.17
3			1.00

To identify the correlation between the ecological zones of water intake and the seasonal dynamics of fish downstream migration, the similarities of fish downstream migration seasonal dynamics in various reservoirs have been studied with application of the Spearman coefficient of ranking correlation. This study does not include Volgogradskoe reservoir where the migration of adult fish has not been taken into account, and Al. Stambolijski reservoir where 99% of the migrants are active migrants (pikeperch). Table 3-26 gives the correlation coefficients for individual pairs of the reservoirs, and Table 3-27 gives averaged correlation coefficients for EZWI groups. HPPs of one EZWI group have high values for these coefficients. The correlation coefficients between the EZWI groups are much lower. It means that, in the EZWI group, the variations of the seasonal dynamics are not so significant as between the groups, i.e., the seasonal dynamics of the fish downstream migration is related to the ecological zones of water intake.

To illustrate these differences, we have grouped all the data on seasons and ecological groups of water intake (Table 3-28). The comparative analysis does not include *Coregonus* larvae in Ust'-Khantajskoe reservoir that, unlike other fish species, migrate before the ice melts in May – June. The analysis shows that the HPPs of the first EZWI group have more migrants in summer than the HPPs of the other EZWI groups. It is primarily associated with the larvae migration. The HPPs of the second and the third EZWI groups have more migrants in winter and spring when the brood and older fish migrate. It can be explained by the fact that the water intake currents have a greater effect on the fish larvae habitat for most species in the first EZWI group (sublittoral and littoral zones). It is especially true for Sheksninskaya HPP.

Table 3-28 Concentration of migrants (%) in various seasons (100% total of the average seasonal concentration values for a reservoir)

Reservoir	EZWI group	Spring		Summer		Fall		Winter	
Sheksninskoe	1	0.2		90.7		7.8		1.3	
Ivan'kovskoe	1	10.8	3.9	64.4	80.7	21.3	11.7	3.4	3.0
Ozerninskoe	1	3.7		86.8		6.1		4.4	
Ust'-Khantajskoe	2	6.1	6.8	77.9	72.8	7.7	8.5	8.3	12.1
Kapchagajskoe	2	7.4		67.7		9.2		15.8	
Mostiste	3	6.3	6.3	74.5	74.5	11.5	11.5	8.7	8.7

Table 3-29 Results of dispersion analysis of average daily concentrations of migrants through HPP water intakes for various EZWI groups

Season	Average concentration value (no./1,000 m^3) for various correlations of factors			
	Group 1	Group 2	Group 3	Group 4
Spring	1.479	3.351	0.203	0.000
Summer	201.849	373.730	58.875	0.000
Fall	1.992	75.088	0.683	0.000
Winter	3.420	6.6333	0.048	0.000
Average	52.185	114.700	14.592	0.000

	Direct analysis			Logarithmic analysis			Degree of freedom
	Influence of factors	Degree of influence		Influence of factors	Degree of influence		
	F_{fact}	%	F	F_{fact}	%	F	K
EGWI	**4.44**	5.6	**4.343**	**15.49**	13.1	**11.004**	3
Season	2.01	2.5	1.908	25.95	21.9	**20.527**	3
Both of the above	1.20	4.6	0.659	**2.60**	6.6	0.975	9

Note. The Fisher criteria values that exceed the critical value for the significance level (0.01 (ke = 207)) have been highlighted.

To confirm the data of the correlation analysis, we have performed a two-factor dispersion analysis of the fish downstream migration seasonal dynamics. The average daily concentration values have been used there for all the fish species and their logarithms[1]. Table 3-29 shows the results of this analysis.

Though any method for calculations of how the ecological zones of water intake affect the concentration of the fish migrants can be used, we are inclined to trust the logarithmic calculations more because their statistical distribution significantly differs from the normal law. The dispersion analysis shows that both season and the EZWI, as well as the combination of these two factors, affect downstream migration, i.e., the concentration of the migrants would vary in various reservoirs during various seasons. However, they affect migration in a slightly different way, i.e., migration would depend more on the season (~ 22% of the value of the influence of all other factors) than the ecological zones of water intake (~13%).

General Patterns of Fish Downstream Migration for Various Types of Ecological Zones of Water Intake

Earlier we identified four types of reservoirs with a slow water exchange, taking into account the water intake conditions and the morphology of the reservoir bottom (Pavlov, Kostin et al., 1985a). According to the previous classification, the HPP water intake groups with various EZWI described in this book belong to the type "HPP reservoirs". However, this book clarifies the previously given classification of the reservoirs. The latest data show that the classification should rather be based on the water intakes and the river outflows from the lake than on the reservoirs. Beyond that, we have slightly modified the conditions of classification, i.e., instead of the water intake conditions and the water reservoir bottom morphology, we now use the quantitative estimation of the ecological zones of water intake. Now we refer the water intakes of various applications, as well as the river outflows from the lakes, to one of the four EZWI types. The schematic presentation of how the intake and outflow currents affect the ecological zones of the reservoirs, depending on the ecological zones of water intake, is provided in Fig. 3.12. In this presentation, only the Nero Lake dam water intake belongs to the first EZWI type, and it all the water is taken from the littoral. The Veksa River outflow from Pletscheevo Lake (it has all the ecological zones), as well as the Vestonice water reservoir dam (Pavlov et al., 1987) where the littoral and sublittoral zones can be identified, belong to the second EZWI type. Those are the water intake locations in these two reservoirs. The third EZWI type includes Lozsko-Azatsky Lake dam and Sheksninskaya sluice water intake where the water is taken from the epipelagic, sublittoral and littoral zones. The fourth EZWI type includes the HPP water intakes in the reservoirs described in this book. Their water intake current primarily affects the bathy-pelagic zone of the reservoirs. Therefore, the groups of the ecological zones of water intake belong to the EZWI type the same way the species belong to the genera (see Fig. 3.1).

[1] Logarithms have been applied to approximate the input data distribution to the normal distribution.

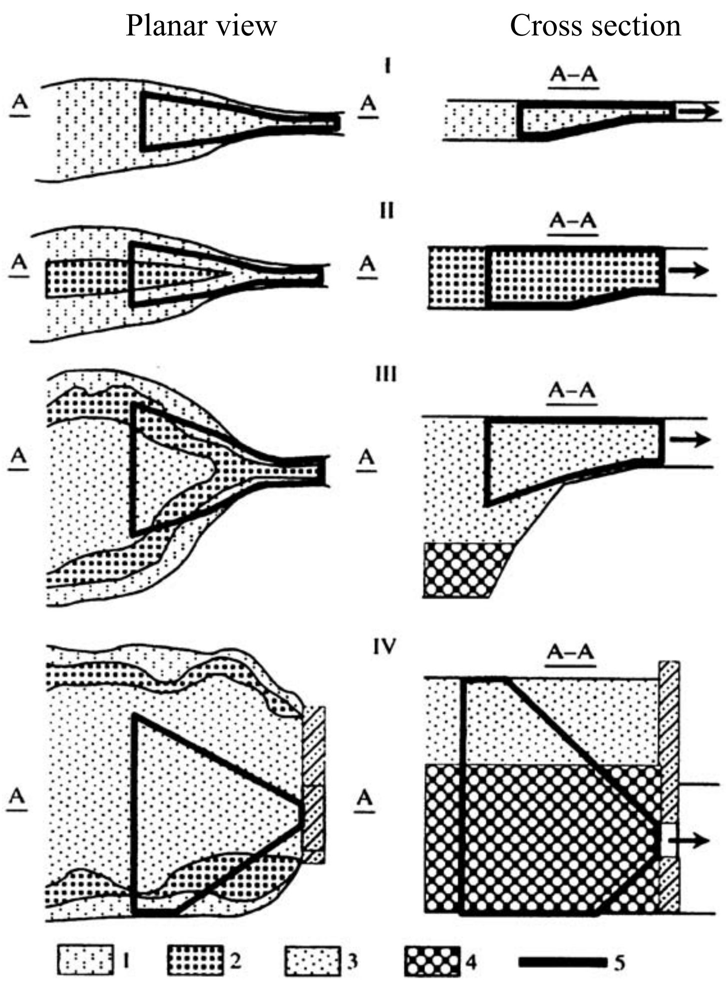

Figure 3.12 Water intake for various EZWI types (I – IV)

Ecological zones: 1 – littoral, 2 – sublittoral, 3 – epipelagic, 4 – bathy-pelagic; 5 – water intake area borderlines

Table 3-30 Dispersion analysis results for average daily concentrations of migrants through HPP water intakes with various EZWI types

Season	Average concentration value (no./1,000 m^3) for various correlations of factors			
	Type I	Type II	Type III	Type IV
Spring	-	10.130	191.377	1.745
Summer	148.600	161.466	182.381	218.574
Fall	29,865.949	0.245	16.449	24.241
Winter	0.015	0.370	0.100	3.494
Average	10,004.854	43.053	97.577	62.014

	Direct analysis			Logarithmic analysis			Degrees of freedom
	Influence of factors	Degree of influence		Influence of factors	Degree of influence		
	F_{fact}	%	F	F_{fact}	%	F	K
EGWI	**18.662**	9.7	**10.917**	**17.040**	12.0	**13.789**	3
Season	**18.837**	9.8	**11.030**	**6.213**	4.4	**4.627**	3
Both of the above	**19.020**	29.7	**8.238**	**7.225**	15.2	**3.499**	9

Note. The Fisher criteria values that exceed the critical value for the significance level (0.01 (ke = 292)) have been highlighted.

Two-factor dispersion analysis has been performed for the highlighted types of ecological zones of water intake. The results (Table 3-30) show that the type of ecological zones of water intake, season, and the combination of the two, affect the concentration of the migrants. In this case, the combination of the two affects the most (15%), while the EZWI type affects more (12%) than the season, i.e., when the EZWI differs significantly, it affects the concentration more (see Table 3-29).

The first EZWI type has the maximum concentration of the migrants in the fall (Fig. 3.13), when the brood (primarily Cyprinidae species) leaves the littoral zone for the pelagic zone. Since, in this case, the lake only has the littoral zone, the species migrate from it.

The second EZWI type is a transition between type I and type III.

One of the characteristics of the third EZWI type is that it has a significant concentration of the migrants in spring when the species migrate after spawning. For example, European smelt has this kind of migration in Lozsko-Azatskoe lake and ruffe in

Sheksninsky sluice. It can be explained by a significant influence of the water intake currents on the littoral and sublittoral zones.

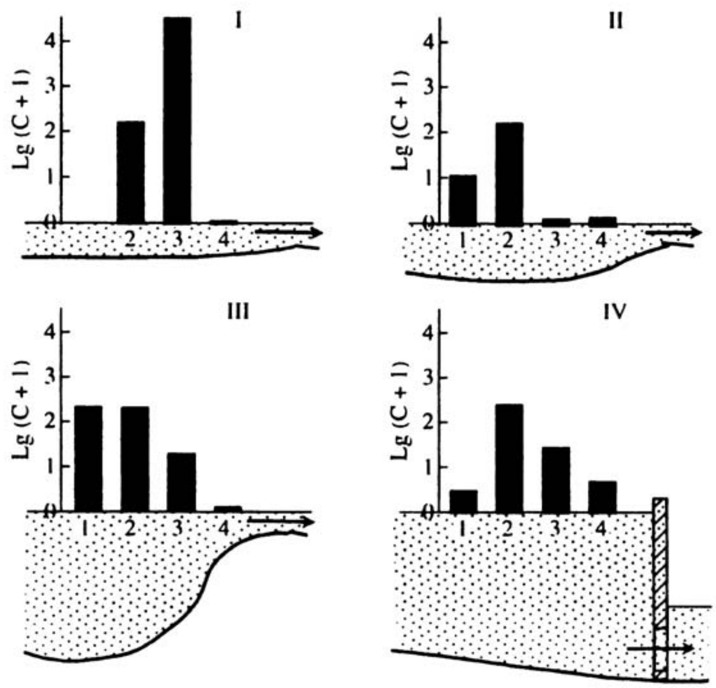

Figure 3.13 Vertical cross-sections of headwaters areas for various EZWI types (I – IV) and seasonal dynamics of migrant concentrations (C) from reservoirs

1 – spring; 2 – summer; 3 – fall; 4 – winter

In comparison with all other types, the fourth EZWI type has the most significant migration during a cold season. It can be explained by the fact that, in those reservoirs, the water intake currents mostly affect the bathy-pelagic zone where the fishes hibernate.

* * *

Therefore, one of the major patterns of fish downstream migration from the reservoirs with a slow water exchange identified in this book is the relationship between, on the one hand, the ecological zones of water intake and, on the other hand, species-specific structure, age and size of the migrating fish species, as well as seasonal and daily dynamics of their migration. However, the quantitative parameters of the downstream migration, to a large extent, depend on other environmental factors.

Table 3-31 Fish downstream migration predictions based on EZWI theory and their verification

Predictions	Actual observations
Downstream migration of fish species with the Ist and IVth types of distribution (pikeperch, peled, sardine cisco, ziege, Caspian anadromous shad, sprat, and European perch) is very likely because they constantly or almost constantly inhabit the pelagic zones	The fishes of the Ist and IVth types of distribution are mass migrants (see Table 3-1)
Downstream migration of fish species of the Vth type of distribution (carp bream, silver bream, and roach) is likely, and the seasonal dynamics of their migration should correspond to the time of their staying in the pelagic zone (see Table 2-3)	Roach have been reported to migrate in seven reservoirs, carp bream in six, silver bream in four reservoirs (see Table 3-1). Mass migration of the juveniles of these species has been observed when they inhabited the pelagic zone (see Table 4.1)
No downstream migration is likely to occur for the fish species of the IInd type of distribution (Northern pike, pumpkinseed sunfish, loaches, and rudd) because the water intake zone does not affect their habitat	Practically no fish species of the IInd type of distribution have been observed to migrate
In all the studied reservoirs, except Nurekskoe reservoir, downstream migration of fish species of the IIIrd type of distribution (ruffe, burbot, sterlet, and Wels catfish) is likely because they inhabit the bathyal zone affected by the HPP water intakes	Downstream migration of ruffe has been observed in six reservoirs (see Table 3-1). The migration of burbot, together with that of other species, has been observed in three reservoirs
The water intakes of the HPPs of the first EZWI group affect a greater number of the ecological zones of the reservoir, and, therefore, more species migrate in those reservoirs. The water intakes of the HPPs of the second EZWI group will effect a lesser number of species. The HPPs of the fourth EZWI group is likely to affect the least number of species.	The index of similarity of species changes as indicated in the predictions (see Table 3-6).
Differences among EZWI groups should be observed depending on the size and age of the migrants	EZWI groups do not give certain correlations with the size and age of the migrants, but the EZWI types do (see Tables 3.15, 3.16)

The end of Chapter 2 gives predictions of the downstream migration characteristics based on analysis of the ecological zones of water intake and the fish distribution in the studied reservoirs. On the whole, those predictions were correct (Table 3-31), thereby confirming the theory of the ecological zones of water intake and making it possible to apply this theory to developing qualitative evaluations of fish downstream migration from water reservoirs with a slow water exchange and, specifically, from man-made reservoirs.