Jun 23rd, 9:35 AM - 10:20 AM

Plenary Speakers: Downstream Migration of Fish in Regulated Rivers: Patterns and Mechanisms

Dmitrii Pavlov
A.N. Severtsov Institute of Ecology & Evolution

Victor Mikheev
A.N. Severtsov Institute of Ecology & Evolution

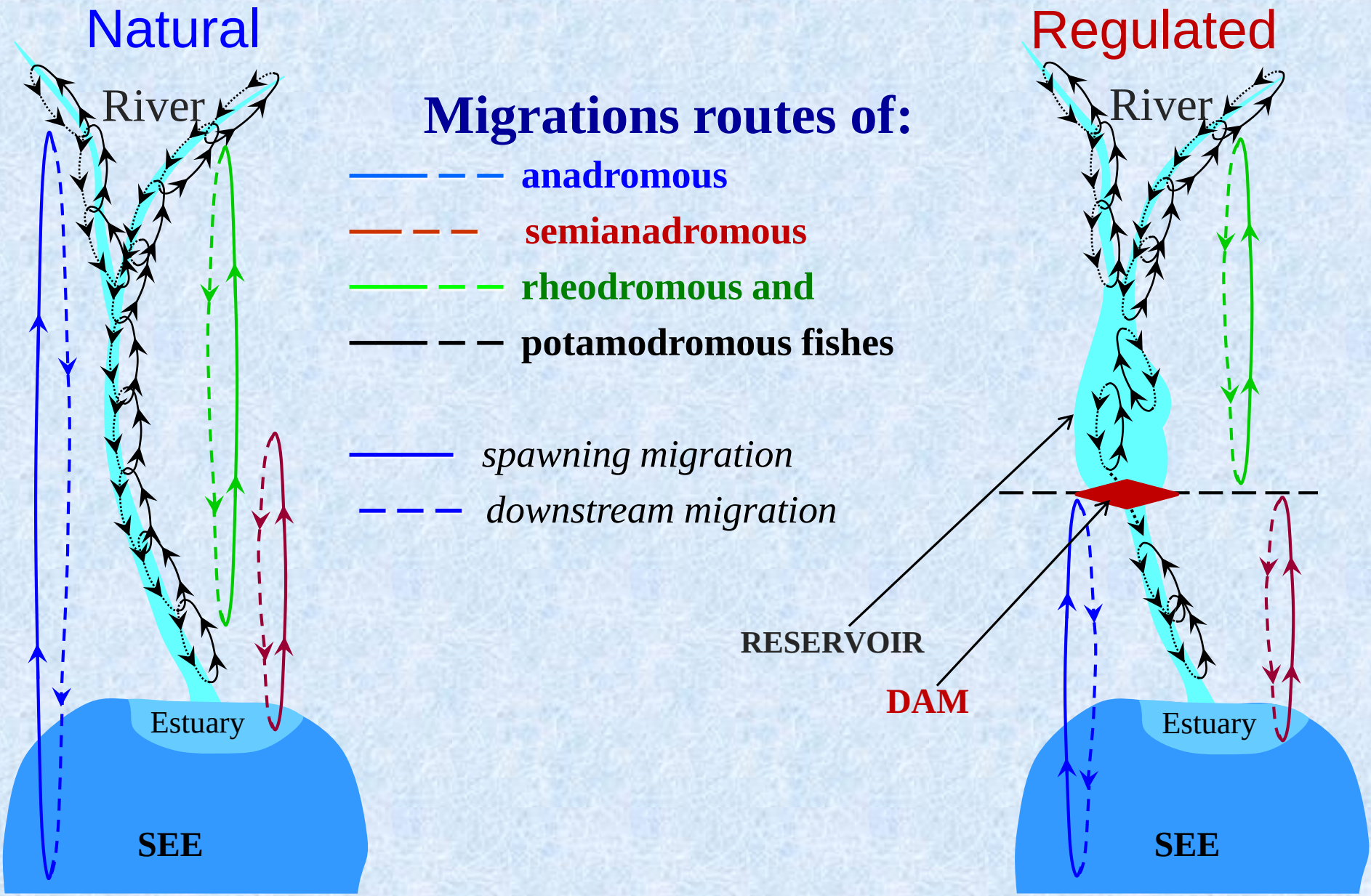
Vasilii Kostin
A.N. Severtsov Institute of Ecology & Evolution

DOWNSTREAM MIGRATION OF FISH IN REGULATED RIVERS: PATTERNS AND MECHANISMS

Dmitrii Pavlov, Victor Mikheev and Vasilii Kostin

A.N. Severtsov Institute of Ecology & Evolution, Russian Academy of Sciences, Moscow

Migration “rings” of fishes in natural and regulated rivers



OUR GOALS ARE TO SHOW

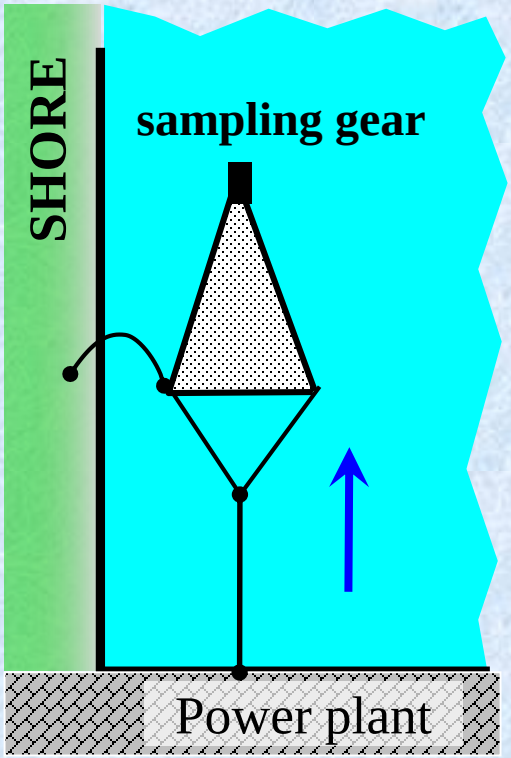
- **General patterns and variability of downstream migration in regulated rivers** (species composition, tendency to migrate, age and size structure of migrants, diel and seasonal dynamics of downstream migration)
- **Mechanisms of downstream migration** (ecological and behavioral aspects of their modifications)
- **Impacts of the type of water abstraction on the downstream migration**. How does distribution of fishes interact with water abstraction?
- How **water turnover rate** in reservoirs influence downstream migration?
- **Injures of fish** migrating downstream through dams
- **Strategies, principles and measures of protection** of fish migrating downstream in regulated rivers

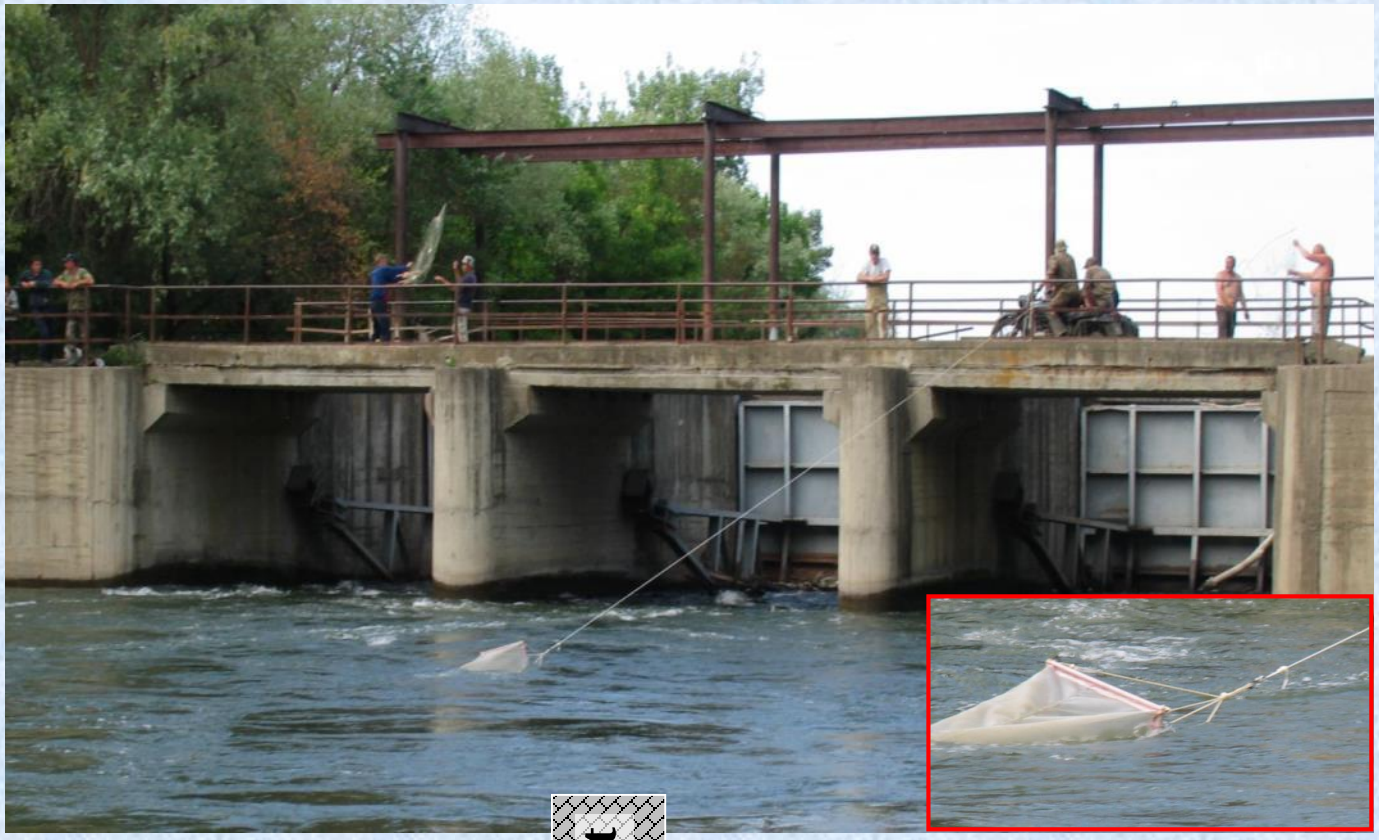
Methods Objects

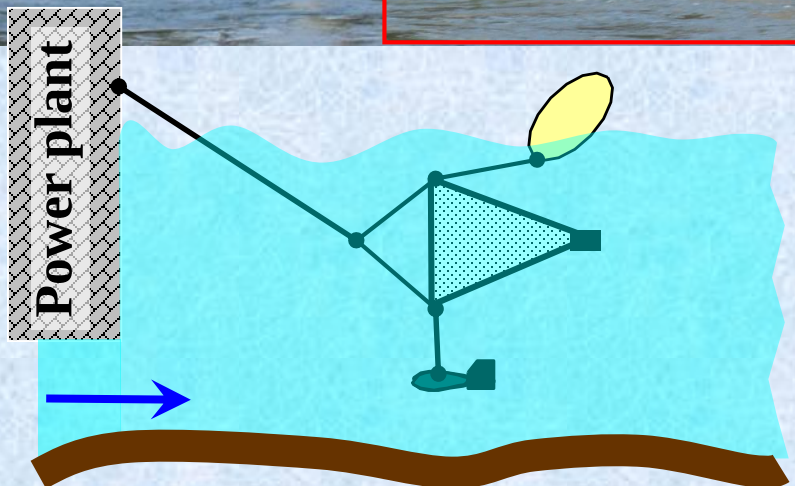
Geography

of our studies

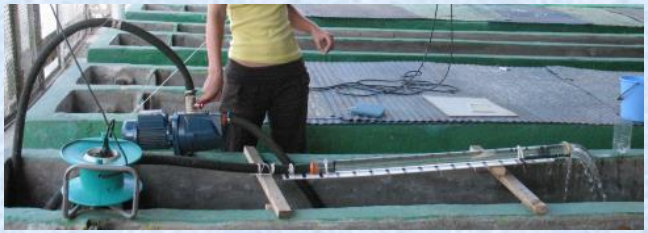
Sampling in the tale race





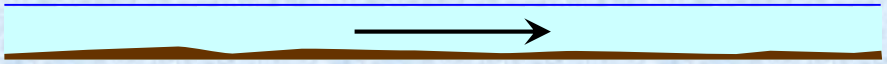


Laboratory and *in situ* experiments

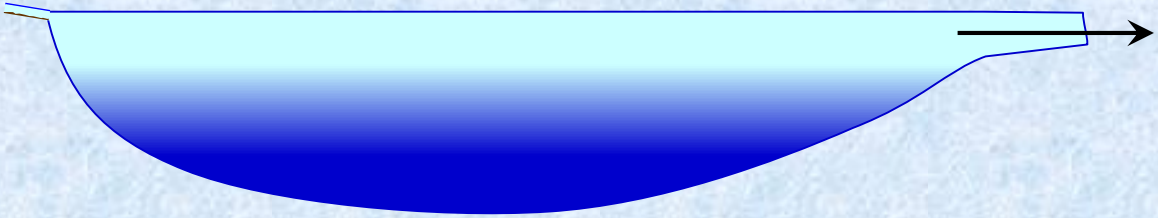


Types of water bodies where downstream migration of young fish was studied

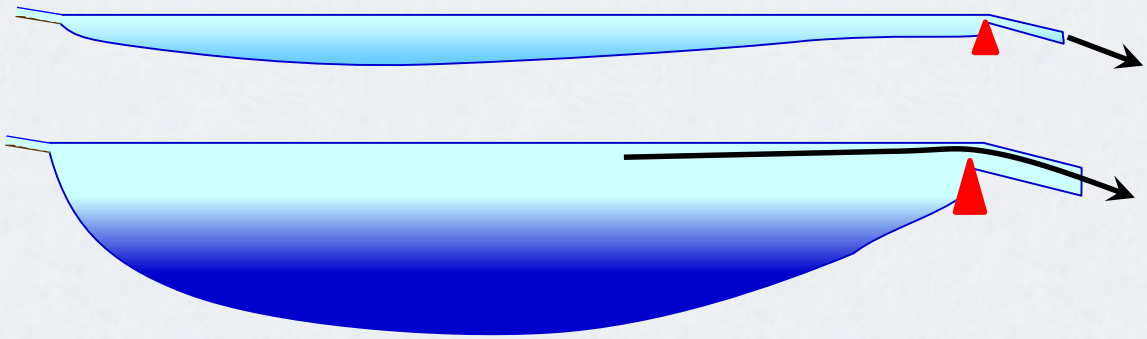
Rivers



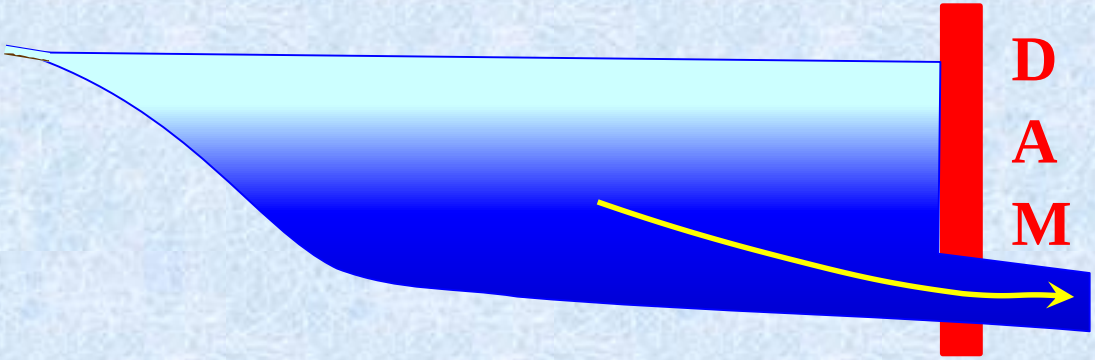
Natural lakes



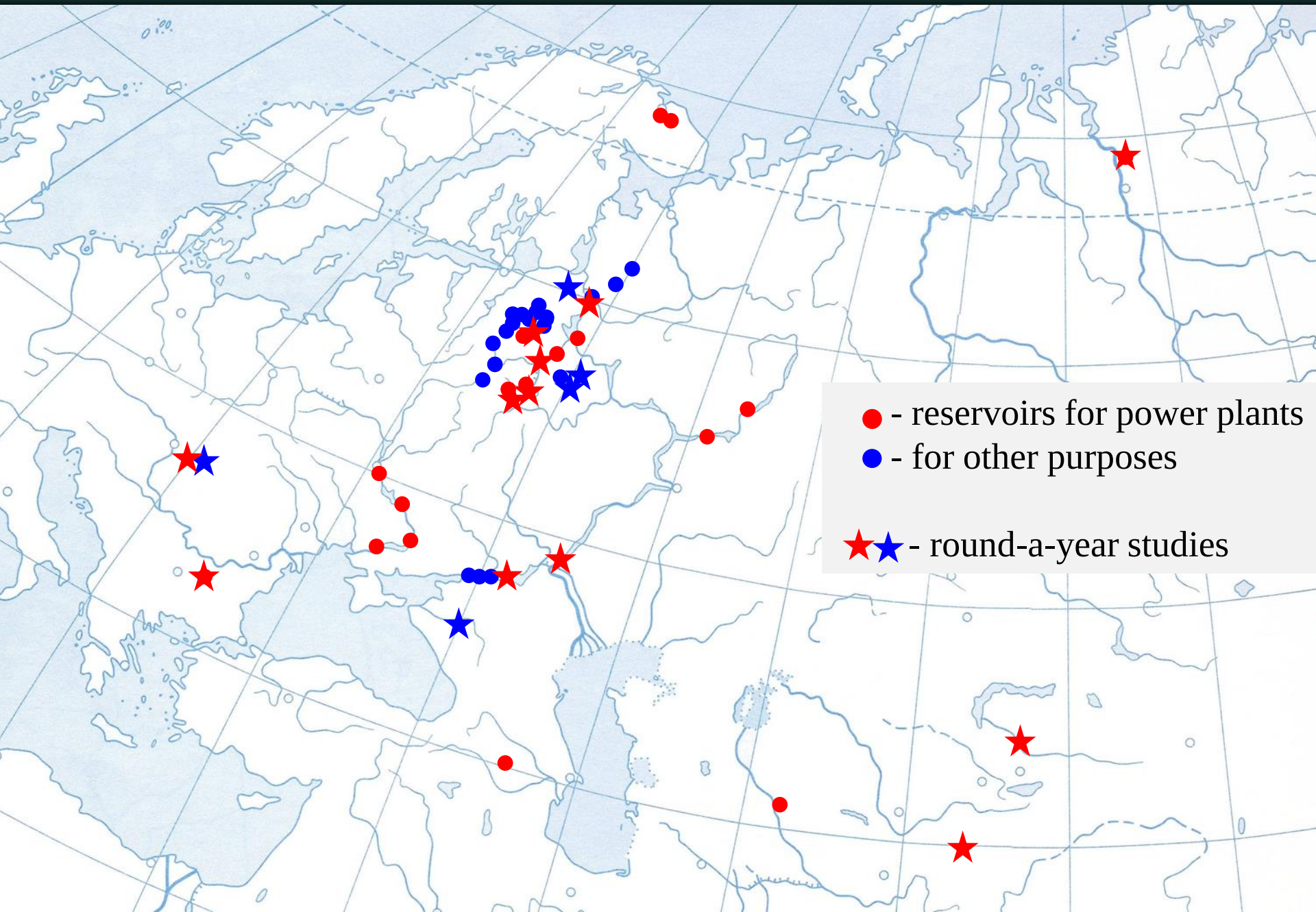
Reservoirs or regulated lakes with **epilimnial release**



Reservoirs with **hypolimnial release**



Water reservoirs where downstream migration was studied



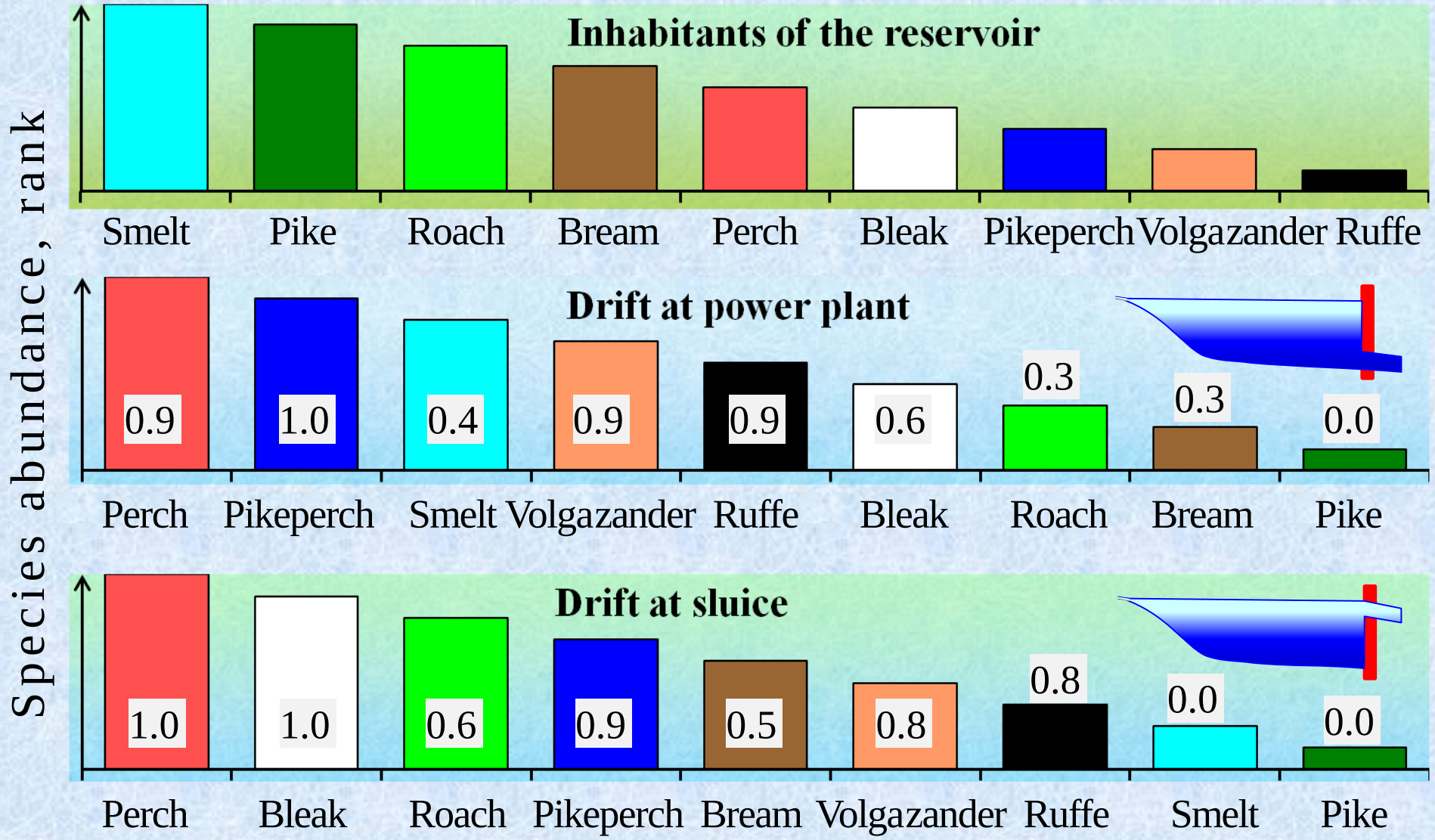
Patterns of downstream migration

Effects of regulation of water discharge

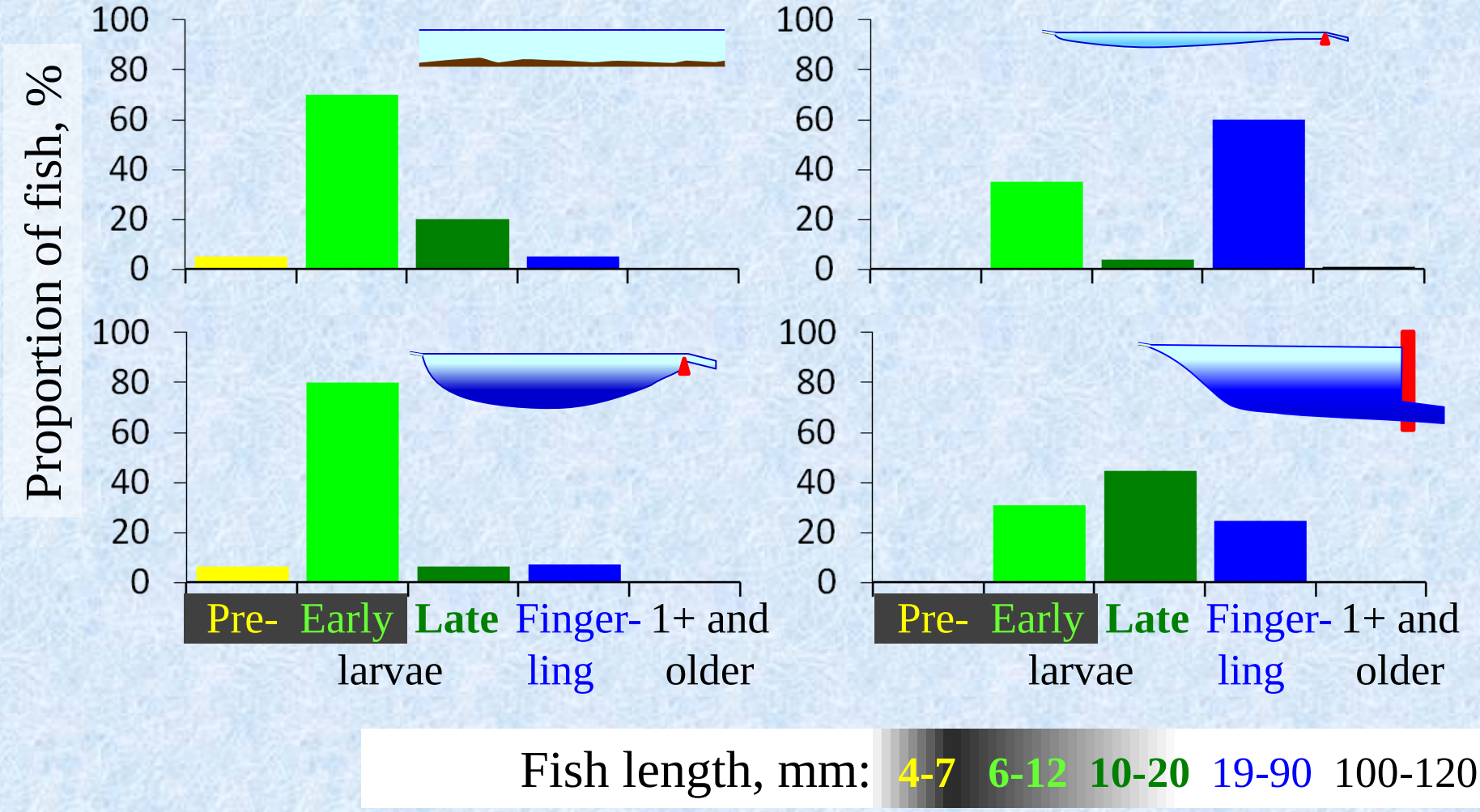
Number of fish (millions per year) passed through the dam of reservoirs with hypolimnial release

Water reservoir	Number of fish	Most numerous fishes
Sheksninskoe	159	Perch, smelt, pikeperch
Ivan'kovskoe	15	Bream, bleak, smelt
Volgogradskoe	72867	Pikeperch, perch, Volga shad
Kapchagaiskoe (Kazakhstan)	362	Pikeperch, bream
Ust'-Khantaiskoe	11	Perch, European cisco, peled
Al.Stamboliiski (Bulgaria)	24	Pikeperch

Index of "migratory state" of fishes drifting from the Sheksninskoe Reservoir through the hypolimnial (power plant) and epilimnial (sluice) outflows

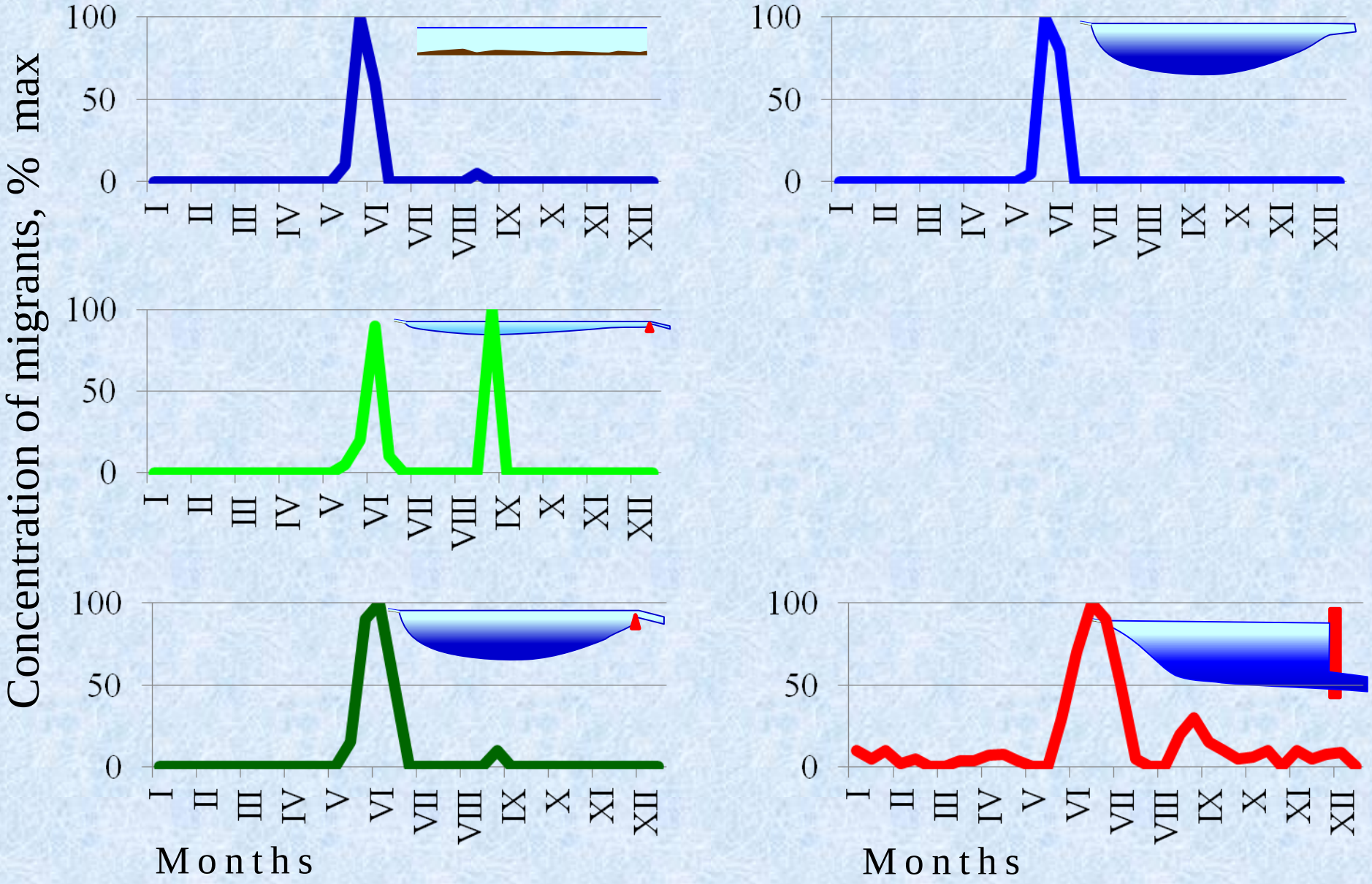


Age and size of young perch migrating through different water bodies

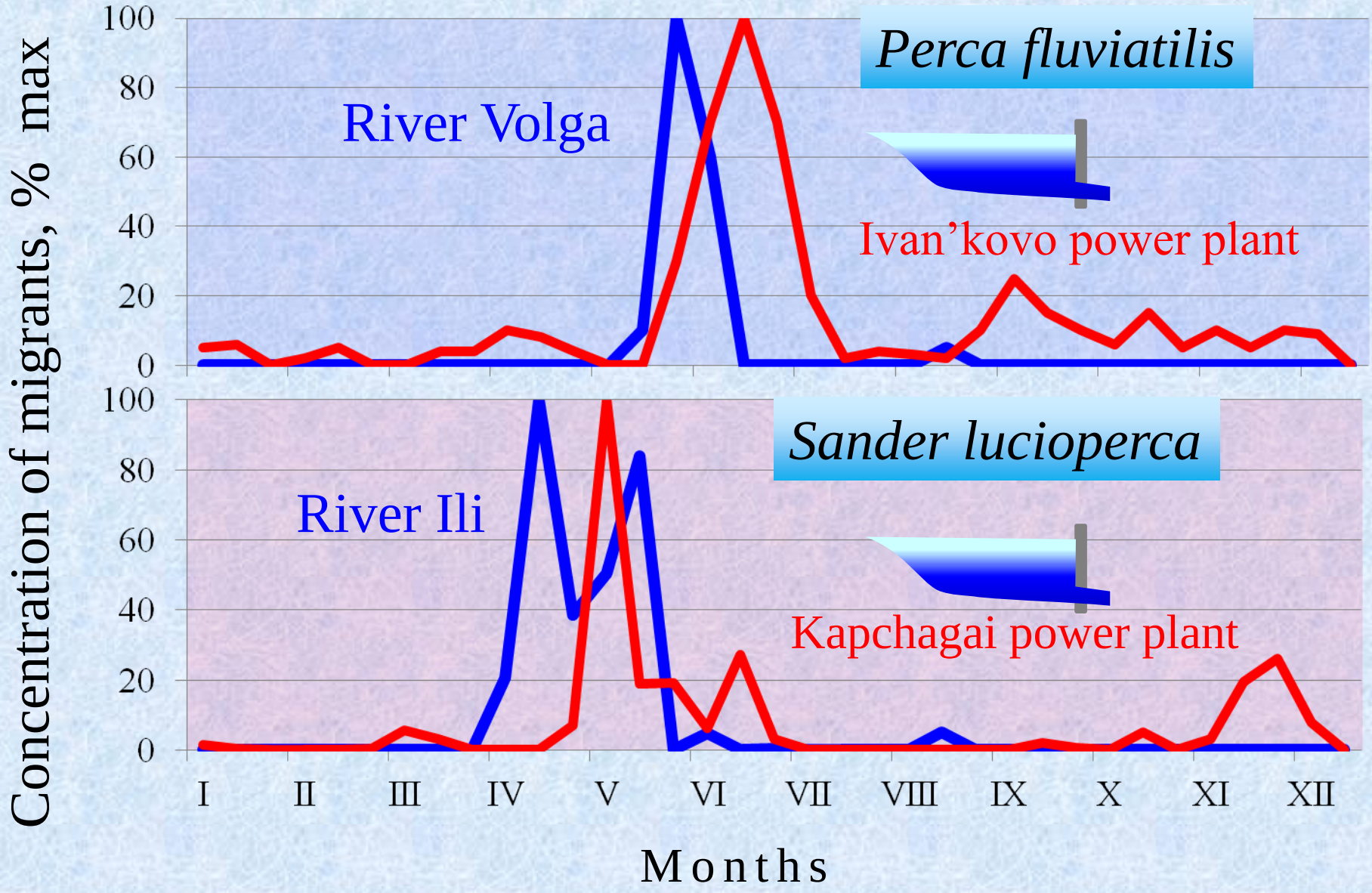


Fish bigger than 120 mm very rarely were recorded among downstream migrants

Seasonal dynamics of perch migration in a river and different reservoirs



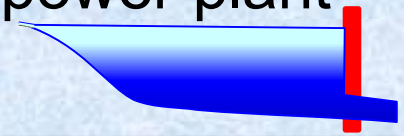
Seasonal dynamics of fish migration in rivers and reservoirs



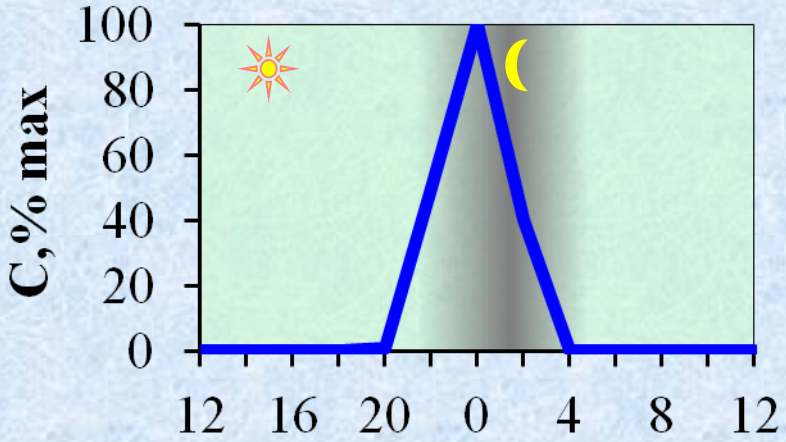
Diel changes of downstream migration of fish larvae in the River Volga and from the reservoir on the same river

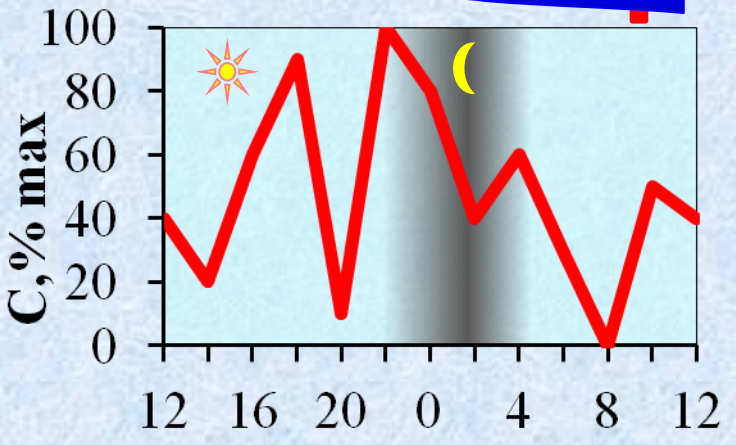
River Volga

Ivan'kovo power plant

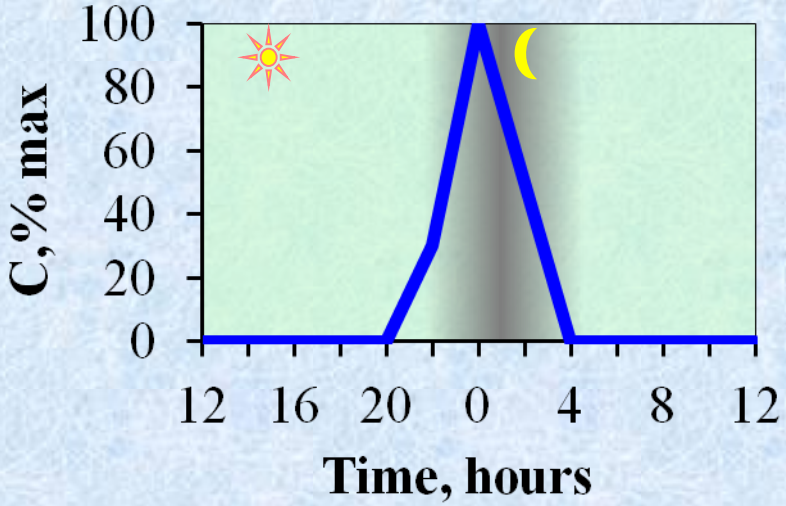


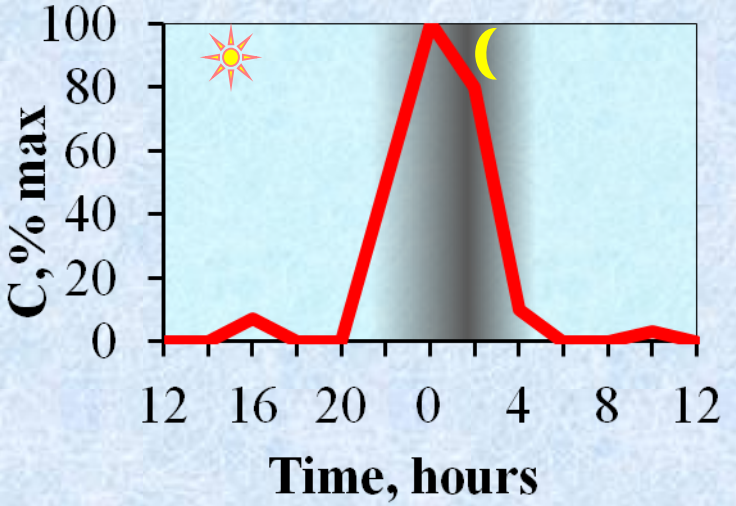
Percidae





Cyprinidae





Multilevel mechanisms of downstream migration

Hierarchy of mechanisms controlling strategy and patterns of downstream migration

Mechanisms of the:

First level → **Create preconditions for migrations**

Second level → **Suppress rheoreaction – major behavioral complex controlling fish activity in the water flow**

Third level → **Modify spatial distribution and dynamics of migrating fish**

Trade-off between the strategies of migration and residency

Shaping of downstream migration patterns

MECHANISMS OF THE FIRST LEVEL

Nonspecific adaptations

Morphological - high content of water, oil drops, swim bladder.

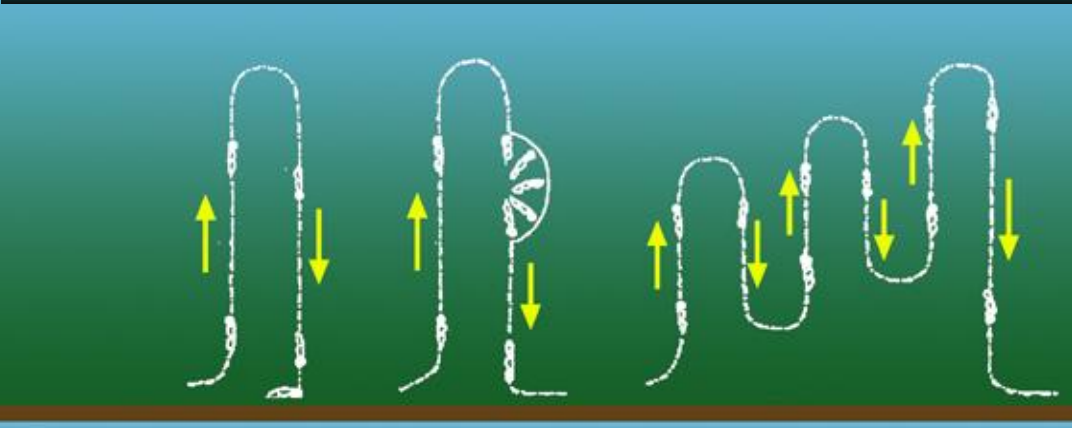
Behavioral – innate, multy-functional reactions (hop-and-sink movements, positive phototaxis, negative thigmotaxis and others).

Specific adaptations

Physiological – diurnal changes of buoyancy, differentiation according to physiology and biochemical state.

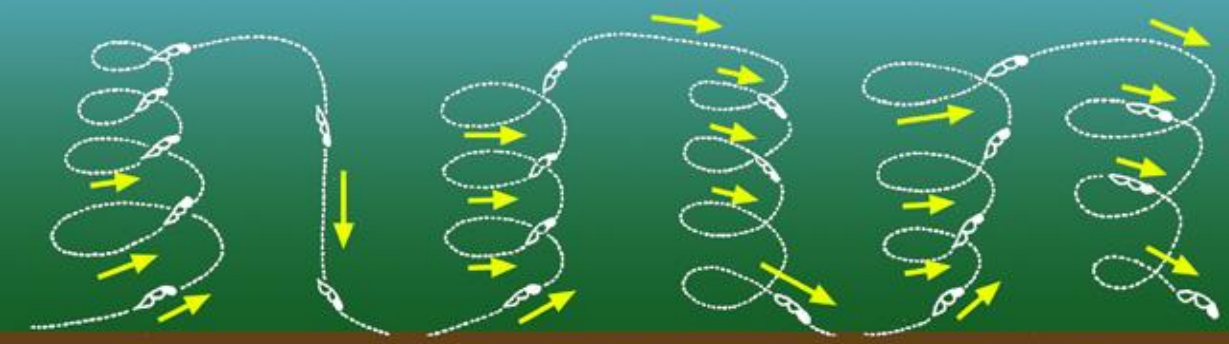
Behavioral – motivated responses to water flow controlled by fish migratory state.

Hop-and-sink movements of prelarvae of sturgeons

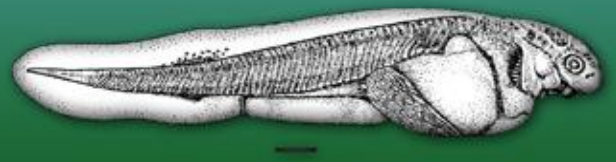


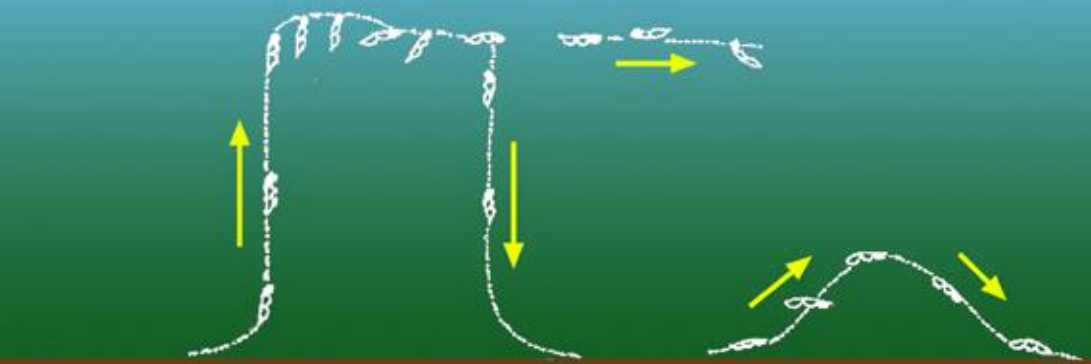
Stages of development:

FIRST



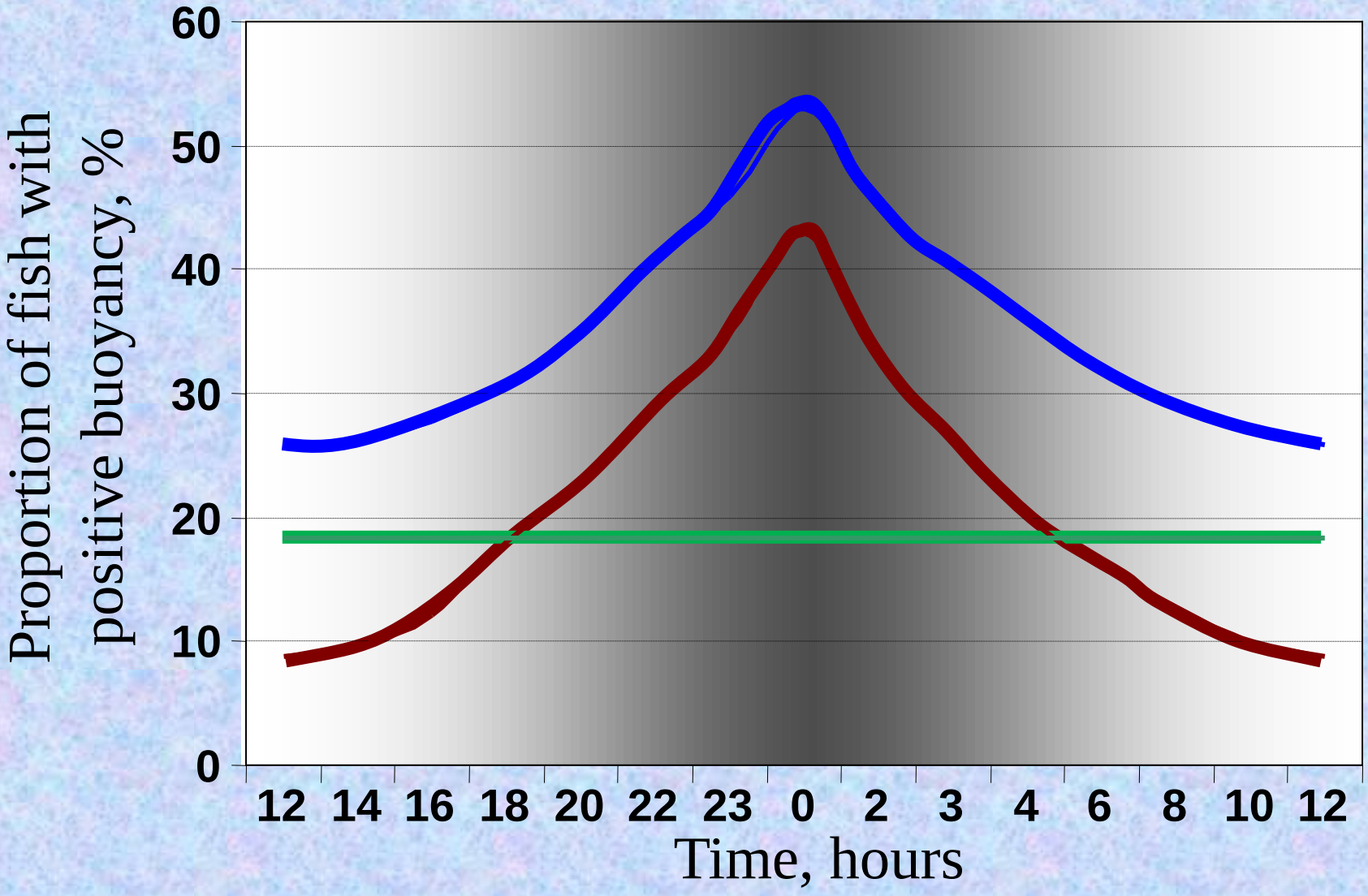
SECOND





THIRD

Diel changes of buoyancy of juvenile cyprinids



MECHANISMS OF THE SECOND LEVEL

Suppression ("neutralization") of rheoreaction which controls fish activity in the water flow

Occurrence of the fish in the flow with velocity (V_f) higher than critical velocity (V_c)

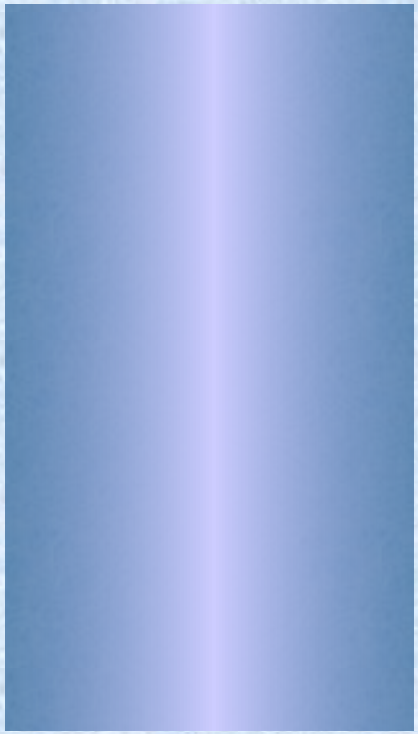
$$V_f > V_c$$

Rheoreaction does not compensate drift

Rheoreaction is modified by migratory state of fish or by other motivations (aggression, shoaling, territoriality)

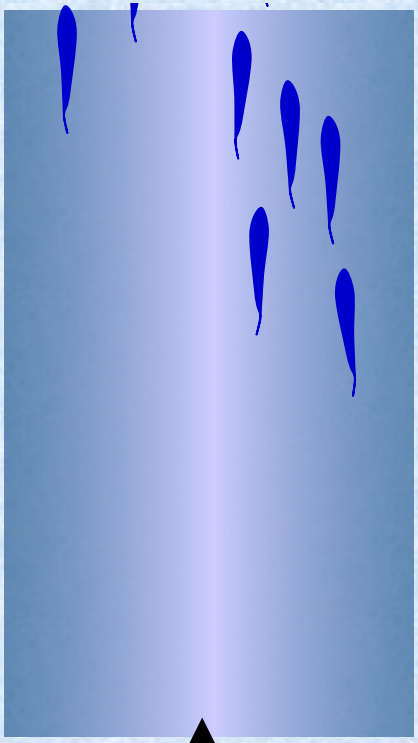
Forms of the downstream migration of fish

Passive



Vf = Vm

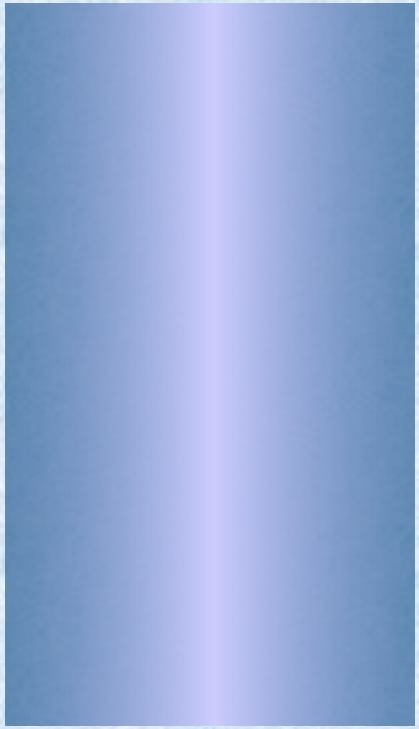
Active-Passive



Vs

Vf > Vm

Active



Vs

Vf < Vm

Vf – flow velocity

Vs – fish swimming velocity

Vm – velocity of migration

MECHANISMS OF THE THIRD LEVEL

Biological

- Fish buoyancy
- Diel vertical migrations
- Feeding and defense behavior
- Phototaxis
- Hydrostatic reactions
- Rheoreaction
- Thermopreferendum

Physical

In rivers:

- lateral circulation
- rheogradient flow
- turbulence

In reservoirs:

- discharge
- wind-induced
- compensatory and
- circulatory ***currents***

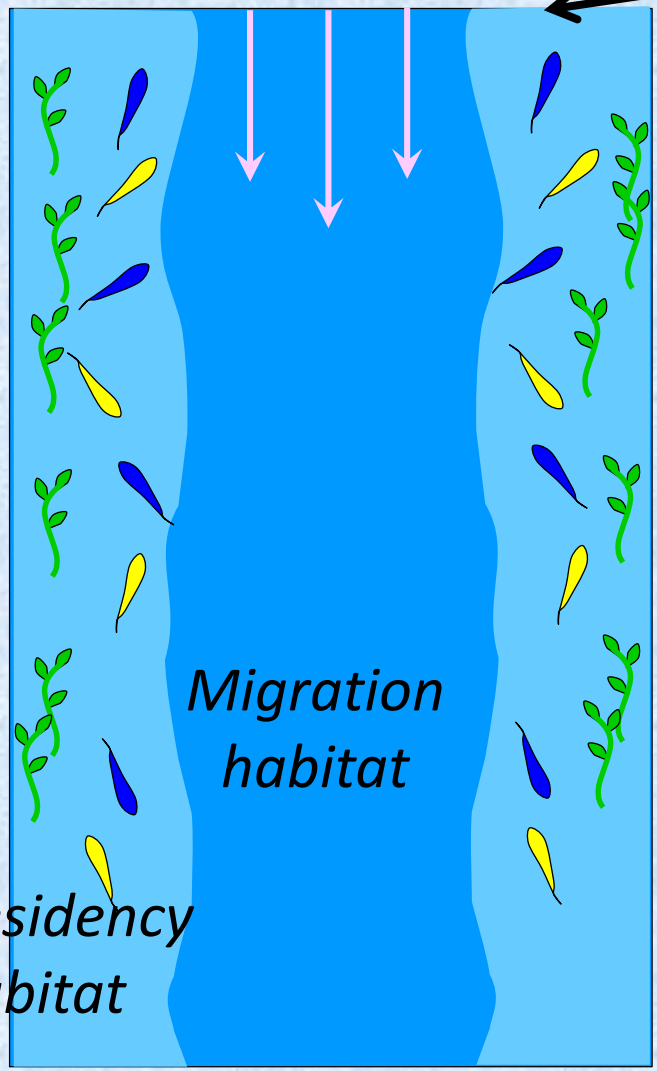
Interactions of **biological factors**

(*behavior, spatial distribution*, …)

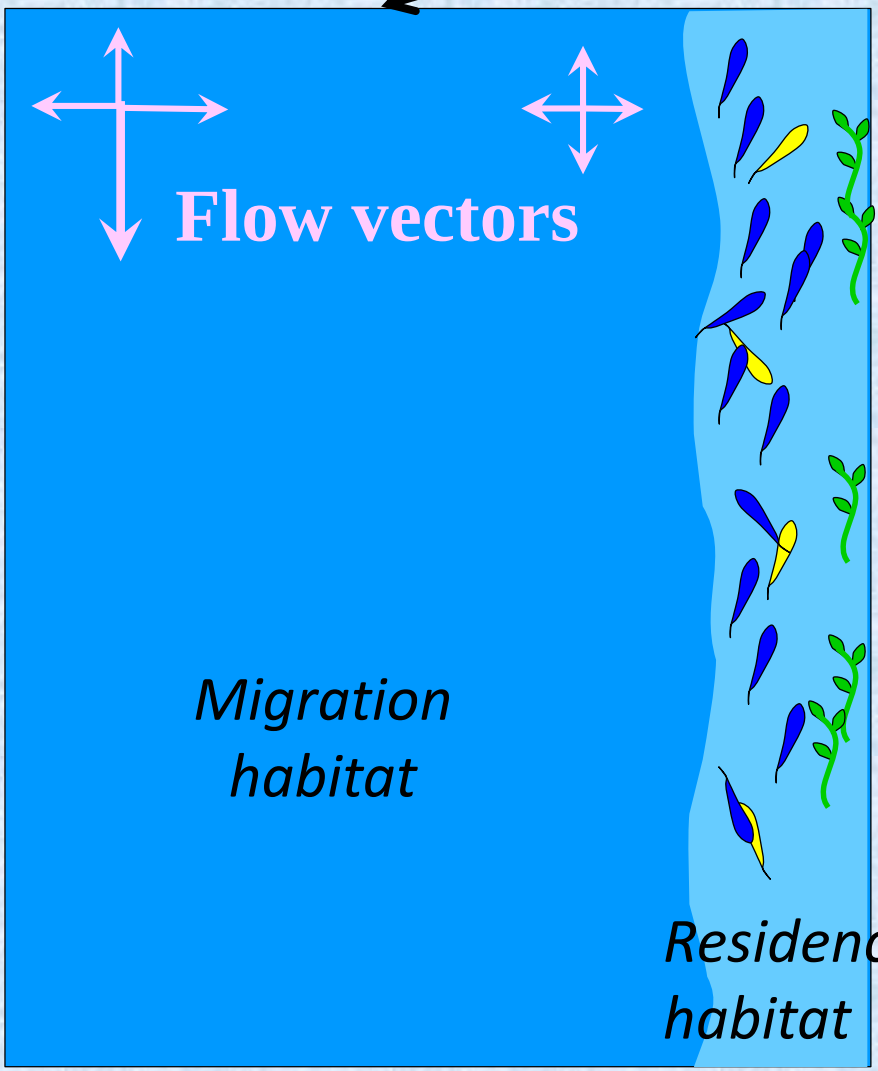
and **hydrology**

(*flow structure, water abstraction*, …)

Day-and-night fish movements as a basis for downstream migration in rivers and reservoirs

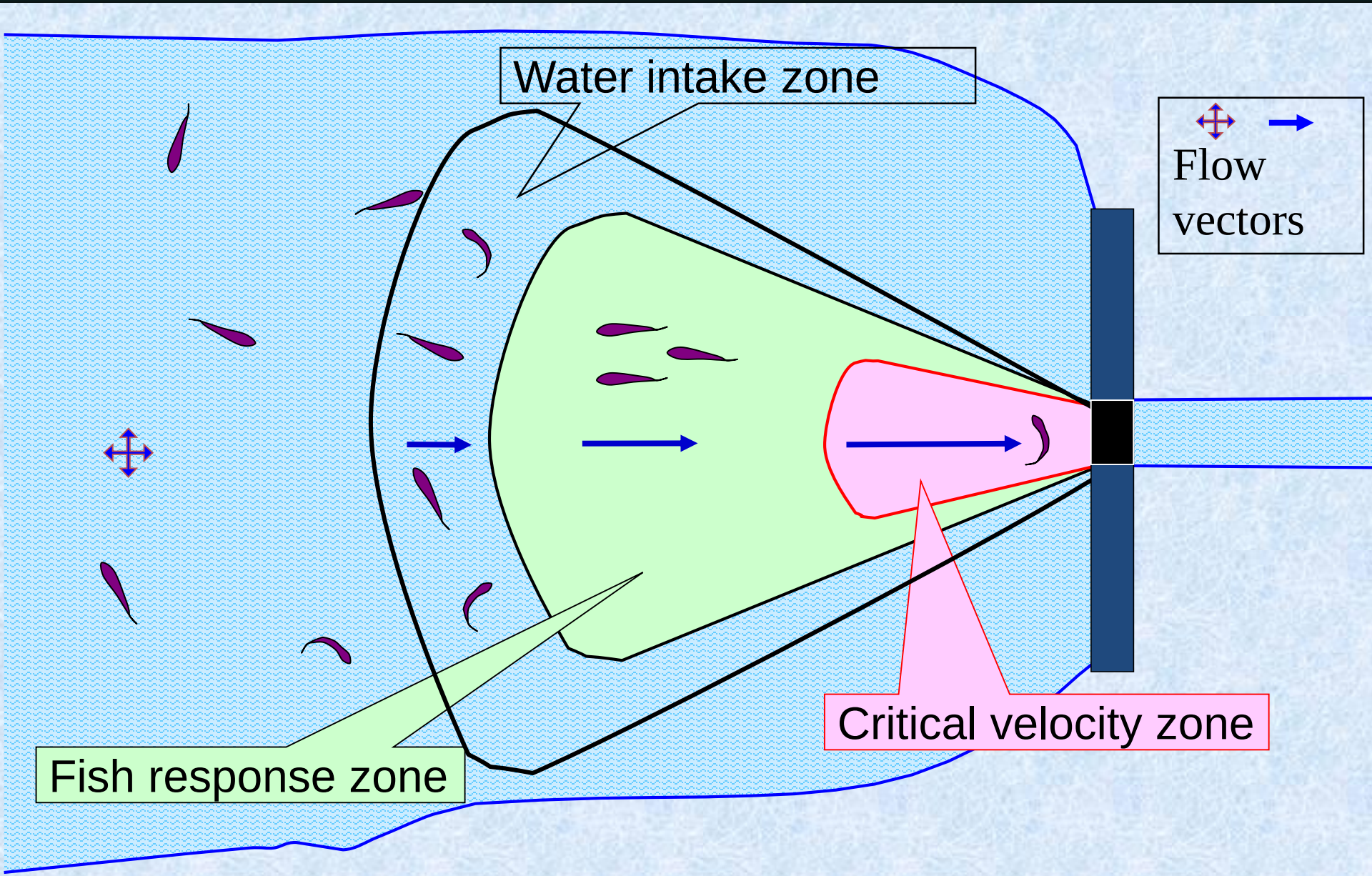


Migratory state ( )

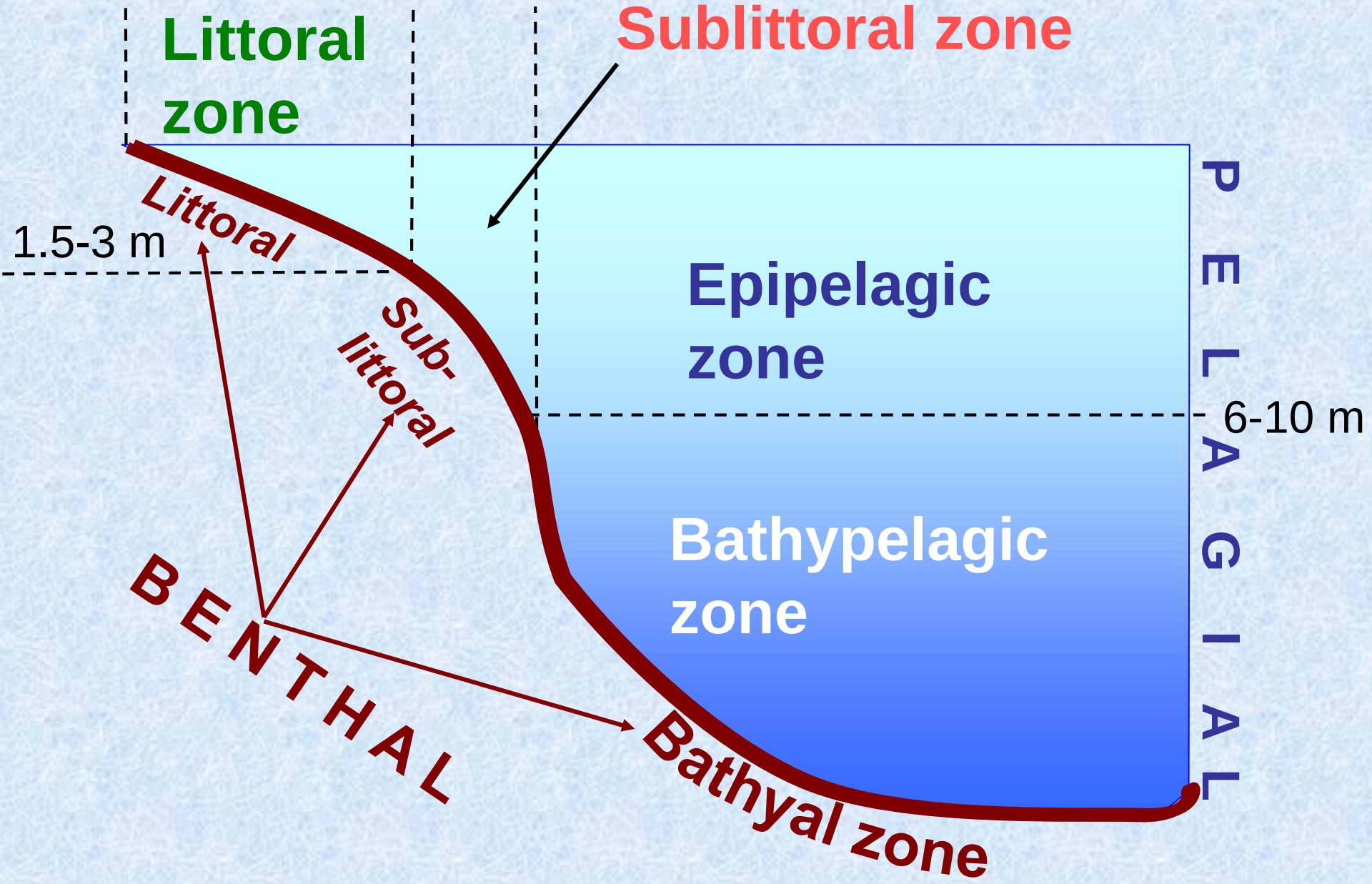


Residency state ( )

Pattern of the water flow at the power plant intake (view from above)



ECOLOGICAL ZONES IN RESERVOIRS AND LAKES

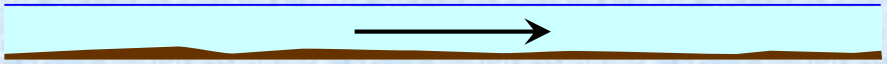


Types of fish distribution according to ecological zones of water bodies

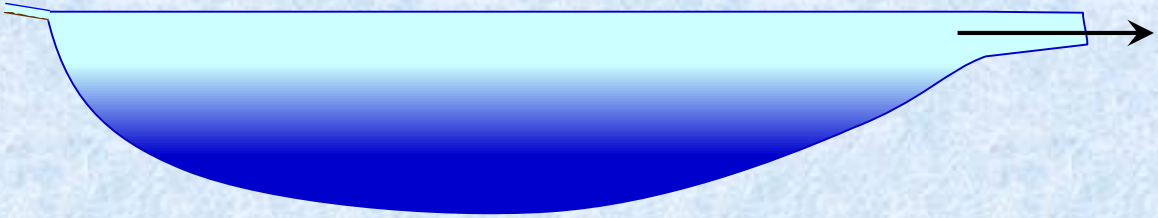
№	Type	Fish species
I	Monozonal pelagic	*pikeperch, smelt, kilka, shad, peled, European cisco, rasorfish*
II	Monozonal littoral	*pike, rudd, tench, crucian carp, ide*
III	Monozonal benthal	*ruffe, sterlet, burbot, catfish*
IV	Polyzonal permanent	*perch, bleak*
V	Polyzonal temporary	*bream, roach, white bream*

Types of water bodies where downstream migration of young fish was studied

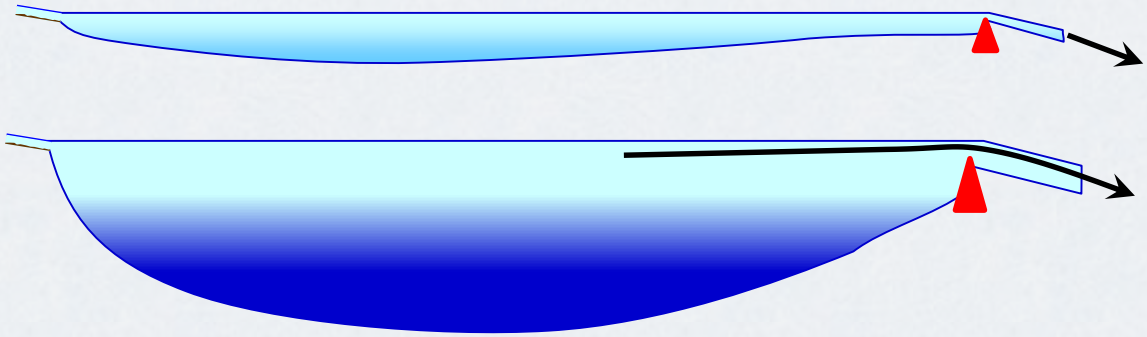
Rivers



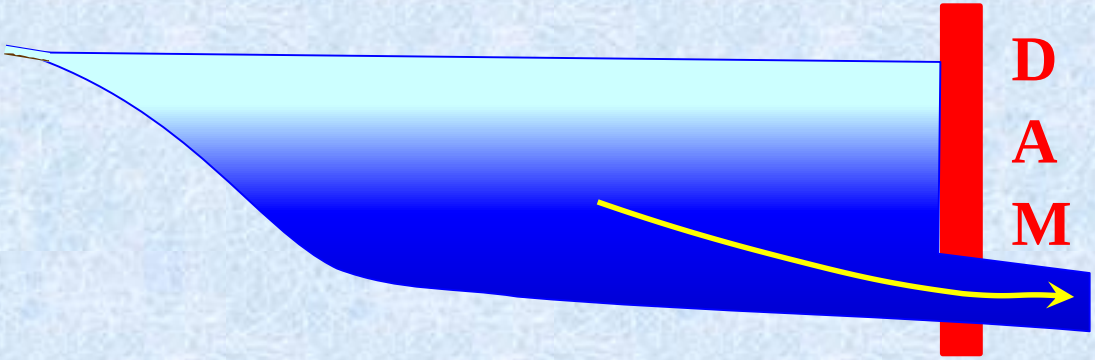
Natural lakes



Reservoirs or regulated lakes with **epilimnial release**



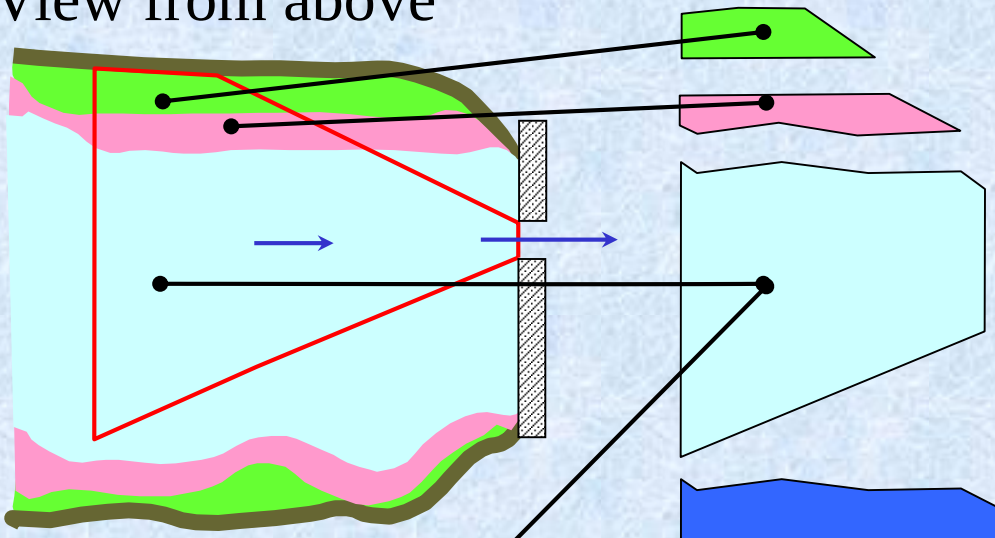
Reservoirs with **hypolimnial release**



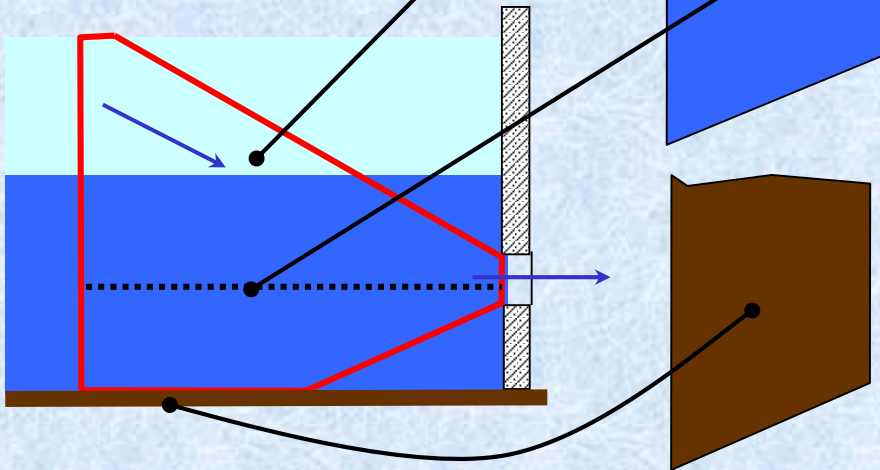
Assessment of the ecological zones in the vicinity of the water intake (IEFS)

The area (S, m^2) of the zones:

View from above



Side view



Littoral (Lit)

Sublittoral (Sub)

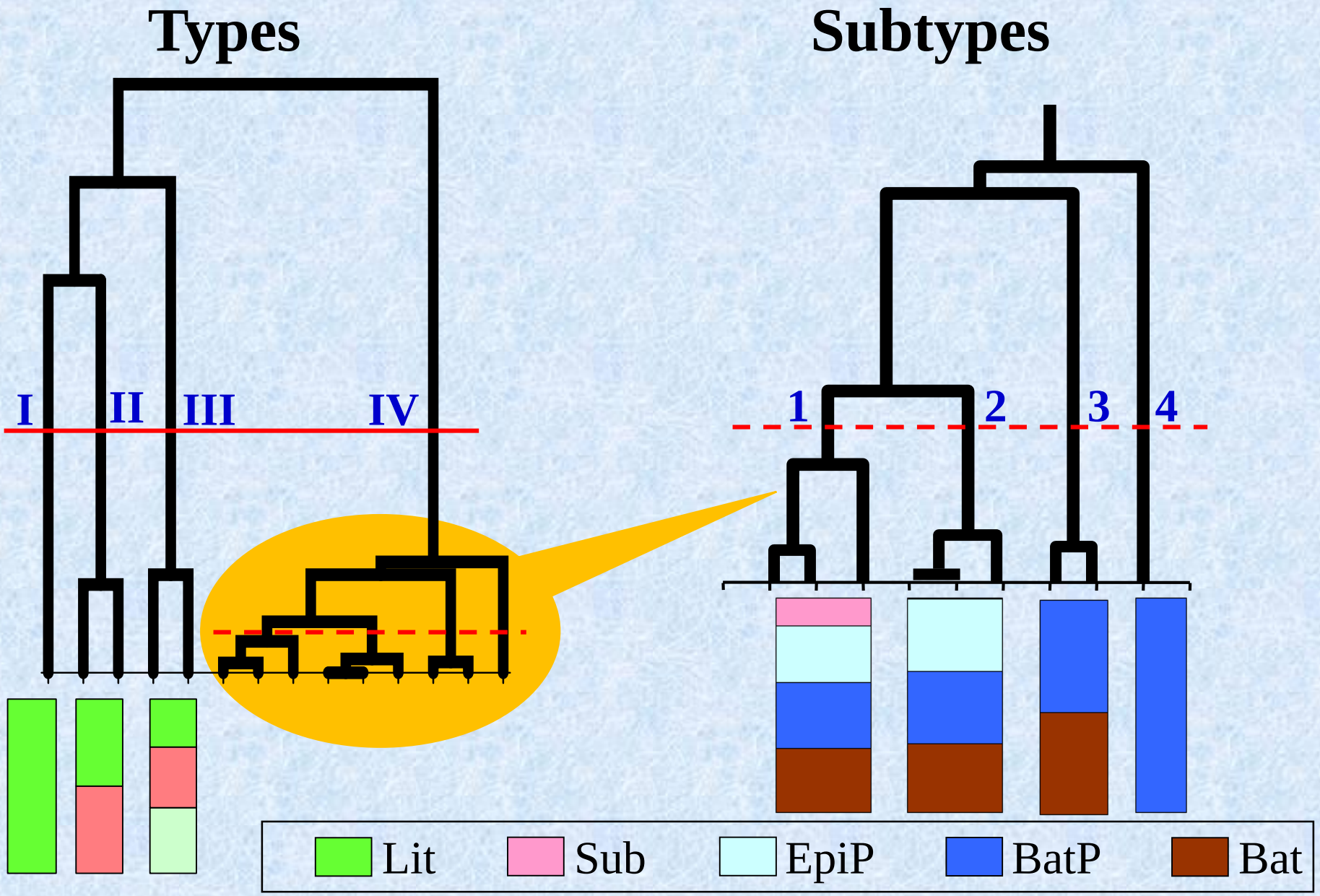
Epipelagic (EpiP)

Bathypelagic (BatP)

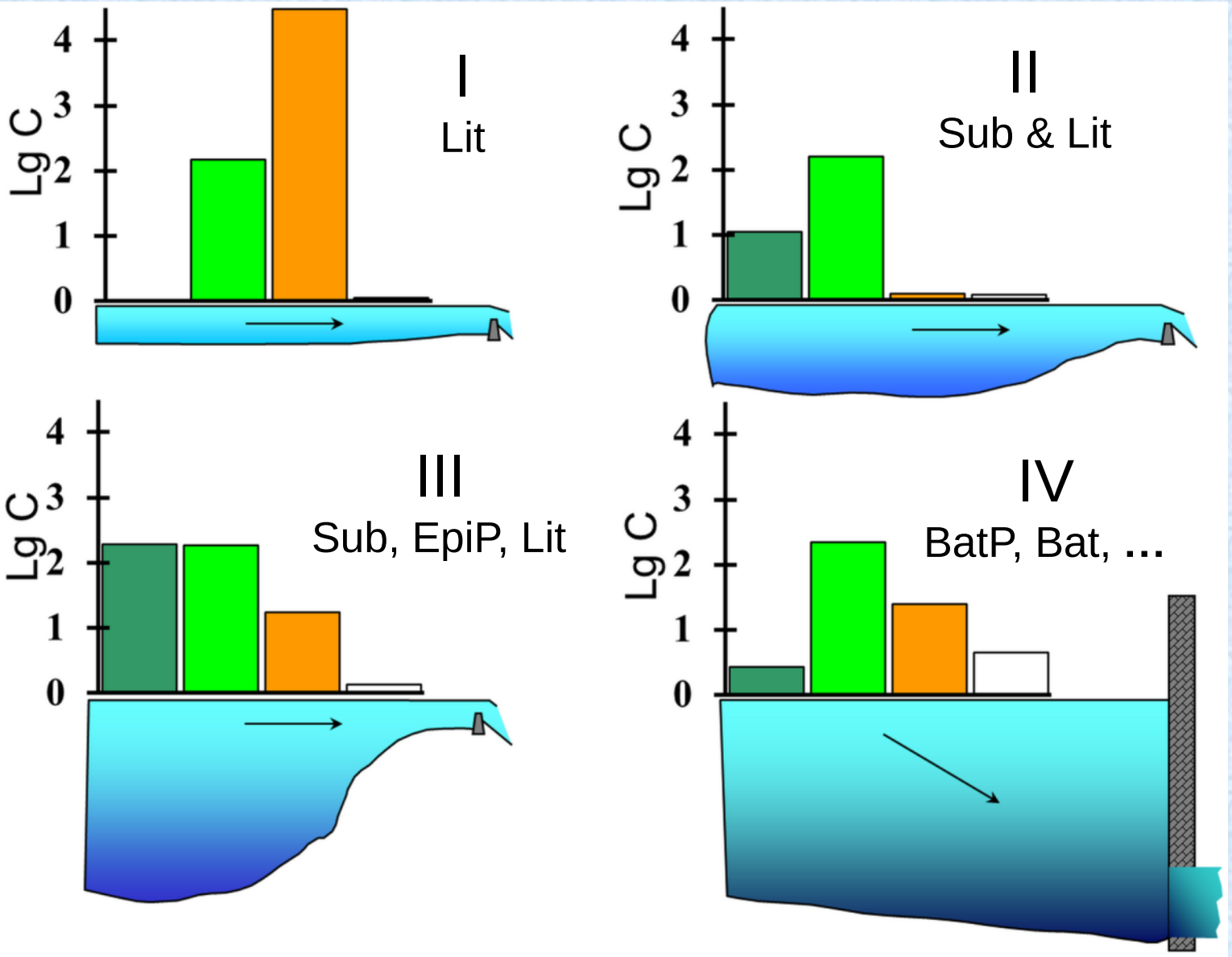
Bathyal (Bat)

IEFS spectrum ($\sum \mathbf{S_i}$)

Types & subtypes of IEFS

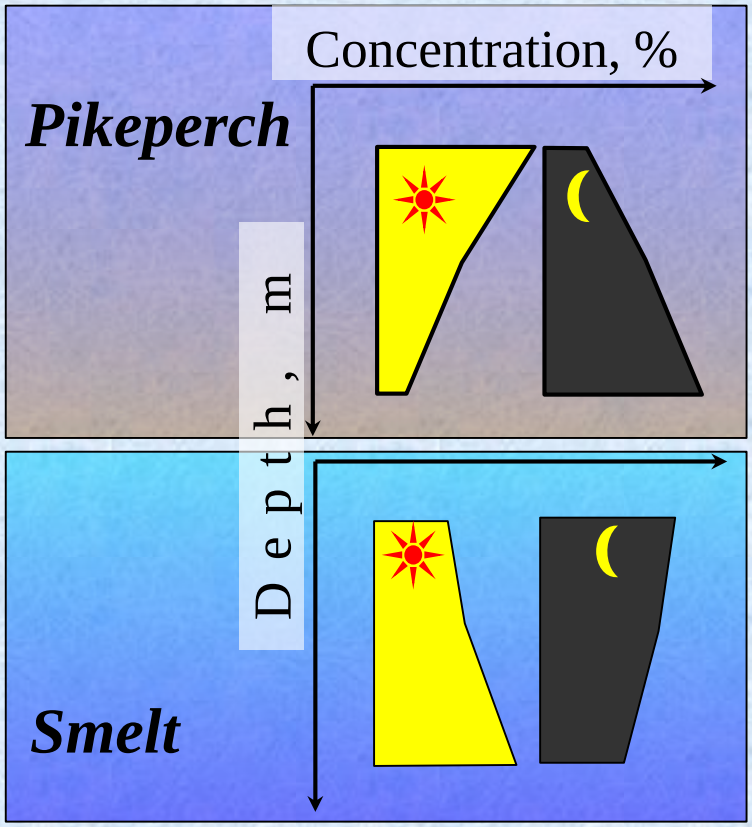


32 Seasonal dynamics of the downstream migration from the water bodies with different types of IEFS

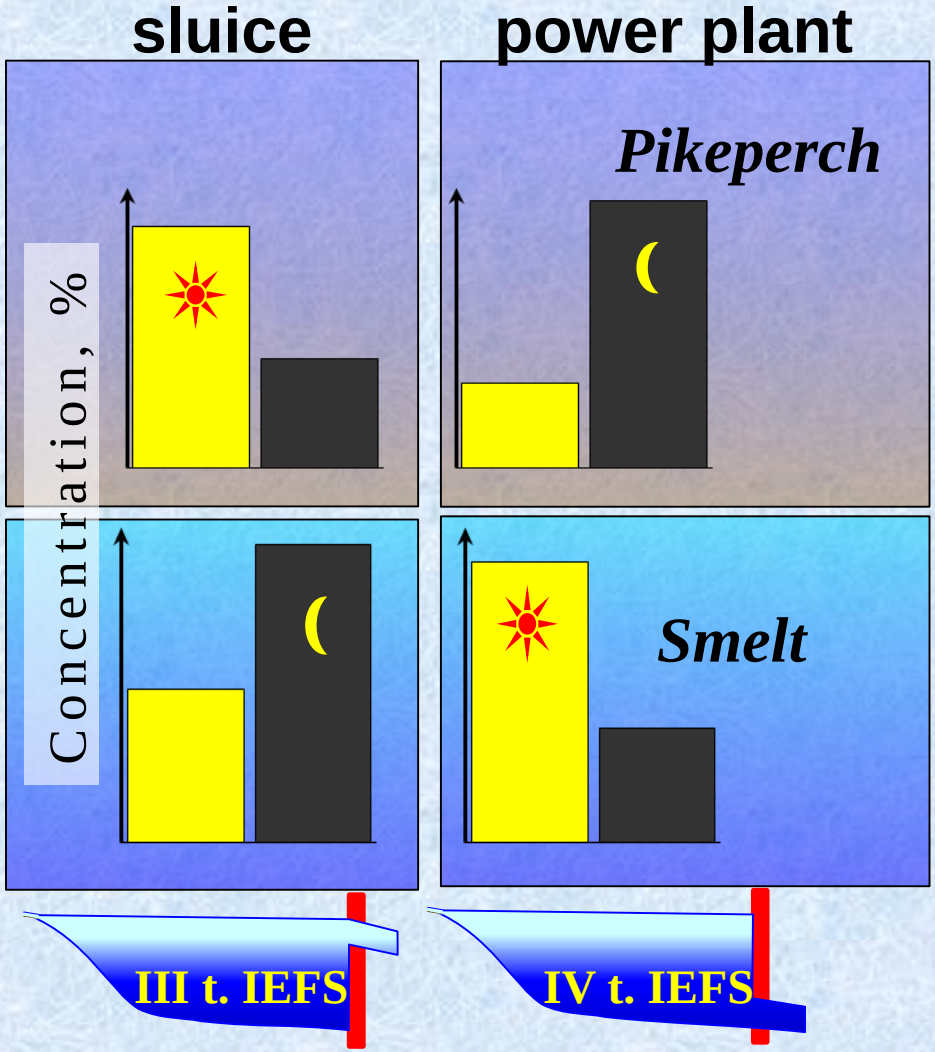


Diel changes of the downstream migration through the power plant and sluice. Sheksna River

Distribution of fish upstream the dam



Downstream migration



- day - night

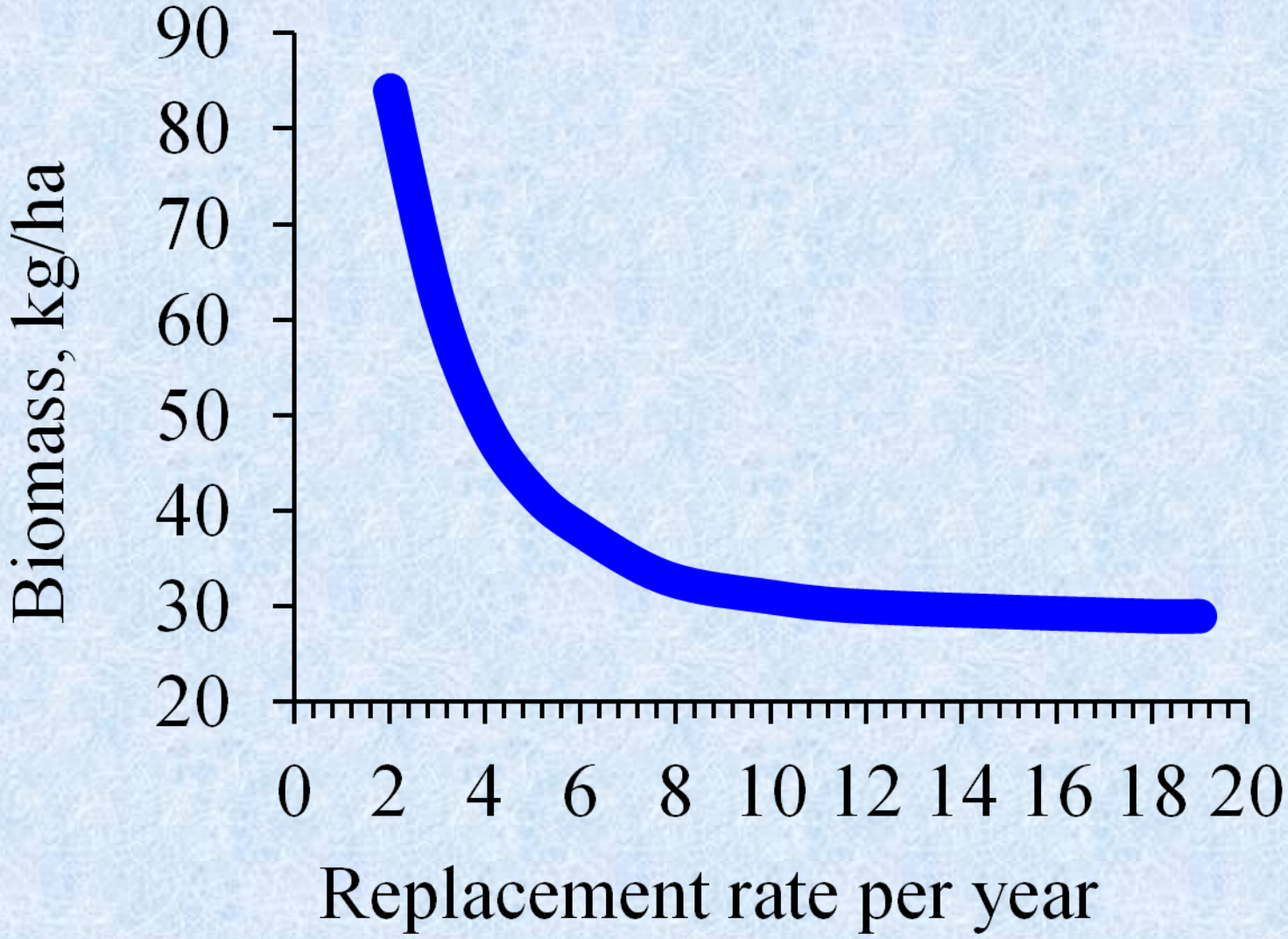
Influence of IEFS on the downstream migration of fish

Characteristic of downstream migration	Influence of IEFS
Species-Specific Structure of Migrants	YES
Age and Size Structure of Fish Migrants	YES
Seasonal Dynamics of Fish Migration	YES
Diel Dynamics of Fish Migration	YES
Fish migration index	YES
Total number of migrants	NO

Influence of water exchange on the downstream migration

IEFS spectrum 	Reservoir	
	Tsimlyanskoe	Volgogradskoe
Water surface area, km^2	2 700	3 100
Actual fishing yield, kg/hectare	**36.0**	**12.0**
Annual coefficient of water exchange	**0.93**	**8.00**
Number of migrants in a year, ind.10^6		
Clupeonella cultriventris	154	11 900
Alosa kessleri	0.57	2 980
Alburnus alburnus	0.32	680
Rutilus rutilus	0.04	600
Abramis brama	0.01	657
Stizostedion lucioperca	0.03	33 200
Other	5	22 900
In total	**161**	**72 917**

Biomass of pelagic fish and water turnover rate in reservoirs of the Volga and Kama



Damages and mortality of downstream migrants

Factors causing mortality of fish migrating downstream through the turbines of power plants

Factors	Target group
1. **Abrupt change** of hydrostatic pressure upstream and downstream the dam	Migrants from the bottom layer
2. **Impacts of turbines**: mechanical injuring, impact of pressure, turbulence shears, cavitation, hypersaturation	A part of migrants (depending on the type of turbines, water flow and rotation speed)
3. **Increased mortality** of fish caused by their impaired behavior	Predominantly small sized migrants
4. **Transfer of migrants** from limnetic to lotic habitats	All migrants

Abrupt change of hydrostatic pressure caused mass kill of the 0+ pikeperch passed through the dam of the Kapchagai power plant (Ili River, Central Asia)

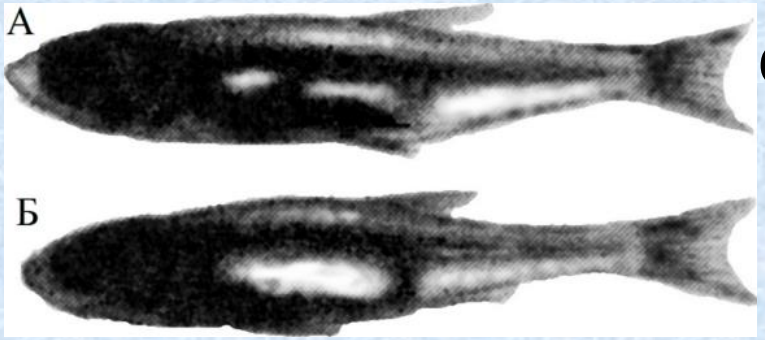
Pressure-induced injures in the pikeperch adults passed through the Tsimlyanskaya power plant (Don River)

intact injured

intact injured

Change of pressure 1.6 — 2.5 bars

Pressure-induced injures of the swim bladder

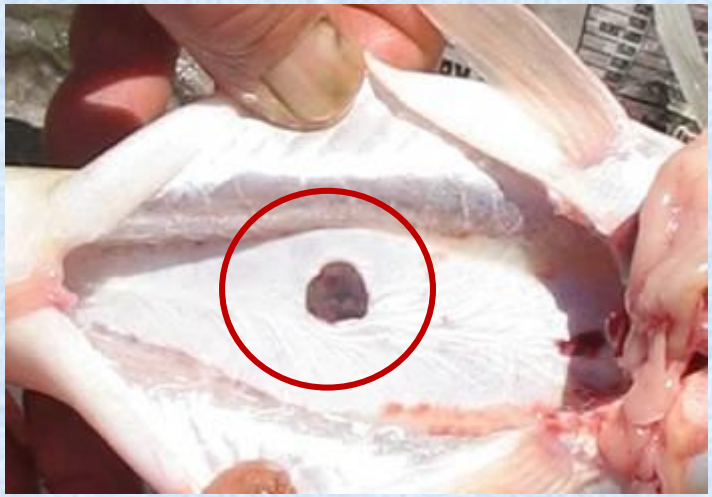


Control

Impact

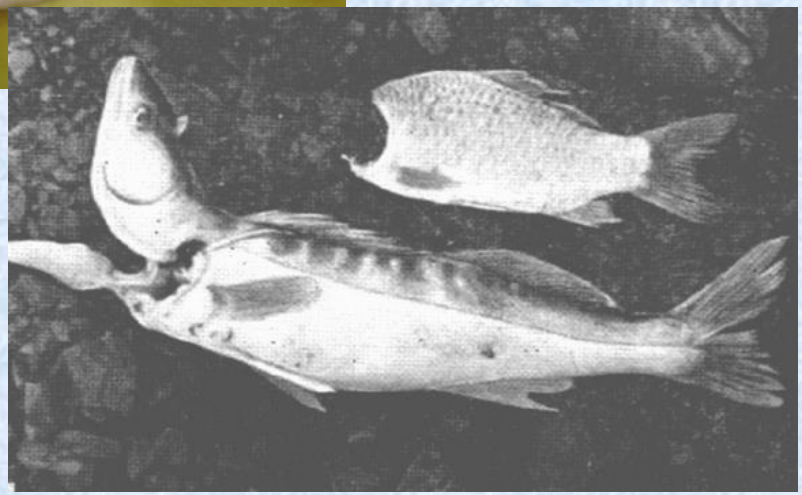
Leucaspius delineatus

Change of pressure-1.5 bar



Pikeperch passed through the Tsimlyanskaya power plant (Don River). Damaged swim bladder in all migrants. Change of pressure – 1.6-2.5 bar.

Mechanical damages in fish passed through turbines of power plants



How to assess the probability (P) of mechanical injures in fish passed through turbines

$$P = N \cdot \ell \cdot n \cdot V^{-1} \cos(\alpha),$$

N – number of blades in the working wheel of the turbine

ℓ – fish body length

n – rotation speed of the turbine wheel

V – flow velocity through the wheel

α – angle of fish position when between blades

Empirical data: $\alpha = 60^0$ then $\cos(\alpha) = 0.5$

$$V = Q / (R^2 - r^2)\,\pi$$

Q – amount of water passed through the turbine

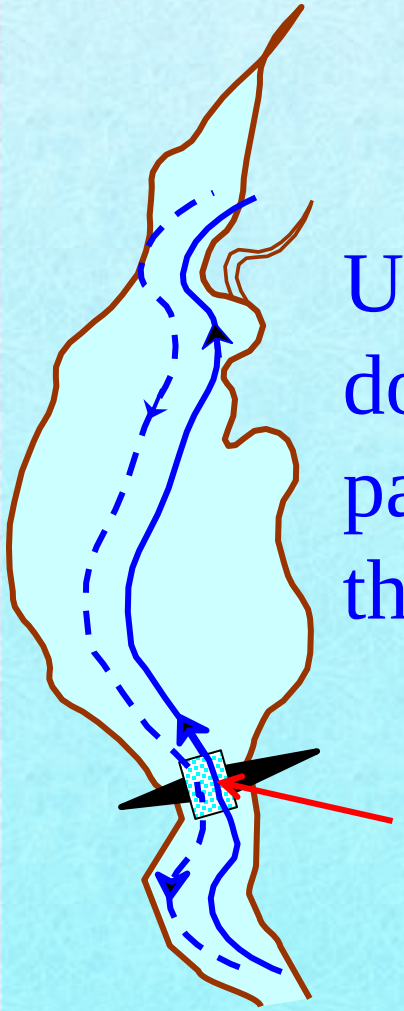
R – radius of the turbine shaft

r - radius of the turbine bush

Protection of migrating fish

Approach to protection of the long-distance migrants and potamodromous fish

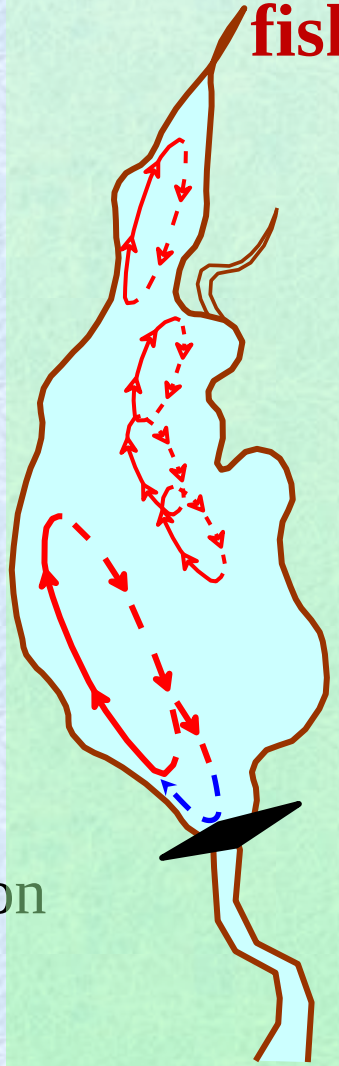
Migrants: anadromous, semi-anadromous, rheodromous



Upstream and downstream passage through the dam

Fish passage installation

Potamodromous fish



To prevent drift through the turbines

Measures to protect fish in regulated rivers

- Restoration of migration "rings" (**obligatory for anadromous, semi-anadromous and rheodromous**), desirable for potamodromous fish

- Protection of fish from drift through turbines.
  Ecological approach – fish friendly control of the water abstraction based on diel, seasonal and spatial regulation of abstraction. Lake like water abstraction system

- Ecologically substantiated improvement of fish community. Release of grown up juveniles (not less than 10-15 cm) into the pelagic zone of reservoirs

Thank you for your attention!

The main books on the topic

1. Pavlov D.S., Barus V., Nezdolij V.K., et al. Downstream fish migration from Mostiste and Vestonice reservoirs // Praha: Academia, 1987. 63 p. engl.
2. Павлов Д.С., Михеев В.Н., Василев М.В. и др. Питание, распределение и миграция молоди рыб из водохранилища «Александр Стамболийски» (НРБ). // М.: Наука, 1988, 120 с. russ.
3. Pavlov D.S. 1989. Structures assisting the migration of non-salmonid fish, USSR // FAO Fish. Techn. Pap. Vol. 308. N 308. P. 1–97 engl. https://books.google.ru/
4. Pavlov D.S., Lupandin A.I., Kostin V.V. 1999. Downstream Migration of Fish through Dams of Hydroelectric Power Plants. M: Nauka. 255 p. russ. Engl. version: http://www.sevin.ru/ or https://dl.dropboxusercontent.com/u/9627661/FishBook.7z
5. Pavlov D.S., Lupandin A.I., Kostin V.V. 2007. Mechanisms of downstream migration of young fish living in rivers. Moscow: Nauka, 2007. 213 p.. russ.: http://www.sevin.ru/
6. Павлов Д.С., Скоробогатов М.А. 2015. Миграции рыб в зарегулированных реках. Москва, Товарищество научных изданий КМК. 2014. 413 с. russ.: http://www.sevin.ru/ https://books.google.ru

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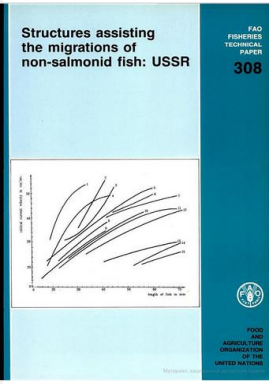

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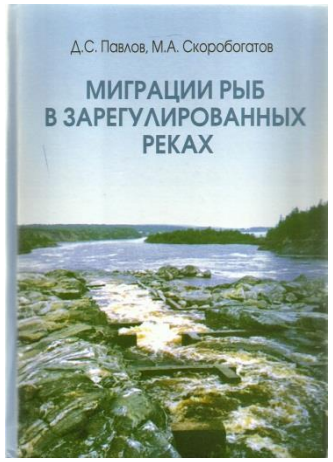

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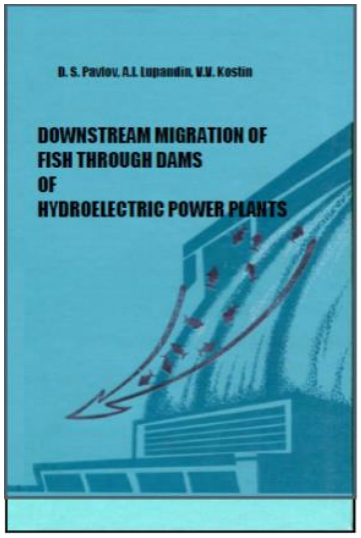

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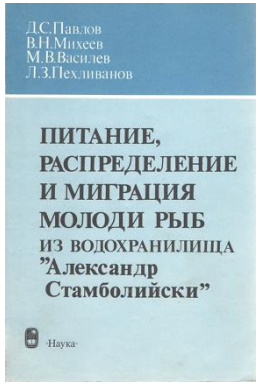

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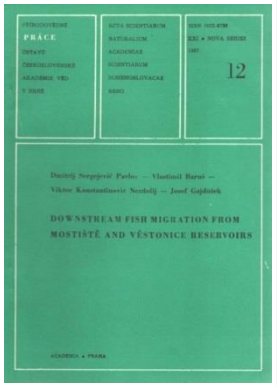

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