Ways of optimizing the fishery in the Small Aral Sea, taking into account the biotopic distribution of fish fauna

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Abstract. The article addresses fishing challenges in the Small (Northern) Aral Sea, formed in 1989 following the Kokaral dam's construction at the Berg Strait. The reduced water salinity has led to an expanded range of native commercial fish species. The ichthyofauna utilizes the entire Small Aral Sea for spawning and feeding, albeit unevenly across zones defined by salinity and biotopic features, a focus of this study. The primary sea biotopes are categorized as salty, brackish, and desalinated. Adapting fishing gear, seasonally and according to fish concentrations, is improved by factoring in salinity, depth, and feeding areas. Fish concentrations were studied via echo sounding and setting up fishing nets. Statistical analysis employed Surfer 20 and ArcGIS Online software, resulting in a map of fish concentration across the Small Aral Sea. A comprehensive strategy for optimal fish stock utilization, considering spatial and biotopic distribution, along with available fishing capacity, was formulated. Presently, the fishery employs only fixed nets, hindering efficient use of fish concentrations. A novel fishing area layout was proposed, accompanied by recommendations for fishing gear quantity in the Small Aral Sea's fishing zones.

Key Words: biotope, fish gear, fishing, fishing concentrations, salinity, Small Aral Sea.

Introduction. The Small (Northern) Aral Sea was formed in 1989 as a result of a decrease in the water level in the Aral Sea and the drying up of the Berg Strait. After the implementation of the project "Regulation of the Syrdarya River and Preservation of the Northern Part of the Aral Sea" (RSRPAS), the level of mineralization of the water of the North Aral Sea decreased several times, the carrying capacity of the Syrdarya River increased. The level of the Small Sea was intensively rising as a result of large winter releases along the river, and in mid-April 2006 it reached the level of 42.0 meters of the Baltic System. With a given water level mark, the Small Sea is currently characterized by the following parameters: volume 27.07 km^3, sea area 3288.0 km^2, maximum depth 15.5 meters, average 8.2 meters. The water quality in the Small Sea after the construction of the Kokaral dam normalized to the state of 1965, and then the salinity indicators were equal to 10-12 ppm (Sambayev 2022). Along with the positive impact of freshening, in the Small Aral Sea, the species composition of fish has expanded to 22 species, of which about 15 species are being developed by fisheries. For the first time in many years, representatives of the native ichthyofauna began to be encountered in the sea: roach *Rutilus rutilus*, bream *Abramis brama*, valuable fish species: carp *Cyprinus carpio*, zander *Sander lucioperca*, asp *Aspius aspius*, catfish *Silurus glanis*, white-eye fish *Ballerus sapa* and others. The previously lost feed base of fish, consisting of freshwater and brackish water organisms, began to recover. Fisheries have grown significantly and now account for about 17 percent of the country's total fish catch (Sambayev 2022).

But in recent years, as a result of irrational fishing, an unsustainable catch of certain species has been observed. The main issue of the effective use of biological resources of water bodies is the sustainable use of their natural biopotential while mitigating the pressure of anthropogenic factors on hydrobiocenosis and the conservation of biological diversity (Sambayev 2022).

According to the territorial inspection of the fish farm, the catches of commercially valuable species (which are carp, the silver carp *Hypophthalmichthys molitrix* and grass carp *Ctenopharyngodon idella*) do not exceed 250 tons (only 3.5% of the total catch), while the total fish catch in the Small Aral Sea is about 7 thousand tons annually in recent years. The annual fish stocking (about 15 million specimens of juveniles of valuable fish species over the past 5 years) by the state and users does not fully replenish the reproductive potential (Sambayev 2022).

For the rational fishing use of the sea in its current state, it is necessary to develop a scheme for the optimal use of fish stocks, taking into account the spatial and biotopic distribution and the availability of fishing capacities. In the Republic of Kazakhstan, reservoirs are divided into separate fishing areas, which, according to the results of the competition, are leased for 10 years to nature users.

In fisheries management, one of the most widely used technical measures to achieve various management goals is the introduction of selective fishing gear into the fishery. However, early and constant involvement of scientists in the process of developing fishing gear is necessary in order to predict the expected consequences of changing the scheme for applying fishing efforts (Veiga-Malta et al 2019). Otherwise, the introduction of new or modified fishing gear will not have the desired effect (Krag et al 2016).

When constructing an optimal model of fishing in a reservoir, it is necessary to model fishing as a single process consisting of three successive characteristics: the intensity of fishing effort, the material consumption of gear, and the intensity of environmental impact (Kuczenski et al 2021). However, the fishing model can also be based on the optimal distribution of fishing efforts in the reservoir in order to minimize losses for the transportation of caught fish (Nurdin et al 2019) and to optimally distribute the available fishing gear over the water area to match the applied effort to fish concentrations.

Statistical fisheries models are often used by researchers and agencies to understand the behavior of marine ecosystems or to estimate the maximum allowable catch of various species of commercial interest (Penas et al 2019). In this study, to minimize the impact of random data when assessing the concentration of fish in the water area, we used the capabilities of statistical processing of spatial data by the Surfer 20 program (a three-dimensional program for drawing the surface of maps that runs in the Microsoft Windows environment), namely, the interpolation of data from echo sounding surveys using the kriging method (Maltsev & Mukharamova 2014). The cartographic basis was the materials of the GIS-project "Fishing and protection of fish stocks", developed on the ArcGIS Online platform. Thus, the problem of creating charts of the distribution of fishing efforts and fish concentrations in the water area of the Small Aral Sea was solved. These maps provide the most accurate information about the entire area of the water body as a whole and at the same time conveniently visualize the current situation for subsequent spatial analysis and decision-making.

The aim of the research is to identify ways to optimize the fishing scheme in the Small Aral Sea, taking into account the biotopic distribution of the ichthyofauna.

Material and Method. Hydrological data were collected quarterly during the period 2011-2021. Sampling was carried out from the surface and bottom layers of water according to the methods adopted in Kazakhstan (Alekin 1959; State control of water quality 2003). Determination of the content of oxygen dissolved in water was carried out by the SAMARA-2B analyzer, the hydrogen index - CONSORT-C932. The instrumental determination was duplicated by laboratory methods. The concentrations of the main ions in water samples were determined.

Fishing was carried out in the order of fixed nets with a mesh pitch of 16 to 80 mm, 25 meters each, and fry drags, which made it possible to obtain information on the species, sex, age composition of fish populations and their relative abundance during research fishing. The assessment of fish stocks was carried out according to the collection data by the method of direct quantitative accounting of fish from control nets, as well as the analysis of catches from fishing nets. Accounting for the abundance and biomass of the commercial fish stock was carried out according to the methods generally accepted in the post-Soviet space (Chugunova 1952; Pravdin 1966; Nikolsky 1974; Rules for the preparation of a biological justification for the use of wildlife: Approved by the order of the MEWR RK 2014; Babayan 2000; Guidelines for assessing the number of fish in freshwater reservoirs 1986; Guidelines for the use of cadastral information for the development of a forecast of fish catches in inland waters 1990; Malkin 1999), taking into account the own developments of the authors of this work (Kulikov et al 2016) and Western scientists (Hoggarth et al 2006; FAO Technical Guidelines for Responsible Fisheries 2010; Methot & Wetzel 2013).

Echo sounder and net surveys were carried out according to a proven method using Humminbird Helix 7 series echo sounders (Rules for the preparation of a biological justification for the use of wildlife: Approved by the order of the MEWR RK 2014). The coordinate referencing of the collected data was carried out using ArcGIS Online tools with the placement of echo sounding points in a separate layer with attributive information on the number of recorded echo marks within the range of the equipment on the existing cartographic basis of the GIS project "Fishing and protection of fish stocks". Further, the data were converted into the Surfer 20 software environment for statistical processing.

To determine the intermediate concentrations of fish in the waters of the Small Aral Sea in the Surfer 20 software environment, interpolation of concentration values (number of specimens per 1 ha) obtained as a result of echo-sounding surveys was carried out.

As an interpolation method, universal type kriging with an exponential empirical variogram model was used. The coastline of the Small Aral Sea acted as a breakline. Unlike other deterministic interpolation methods, kriging is geostatistical. It builds a statistical model of reality rather than a model of an interpolation function, which makes it possible to take into account the spatial correlation of data (Maltsev & Mukharamova 2014). The choice of this interpolation method is also due to the predictive purpose of the study since the obtained data on the concentration of fish are a rather variable indicator in space. The universal type of kriging was chosen, since the mathematical expectation of the random function Z is unknown and inconsistent, which is due to the nature of the data under study. In the process of analyzing the spatial behavior of the data, the best result was shown by the exponential variogram model with minimal prediction errors.

The interpolated fish concentration values across the Small Aral Sea's water area, derived from geostatistical processing, were converted into a raster GRID file. This file was integrated onto a pre-arranged cartographic base using the ArcGIS Online platform. Employing an optimal visualization approach, the attained results were synthesized into a map illustrating fish concentration patterns within the Small Aral Sea.

In total, 36 echo sounding tracks were conducted, complemented by 16 deployed nets, 10 hydrochemical samples for analysis, 385 fish specimens subjected to biological analysis (length, weight, fertility, fatness), and 46 fishing effort indicators.

Results and Discussion. The sustenance and protection of fish resources in the Small Aral Sea exhibit direct reliance on its hydrological, hydrochemical, and hydrobiological conditions. The hydrological state is influenced by the Syrdarya River, a primary nutrient source, regulated through water system interactions and their releases. Notably, substantial winter releases lead to the sea's water level peaking at 42.5 meters Baltic System level until mid-April. Subsequent to April, water influx into the sea diminishes, correlating with water withdrawals for agricultural irrigation. Table 1 presents a comparison of commercial stock, fish catches, hydrological, and hydrochemical indicators in recent years (own research data). Changes in hydrological conditions induce alterations in the hydrochemical regime.

Table 1
Relationship between water content, catches, and observational years in the Small Aral Sea

Observational years	*Average annual level (mBS)*	*Average annual volume of water (km^3)*	*Salinity of water ($g\ dm^{-3}$)*	*Commercial fish stock (tons)*	*Annual fish catch (tons)*
2011	41.15	26.50	9.9	11897	3520
2012	42.06	27.28	8.6	14635	4189
2013	42.05	25.10	7.8	12281	4248
2014	42.38	26.40	8.2	20385	5590
2015	41.25	26.68	9.1	25905	7165
2016	42.30	26.20	9.8	24788	7100
2017	42.56	28.50	9.9	26771	6800
2018	42.35	27.51	10.1	25160	6700
2019	41.52	27.36	10.5	24196	6678
2020	40.85	24.12	11.8	22484	6869
2021	40.12	24.10	12.5	24256	6637

With a decrease in water content, a relative increase in water salinity is observed. Since 2014, the commercial fish stock has been in the range from 20385 to 26771 tons, while the annual catch, on the contrary, has decreased from 7165 to 6637 tons. Such a decrease is obviously associated with irrational fishing without taking into account the spatial and biotopic distribution of fish and the non-optimal use of fishing capacities.

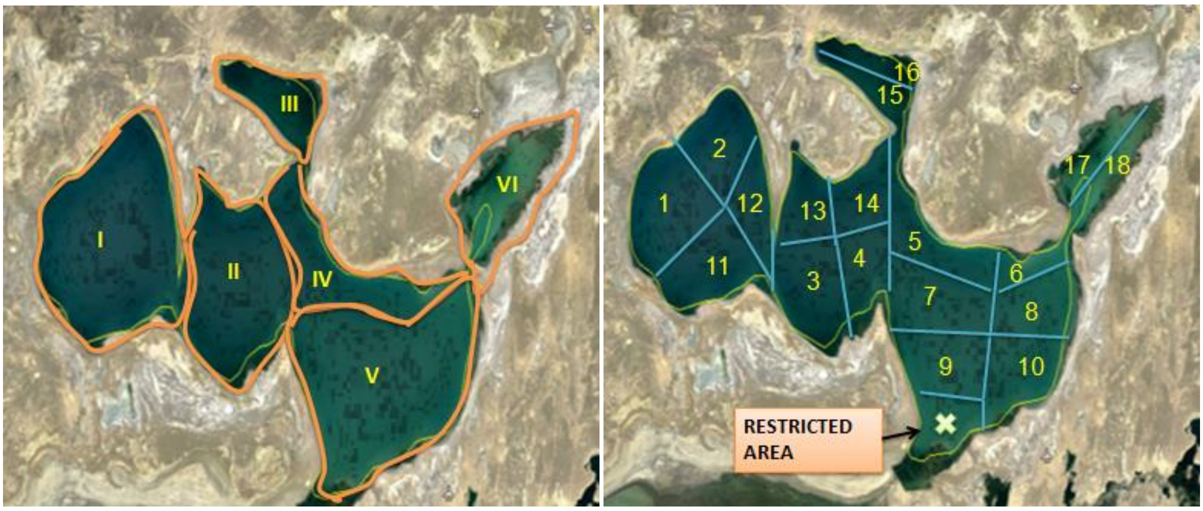
At present, the water area of the Small Aral Sea is divided into 6 fishing areas, which differ in different hydrological, hydrochemical and hydrobiological indicators and different fish productivity. In turn, within the districts there are 18 sites, that is, in each district there are from 2 to 5 fishing sites (Figure 1):

- fishing ground I: Shevchenko Bay characterized by a small area and depth, but high salinity;
- fishing ground II: the central area, which occupies the entire deep-water part of the Small Sea;
- fishing ground III: Butakov Bay, a separate bay in the northern part of the sea, characterized by a small area and depth, but high salinity;
- fishing ground IV: the northeastern part, which covers about 30% of the area of the reservoir;
- fishing ground V: a near-estuary area, including a desalinated area where river and sea water mixes in an easterly direction;
- fishing ground VI: Saryshyganak Bay, where, after the construction of the Kokaral dam, the water level is currently stabilizing.

Each site is assigned to a nature user who, during the year, develops the limit allocated to him (catch quota). In accordance with the data of fishing statistics, 11 fishing organizations with 53 teams of fishermen operate in the Small Aral Sea.

Similar to other nations, Kazakhstan also contends with illegal, unrecorded, and unregulated (IUU) fishing catch, a significant industry challenge. Fishing management encompasses various measures beyond setting annual catch limits and spawning period bans, including restrictions on fishing gear and fishermen. Establishing fishing standards (maximum allowable fishing effort for sustainable and resource-preserving fishing) serves as an effective tool for monitoring and promptly adapting to fishing stock changes by adjusting fishing effort.

In 2006, a non-scientific, intuitive approach to demarcating water bodies and sites resulted in numerous fishing sites. Users of these sites are confined to their designated areas (refer to Figure 1B), with limited catch quotas that hinder profitable fishing through automated methods and fishing vessels.



A B

Figure 1. Schematic maps of the Small Aral Sea (no scale): A - fishing grounds; B - fishing areas.

Fish catches within fishing grounds exhibit disparities influenced primarily by biotopic zoning and the selected fishing ground's water expanse. Analyzing the fishing dynamics in the Small Aral Sea during summer periods reveals an average utilization of only 4.2% of the annual fish catch limit. This limited utilization is attributed to the declining water level in the Small Aral Sea post-spring. Substantial shoreline silting causes water retreat from the fishing vicinity by several tens of meters, posing challenges for fishermen venturing into the sea. The primary fish catch occurs during autumn and winter. The annual fish catch of 2021, organized by fishing grounds and areas, is presented in Table 2.

Table 2

Fish catches by fishing grounds of the Small Aral Sea

Fishing grounds	*Fishing areas*	*Fish catch (tons)*
I	№ 1, 2, 11, 12	1587
II	№ 3, 4, 13, 14	1568
III	№ 15, 16	431
IV	№ 5, 6	797
V	№ 7, 8, 9, 10	2005
VI	№ 17, 18	472
Total	-	6860

The analysis of 2021 catches shows that for the most abundant fish species (roach, sabre carp *Pelecus cultratus*, and rudd *Scardinius erythrophthalmus*), the utilization of allocated limits reaches 67%. Predatory fish species, including catfish, pike *Esox Lucius*, and snakehead *Channa argus*, exhibit development rates of 37.5%, 69.0%, and 48.5%, respectively. Notably, the most valuable fish species, carp and asp, have development rates of 68% and 81% of the total catch, respectively.

Fixed nets of varying modifications are the primary fishing gear employed in the Small Aral Sea. These nets feature mesh sizes starting from 36 mm and above. Nets constitute fishing gear with adjustable selective impacts on stocks through modifications in allowable mesh size and net quantities. It's crucial to acknowledge that each fish species possesses distinct physical attributes. Seine fishing gear is exclusively employed in fishing ground II, specifically fish areas No. 3 and No. 4, during certain seasons, predominantly autumn. Overall, seine fishing is of marginal significance due to limited usage, primarily attributed to the lack of seine vessels among most users (Table 3).

Table 3

Material and technical base of fishing enterprises in the Small Aral Sea

Water body	*Number of organizations*	*Number of brigades/links*	*Number of fishermen*	*Self-propelled fleet*	*Non-self-propelled fleet*	*Seine*	*Fixed net*
The Small Aral Sea	11	53	553	20	228	31	21337

Empirical evidence highlights that a restricted array of fishing gear results in the underexploitation of stocks, not solely encompassing a minor portion such as bream and roach, which constitute substantial populations within the reservoir, but also extends to predatory fish species. An ambiguous fishing allocation scheme, devoid of biotopic fish distribution considerations, undermines the optimal utilization of fishing quotas.

In the Small Aral Sea, commencing from late March, pre-spawning migration among producers unfolds, as they transition from wintering habitats to shores and the Syrdarya River's mouth. Carp, zander, bream, roach, and asp journey to their spawning grounds downstream. Notably, the estuarine region experiences peak catches during this period. Optimal fishing windows, synchronized with migration locations and timings in spring, primarily transpire in April-May, predominantly within the estuarine area. Additionally, shallow waters along the central and northeastern coastal parts of the sea are conducive to fishing.

By May, spawners exit the coastline post-spawning, venturing into the open sea for feeding. Throughout summer, optimal fishing spans from late May to mid-July, applicable across all areas until elevated temperatures prevail. Approaching autumn, the migration of diverse fish species to wintering habitats initiates. During this period, fish congregates within deeper zones in preparation for winter (Figure 2).

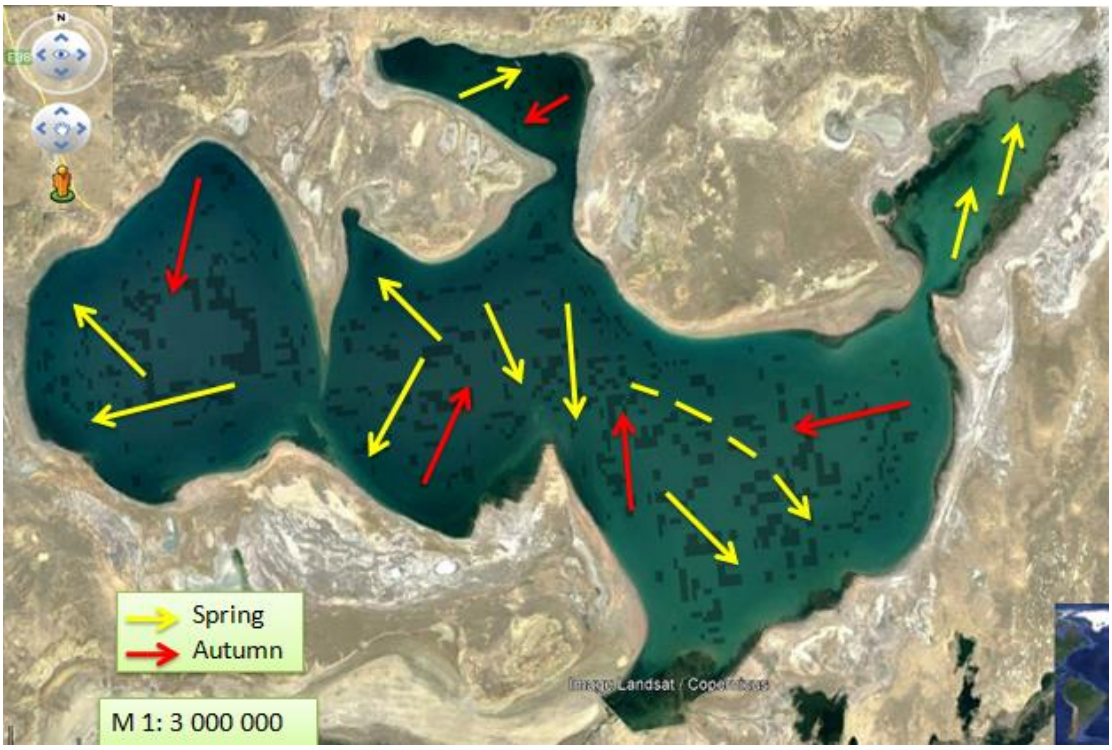


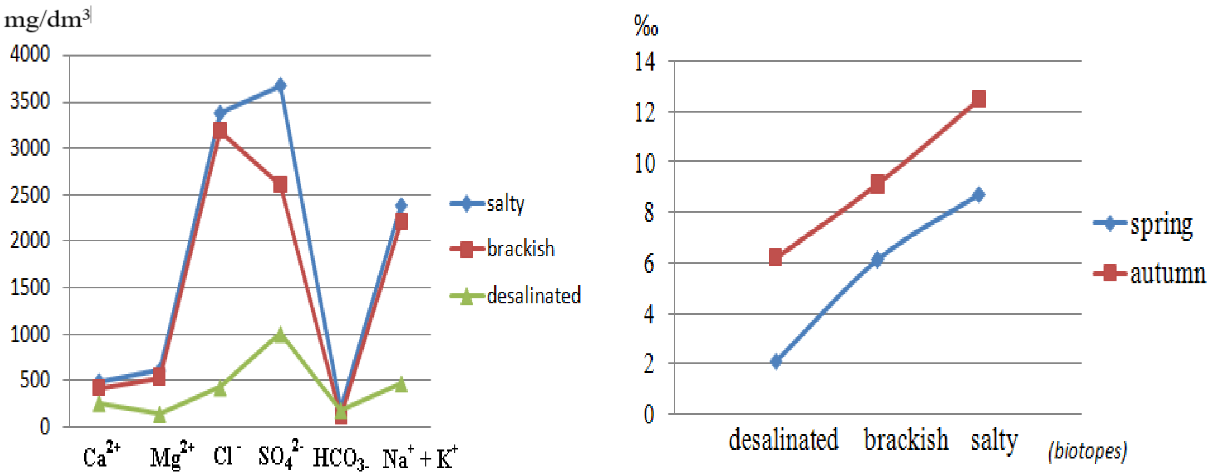
Figure 2. Spring and summer-autumn migration of fish in the Small Aral Sea.

During arid years, fish tend to aggregate in the mouth area for wintering due to diminishing dissolved oxygen levels in the water. The majority of fish relocate to areas enriched with oxygen. Conversely, in periods of high water levels, fish accumulation occurs in central regions. Notably, winter ice fishing identifies peak commercial population concentration in the eastern sections of Tastubek and Shevchenko bays.

Springtime elevation in water levels fosters fishing ground expansion, leading to diluted fish concentrations throughout the reservoir. Consequently, certain fishing areas lack profitability due to low fish concentrations.

The Small Aral Sea is categorized into three hydrochemical water biotopes: salty, brackish, and desalinated. Shevchenko Bay encompasses the salty biotope, covering an area of approximately 83552 hectares with depths ranging from 2 to 16 meters. The water composition is markedly saline, reflecting chemocline characteristics akin to meromictic water bodies (Data from Wikipedia. Chemocline 2022). The brackish biotope occupies the Domalak region, central to the sea, spanning around 74953 hectares. Depths in this biotope range from 4.5 to 8.2 meters, with increasing water physical properties in the pinocline, favoring saline waters over desalinated waters. Both salty and brackish biotopes host wintering depressions, serving as primary winter fish concentrations. The desalinated biotope encompasses the Kokaral region and the estuarine segment of the sea. This biotope spans about 110993 hectares with depths ranging from 1.3 to 5.6 meters. The Syrdarya River's flow rate into the desalinated biotope averages 260 m s^{-1}, attributed to complete mixing and desalination attributes specific to this biotope (Sambayev 2021).

Hydrochemical analysis of biotopes reveals alterations in the qualitative composition of water's primary ions. SO_4^{2-}, Cl^-, K^+, Na^+, Ca^{2+}, HCO_3^- and Mg^{2+} emerge as predominant ions. Consequently, the water's ionic composition shifts from bicarbonate-calcium to sulfate-chloride. Interestingly, sulfate ions exhibit a relatively significant proportion among ions, while calcium and magnesium ions exhibit the smallest contribution (Figure 3).



A B

Figure 3. Dynamics of ionic composition (A) and salinity (B) of water across Small Aral Sea's biotopes.

The Small Aral Sea's biotopic diversity warrants thorough analysis of its impact on ichthyofauna and the fish feed base. The monoclimax concept suggests the formation of stable climax communities (biocenoses) within each biotope over time, following anthropogenic or natural disturbances (Data from Wikipedia. Chemocline 2022).

To ascertain ichthyocenoses composition and pinpoint underexploited fish stocks' specific geographical locations within these biotopes, spring echo sounding surveys were conducted. Comparative analysis highlights considerable fish concentrations within the desalinated biotope, particularly during the pre-spawning period when fish migrate to pre-estuary regions with favorable desalinated water and temperature conditions for spawning (Figure 4).

Echo-sounder surveys in the Small Aral Sea incorporated a biotope division into 4 quadrants. Each quadrant entailed depth measurement, comprehensive water sample analysis, transparency assessment, flow rate, and temperature measurements. Echo sounding surveys encompassed 500 hectares per studied quadrant along straight and zigzag lines with a triangular closure. Fish and coverage intervals were calculated during scanning. The entire Shevchenko Bay constitutes the salty biotope of the Small Aral Sea. Echo sounding surveys in four biotope areas, totaling 2000 hectares, revealed fish numbers ranging from 49 to 65 specimens per hectare, amounting to approximately 4 million fish specimens across the entire biotope's water expanse (Table 4).

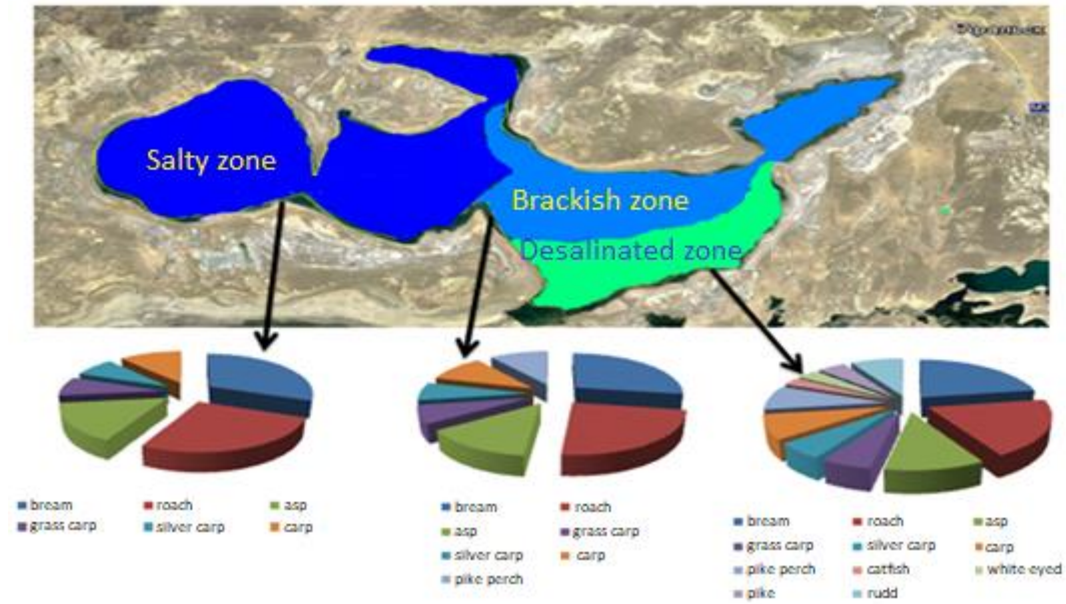


Figure 4. Species composition of fish and their distribution by biotopes of the Small Aral Sea.

Table 4

Fish concentrations in the salty biotope of the Small Aral Sea

No. echo sounding section	*Square area (ha)*	*Echo sounding area (ha)*	*Depth (m)*	*Fish concentrations, (ind. ha^{-1})*
1-A	17374	500	4-9	54
2-B	21356	500	5-11	65
3-D	26504	500	3-9	49
4-E	18318	500	2-6	51
Total	83552	2000	4-11	-

The brackish biotope of the Small Aral Sea occupies the central part of the sea. An echo sounding survey on a total area of 2000 ha showed that, according to calculations per 1 ha, the number of fish varies from 44 to 69 specimens (Table 5).

Table 5

Fish concentrations in the brackish biotope of the Small Aral Sea

No. echo sounding section	*Square area (ha)*	*Echo sounding area (ha)*	*Depth (m)*	*Fish concentrations, (ind. ha^{-1})*
5-A	15100	500	2-6	44
6-B	16343	500	4-7	56
7-D	22014	500	2-5	69
8-E	21496	500	3-8	46
Total	74953	2000	2-8	-

The desalinated biotope of the Small Aral Sea occupies the Kokaral region with the estuarine part of the sea. An echo sounding survey on a total area of 2000 ha showed that, according to calculations per 1 ha, the number of fish varies from 56 to 88 specimens. This indicator confirms that the desalinated biotope is the most favorable for the life of fish (Table 6).

Table 6

Concentrations of fish in the desalinated biotope of the Small Aral Sea

No. echo sounding section	*Square area (ha)*	*Echo sounding area (ha)*	*Depth (m)*	*Fish concentrations, (ind. ha^{-1})*
9-A	21837	500	2-4	88
10-B	31891	500	3-6	85
11-D	29477	500	3-8	65
12-E	27788	500	2-3	56
Total	110993	2000	2-5	-

The analysis of data derived from echo sounding surveys for distinct biotopes underscores their unique attributes. Salinity, depth, and feeding areas influence fishing gear selection, optimizing their use in accordance with seasonal shifts and fish concentrations. Within the Small Aral Sea, the Butakov and Sarshyganak bays exhibit notable biotopic characteristics, positioning Butakov Bay within a highly saline zone and classifying Sarshyganak Bay as brackish. These bays are interlinked by a channel, potentially permitting compartmentalization during dry periods. Each bay further subdivides into fishing areas. Commercial catches reflect minimal fishing activity in the intensely saline Butakov Bay, characterized by salinity levels of up to 16 ppm and depths not exceeding 2.5 meters across its 18100-hectare expanse. Echo sounding scans indicate an average of 8 fish specimens per hectare. In contrast, Sarshyganak Bay, situated in the northeastern region of the sea, spans an area of 28263 hectares, with depths ranging from 1.2 to 2.8 meters and a heavily overgrown seabed. Echo sounding surveys within this region identified a fish concentration of 23 specimens per hectare (Table 7).

Table 7

Fish concentrations in the bays of the Small Aral Sea

No. echo sounding section	*Square area (ha)*	*Echo sounding area (ha)*	*Depth (m)*	*Fish concentrations, (ind. ha^{-1})*
13-A, Butakov	18100	500	0.8-2.5	8
14-A, Sarshyganak	28263	500	1.2-2.8	23

When evaluating the commercial status of the two bays, a careful selection of their optimal use becomes imperative. For Butakov Bay, a recommended approach involves amalgamating its fishing areas with the adjacent fishing area of the main sea expanse. In this integrated zone, efforts can be directed towards acclimatizing new fish species well-suited to saline waters, along with fostering the growth of essential feed organisms.

On the other hand, Sarshyganak Bay's unique characteristics present distinct challenges. Its water exhibits brackish properties and experiences reduced water levels during the summer months. Additionally, fishing activities encounter difficulties due to shallow waters, particularly in the summer-autumn period when depths plummet to 1.2 meters and below. Overgrowth on the seabed hampers vessel movement. Recognizing its significance as a spawning ground for numerous commercial fish during the spring-summer period, it is advisable to institute a year-round ban on fishing within Sarshyganak Bay. Moreover, a prohibition on fishing has been in place from ice melting until June 10 in both Sarshyganak and Butakov bays (Order acting Chairman of the Committee for Forestry and Wildlife of the Ministry of Ecology, Geology and Natural Resources of the Republic of Kazakhstan 2020).

In light of the statistical analysis of echo sounding data, visualized in Figure 5, a discernible non-uniformity in fish concentration distribution across the Small Aral Sea's water expanse is evident.

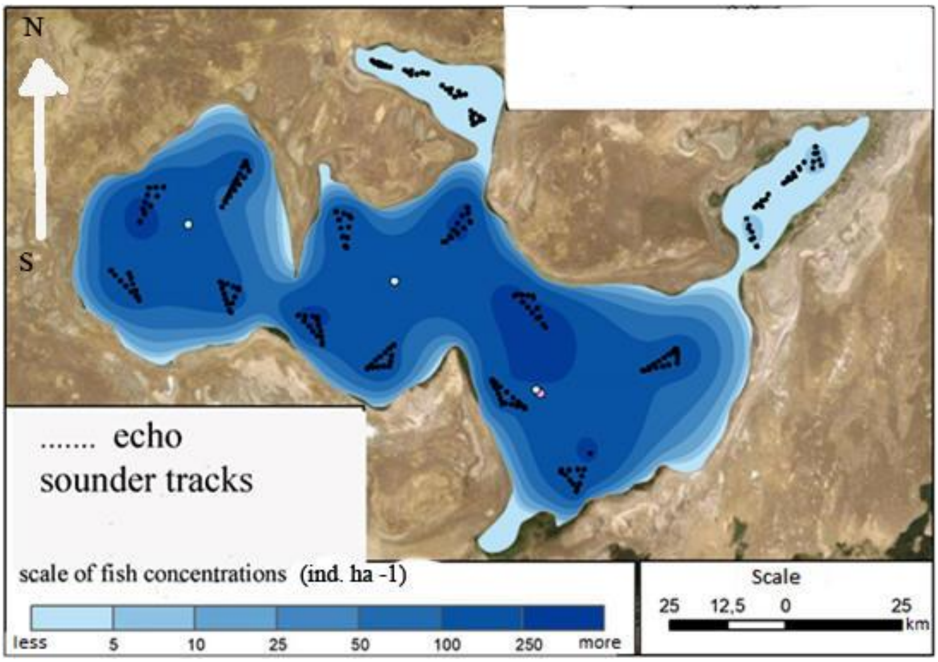


Figure 6. Schematic map of the distribution of fish concentrations in the Small Aral Sea.

The maximum concentration of fish (over 250 ind. ha^{-1}) was recorded in the brackish zone on the border of fishing areas IV and V. Zones with the highest concentration of fish above 250 ind. ha^{-1} are located in separate foci along the salty, brackish and desalinated zones within the fishing grounds I, II, IV, V.

Practically throughout the water area of the listed fishing areas I, II, IV, V, the concentration of fish is quite high, ranging from 50 to 250 ind. ha^{-1}.

Zones with the lowest concentration of fish (less than 5 ind. ha^{-1}) are located mainly in fishing grounds III and VI in the saline and brackish zones of the Butakov and Sarshyganak bays.

Given the fishing situation, the current fishing scheme is not optimal both in the main water area of the sea and in the bays. Our analysis of fishing practices shows that in recent years, the priorities of fisheries management in natural reservoirs are, along with the preservation of the current level of biodiversity, the maximum use of the productive capabilities of aquatic ecosystems and the improvement of the qualitative composition of fish products.

In order to ensure the rational use of fish stocks, on saline and brackish biotopes, it is recommended to use seine fishing. Seine parameters: length from 500 to 1000 m, height from 9 to 11 m at the coil, mesh size in the coil 36 mm, in wings and drives not less than 50 mm. However, the use of cast nets without special equipment leads to the destruction of bedrock silts, which adversely affects the survival of benthic invertebrates. To reduce the negative effect of seines on zoobenthos, we recommend equipping the lower seine line with a veil, which will slightly raise the seine, thereby reducing the destruction of bottom silt.

As in other countries, in Kazakhstan there is the so-called IUU fishing, which is one of the main problems of the industry. Fishing regulation can be carried out not only by setting annual catch limits and prohibitions on fishing during the spawning period and in certain especially valuable areas of the reservoir, but also by limiting the number of fishing gear and fishermen. The development of fishing standards (maximum allowable fishing effort for safe and resource-saving fishing) is another effective mechanism for monitoring and promptly responding to changes in fishing stocks by adequately changing fishing effort.

In 2006, the allocation of water bodies and sites on a non-scientific intuitive basis has led to the fact that in many water bodies there were a large number of fishing sites, the users of which have the right to fish only within the boundaries of their site, and the catch quotas are small and do not allow for profitable fishing from using automated fishing methods and fishing vessels.

It is necessary to establish for each reservoir the maximum allowable number of fishing gear used in the fishery. In the process of research, we determined such an amount for the Small Aral Sea. The number of fishermen in a water body should also not only meet the criteria for safe fishing, but also allow fishing organizations to fish profitably. The annual catch per fisherman, taking into account the profitability of the enterprise, should be at least 10 tons of fish (Kulikov et al 2019a, b). We also considered that the total catch limit (quota) for one area should be at least 1000 tons so that the user can develop production. The total annual limit on the Small Aral Sea is currently 6872-6937 tons of fish, that is, about 7 thousand tons. In this case, the recommended number of fishing sites is 7 per pond (Figure 6). When dividing the sea area into sections according to the area of individual sections, we took into account that the average density of fish accumulations in saline and brackish biotopes is almost the same (53.8-54.8 specimens per hectare), in a desalinated biotope it is much higher (73.5 specimens per hectare), hence the areas need to be smaller to ensure equal fishing conditions for all users, and in the bays, fish concentrations are very low and do not allow for profitable fishing.

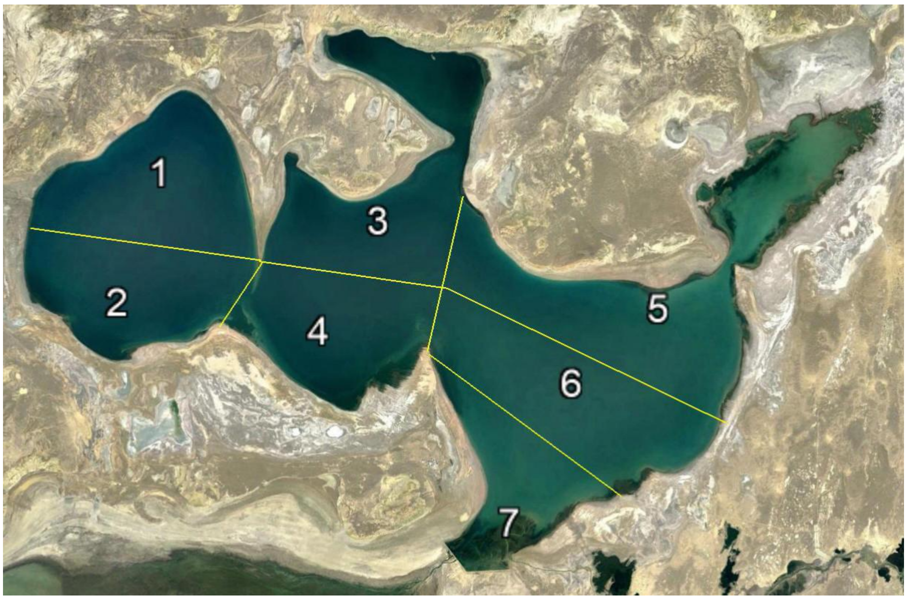


Figure 6. Recommended scheme for dividing the Small Aral Sea into 7 fishing grounds.

As fish catch data show, the limited set of fishing gear leads to the formation of underexploited stocks of small-sized fish (bream and roach), whose populations are most numerous in the desalinated biotope. For a more complete development of these small-sized numerous species, it is necessary to introduce venter fishing, since these fish are caught by fishing gear with a mesh size of less than 36 mm. The advantage of vents is that they can be installed on any part of the reservoir. Fish in the vents do not pool and remain alive for a long time, which makes it possible to release the by-catch of fish of non-commercial sizes back. The use of trawlers will make it possible to develop underexploited stocks of small-sized fish, and at the same time, makes it possible to release by-catch of fish of non-commercial sizes.

In order to ensure the efficiency of fishing and the rational use of fish stocks, fixed nets are recommended, which are typical for shallow areas of the sea: from 25 to 100 meters long and from 3 to 5 meters high. The actual use of fixed nets in the Small Aral Sea is 21337 pieces, we recommend reducing the number to 7000 pieces, based on the use of 35 nets.

Thus, the recommended number of fixed nets is 7000 pieces (1000 pieces for each fishing area), the number of cast nets is 35 pieces (5 for each area), the number of fishermen is 700 people (100 for each area).

This fishing effort will allow regulating the fishing load on water bodies by the number of fishing gear declared by nature users for organizing fishing and taking into account favorable days for fishing. This will reduce the presence of excess fishing effort in water bodies.

Conclusions. In summary, the assessment of the Small Aral Sea's fishing status underscores the inadequacy of the existing fishing scheme. Effective improvements must account for ichthyofaunal biotopic distribution, adjacent bay conditions, primary spawning areas, and the strategic implementation of fishing gear based on seasonal variations. Each biotope features distinct attributes encompassing depth fluctuations, foraging regions, winter habitats, and topography.

Presently, a reduction in net fishing gear usage is advised, favoring cast nets for capturing valuable species and venters for smaller fish species. To optimize the fishing scheme in the Small Aral Sea, alongside seine and net fishing, the supplementary use of echo sounders for locating fish clusters is recommended. This strategy holds the potential to enhance the exploitation of underexploited fish stocks.

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Conflict of interest. The authors declare that there is no conflict of interest.

References

Alekin O. A., 1959 [Methods for studying the organic properties and chemical composition of water]. Zhızn presnykh vod SSSR 4:213-298. [in Russian]
Babayan V. K., 2000 [Precautionary approach to estimating total allowable catch (TAC)]. Moscow: Publishing House of AIIF, 191 pp. [in Russian]
Chugunova N. I., 1952 [Method for studying the age and growth of fish]. Moscow: Sovetskaya nauka, 167 pp. [in Russian]
Data from Wikipedia. Chemocline 2022. Available at: https://en.wikipedia.org/wiki/Chemocline. Accessed: December, 2022.
FAO Technical Guidelines for Responsible Fisheries, 2010 Russian version of: FAO. Aquaculture development. 4. Ecosystem approach to aquaculture. FAO Technical Guidelines for Responsible Fisheries 5, Suppl. 4, 53 pp.
Hoggarth D. D., Abeyasekera S., Arthur R. I., Beddington J. R., Burn R. W., Halls A. S., Kirkwood G. P., McAllister M., Medley P., Mees C. C., Parkes G. B., Pilling G. M., Wakeford R. C., Welcomme R. L., 2006 Stock assessment for fishery management - a framework guide to the stock assessment tools of the Fisheries Management Science Programme (FMSP). FAO Fisheries Technical Paper No. 487, FAO, Rome, 261 pp.
Krag L. A., Herrmann B., Feekings J., Karlsen J. D., 2016 Escape panels in trawls – a consistent management tool? Aquatic Living Resources 29:306.
Kuczenski B., Poulsen C. V., Gilman E. L., Musy M., Winkler B., Geyer R., 2021 A model for the intensity of fishing gear. Journal of Industrial Ecology 26(6):1847-1857.
Kulikov Y. V., Isbekov K. B., Assylbekova S. Z., 2016 [Finding the withdrawal coefficients for fish populations that have reached critical values of the commercial stock biomass]. Voprosy rybolovstva 17(3):368-374. [in Russian]
Kulikov Y. V., Isbekov K. B., Assylbekova S. Z., 2019a [Development of fishing effort standards for regulating fisheries in the reservoirs of Kazakhstan]. Rybnoe khozyaıstvo 20(2):206-215. [in Russian]
Kulikov Y. V., Zharkenov D. K., Anuarbekov S. M., Kadimov Y. L., Barakbayev T. T., Tsoi V. N., 2019b [Fishing effort standards - a new word in science and practice]. [The state of aquatic biological resources and aquaculture of Kazakhstan and neighboring countries: Collection of scientific papers dedicated to the 90th anniversary of the SPC F. Almaty, September 2019]. Almaty: Kazakh University, pp. 350-358. [in Russian]

Malkin Y. N., 1999 [Reproductive and numerical variability of commercial fish populations]. Moscow: Ed. AIIF, 144 pp. [in Russian]
Maltsev K. A., Mukharamova S. S., 2014 [Building models of spatial variables (using the Surfer package): tutorial]. Kazan: Kazan University, pp. 57-64. [in Russian]
Methot Jr. R. D., Wetzel C. R., 2013 Stock synthesis: a biological and statistical framework for fish stock assessment and fishery management. Fisheries Research 142:86-99.
Nikolsky G. V., 1974 [The theory of fish herd dynamics]. Moscow: Food industry, 448 pp. [in Russian]
Nurdin, Zarlis M., Tulus, Efendi S., 2019 Data driven optimization approach to fish resources supply chain planning in Aceh Province. Journal of Physics: Conference Series 1255:012081.
Penas D. R., Gómez A., Fraguela B. B., Martín M. J., Cerviño S., 2019 Enhanced global optimization methods applied to complex fisheries stock assessment models. Applied Soft Computing 77:50-66.
Pravdin I. F., 1966 [Guide to the study of fish]. Moscow: Food industry, 376 pp. [in Russian]
Sambayev N. S., 2021 [Ion-salt composition of biotopes of the Small Aral Sea]. Vektor Geonauk 4(2):70-75. [in Russian]
Sambayev N. S., 2022 [Ways to optimize a set of fishing gear taking into account the ichthyocenosis in the Small Aral Sea]. Bulletin of the Kazakhstan-German University 1(13):42-50. [in Russian]
Veiga-Malta T., Feekings J. P., Herrmann B., Krag L. A., 2019 Industry-led fishing gear development: can it facilitate the process? Ocean and Coastal Management 177: 148-155.
*** [Guidelines for assessing the number of fish in freshwater reservoirs, 1986]. Moscow: ARIFF, 50 pp. [in Russian]
*** [Guidelines for the use of cadastral information for the development of a forecast of fish catches in inland waters, 1990]. Moscow: AIIF. Part 1, 56 pp. [in Russian]
*** [Order acting Chairman of the Committee for Forestry and Wildlife of the Ministry of Ecology, Geology and Natural Resources of the Republic of Kazakhstan, 2020]. Dated April 1, 2020, 27-5-6/72. [in Russian]
*** [Rules for the preparation of a biological justification for the use of wildlife: approved by the order of the MEWR RK, 2014]. Dated 04.04.2014, 104-Ө. Astana, 66 pp. [in Russian]
*** [State control of water quality, 2003 Collection of state standards: MPPC, Standards Publishing House]. 541 pp. [in Russian]

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