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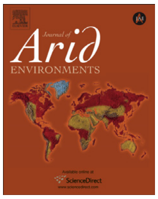

Hydroecological condition and potential for aquaculture in lakes of the arid region of Khorezm, Uzbekistan

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ABSTRACT

With >400 small (<1 ha) lakes, the arid Khorezm Province in Uzbekistan may be well-suited for aquaculture production. Developing water resources to provide a local food supply could increase fish consumption while improving the rural economy. Hydroecological (biological and physical) and chemical characteristics (including legacy pesticides ΣDDT and ΣHCH) of four representative drainage lakes in Khorezm from 2006 to 2008 were analyzed for the lakes' capability to support healthy fish populations. Lake characteristics were categorized as "optimal" (having little or no effect on growth and development), "tolerable" (corresponding to chronic or sub-lethal toxicity) and "lethal" (corresponding to acute toxicity). Results indicate that three lakes are likely well-suited for raising fish species, with water quality meeting World Bank aquaculture guidelines. However, the fourth lake often had salinity concentrations > optimal levels for local fish species. Pesticide concentrations in water of all four lakes were within tolerable aquaculture ranges. Although water ΣDDT concentrations were >optimal limits, results from chemical analysis of fish tissues and semi-permeable membrane devices indicated that study lake ΣDDT concentrations were not accumulating in fish or posing a human health threat. Land and water management to maintain adequate lake water quality are imperative for sustaining fish populations for human consumption.

1. Introduction

Aquaculture is currently the world's fastest growing animal-producing sector (FAO, 2009) and it is commonly suggested to aid in rural development. Increasing aquaculture production in the Aral Sea Basin province of Khorezm, Uzbekistan, could improve the livelihoods of rural households in this arid region by diversifying the local economy, providing farmers with an additional source of income, and promoting fish consumption by offering a low-cost source of protein.

Historically, fisheries in the Republic of Uzbekistan have played an important role in the lower reaches of the Amu Darya and Aral

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Sea. Before 1960, the Aral Sea annually produced an estimated 20,000 tonnes of fish (Karimov et al., 2005). Fisheries in the Aral Sea have disappeared due to the diversion of its largest tributary rivers, the Amu Darya and Syr Darya, for irrigation (Micklin, 2007). To make up for the loss of fish production in the Aral Sea, the Soviet Union government invested in a successful nation-wide aquaculture development program. Research centers, fish-culture farms, and aquaculture education were funded to promote the polyculture production of cyprinids such as common carp (*Cyprinus carpio*), silver carp (*Hypophthalmichthys molitrix*), bighead carp (*H. nobilis*) and grass carp (*Ctenopharyngodon idella*). The successful implementation of aquaculture throughout Uzbekistan generated between 20,000 and 25,000 tonnes of fish each year during the 1970s and 1980s. Polyculture, generally with carp species, was utilized in earthen ponds. Fish were raised under semi-intensive conditions (i.e., fish were raised in mostly natural systems with limited additional inputs such as nutrients and food; Karimov et al., 2009).

After gaining independence in 1991, Uzbekistan transformed from a planned economy to a market-based economy, which had a detrimental effect on aquaculture. Lacking private investments to replace lost government subsidies, capture fisheries and aquaculture fish production decreased from 27,200 tonnes in 1991 to 4300 tonnes in 2004, and fish consumption decreased from about 12 kg of fish per person per year before 1991 to 1 kg of fish per person per year post-1991 (Karimov et al., 2009; Wecker et al., 2007). Since the 1980s, aquaculture has provided 60 to 80 percent of the country's total fish production. Aquaculture in Uzbekistan continues to be predominately semi-intensive, polyculture pond aquaculture with traditional carp species (Wecker et al., 2007).

There has been growing interest in developing surface water resources for increased aquaculture in Uzbekistan, Central Asia, with particular interest in the Khorezm Province (Wecker et al., 2007). Khorezm is in the Aral Sea Basin and has about 400 lakes that are 1 ha up to approximately 2340 ha in size. These lakes are not man-made, occur throughout the province and are hydraulically linked to the extensive irrigation network connected to the Amu Darya in Khorezm (Scott et al., 2011). Some of these lakes are currently being used to raise fish and many more may be suitable for developing semi-intensive pond aquaculture, but both water quality and water availability are a concern.

The Khorezm region in western Uzbekistan has a continental climate with about 100 mm/year of precipitation. Despite the arid climate, Khorezm is one of the most agriculturally productive regions in Uzbekistan. An extensive network of canals diverts water from the nearby Amu Darya and transports it throughout the province for most of the year (Veldwisch, 2008; Wehrheim et al., 2008). This large-scale irrigation network, which has 16,000 km of irrigation canals and 9000 km of irrigation collectors (also called drainage canals), diverts about 3.5–4.0 km^3 of water from the Amu Darya during the spring growing season and about 1.0–1.5 km^3 of water during the fall to produce cash crops such as cotton, wheat, and rice (Oberkircher et al., 2010).

The large influx of irrigation water greatly impacts water availability and quality in Khorezm. This irrigation has resulted in raising groundwater tables that now are approximately 1–2 m below the ground surface (Ibrakhimov et al., 2007) and has likely contributed to the large number of small, shallow lakes throughout the province. Water levels in the lakes generally fluctuate with irrigation and rise in the spring when leaching is used to flush salts from soils and decline in late summer and fall (Ibrakhimov et al., 2011; Tischbein et al., 2012). Water quality in the lakes is also impacted by irrigation. Previous studies (Scott et al., 2011; Shanafield et al., 2010) indicate water quality in the lakes reflect both Amu Darya water quality and agricultural activities. The Amu Darya's water quality in conjunction with local impacts from land use and the historical use of pesticides make nutrient loading, salinity, and persistent pesticides the major water quality concerns in the Khorezm lakes.

The objectives of this study were to examine the hydro-ecological and chemical characteristics of four representative lakes in Khorezm to determine if the lakes can sustain healthy fish populations for aquaculture. These lakes were considered representative because they are a similar size and depth to many of the other lakes in the region. They also have similar water quality parameters to other lakes that we have tested periodically. These lakes are also located within the agricultural region and so have similar land use and topography to many of the other lakes in the region.

We analyzed fish and zooplankton composition, and physical and chemical parameters that could affect fish health and productivity including temperature, pH, salinity, nitrogen (N) and phosphorus (P), and dissolved oxygen (DO). Pesticide concentrations of ΣDDT and ΣHCH were also evaluated. ΣDDT is the sum of dichlorodiphenyltrichloroethane (p,p'-DDT) and two degradation products, dichlorodiphenyldichloroethylene (p,p'-DDE) and dichlorodiphenyldichloroethane (p,p'-DDD). ΣHCH is the sum of two forms of hexachlorocyclohexan (γ-HCH and α-HCH). Both of these pesticides were historically used in large quantities for agriculture in Khorezm and high concentrations have been documented in Uzbekistan's water resources (Ataniyazova et al., 2001; Bogdasarov et al., 2001; Bragin et al., 2001; Galiulin and Bashkin, 1996).

While aquaculture could include shellfish harvesting, shellfish have not been a traditional part of the Khorezm or Uzbek diet in general, so assessing the lakes for shellfish suitability is not part of this study. Likewise, because Uzbekistan is a landlocked country that makes little use of marine fish species, we did not consider marine aquaculture species. Instead, we focused on the production of fishes that are typically eaten and already reared in Uzbekistan to bolster this under-utilized resource.

2. Physiogeographical characteristics of the investigated lakes

The four lakes, Eshanrabat (ESH), Khodjababa (KHO), Shur (Koshkopir) (SHK), and Tuyrek (TUY), were chosen for this study because they are characteristic of the small, shallow lakes (<5 m at their deepest point) found throughout Khorezm and were relatively easy to access for data collection (Fig. 1; Table 1). Typical for this region, all four lakes are primarily fed from nearby irrigation collectors. The irrigation regime along with groundwater levels and evaporation rates greatly impact these lakes' water budget and hydrochemistry (Scott et al., 2011). All four subject lakes also had existing zooplankton communities.

3. Materials and methods

Monthly water quality and seasonal biological data were collected from the four representative Khorezm lakes over 2.5 years between June 2006 and October 2008.

3.1. Water quality

In situ data (temperature, pH, DO, and salinity) were collected from all four lakes approximately monthly using a hand-held sonde (YSI-85, Yellow Springs, OH). Clarity measurements were taken with a Secchi disk. Water quality readings were taken at 0.5 m below the lake surface in the deepest part of the lake and at 0.5 m intervals until the bottom of the lake was reached. Because no stratification was observed, *in situ* readings from the water column

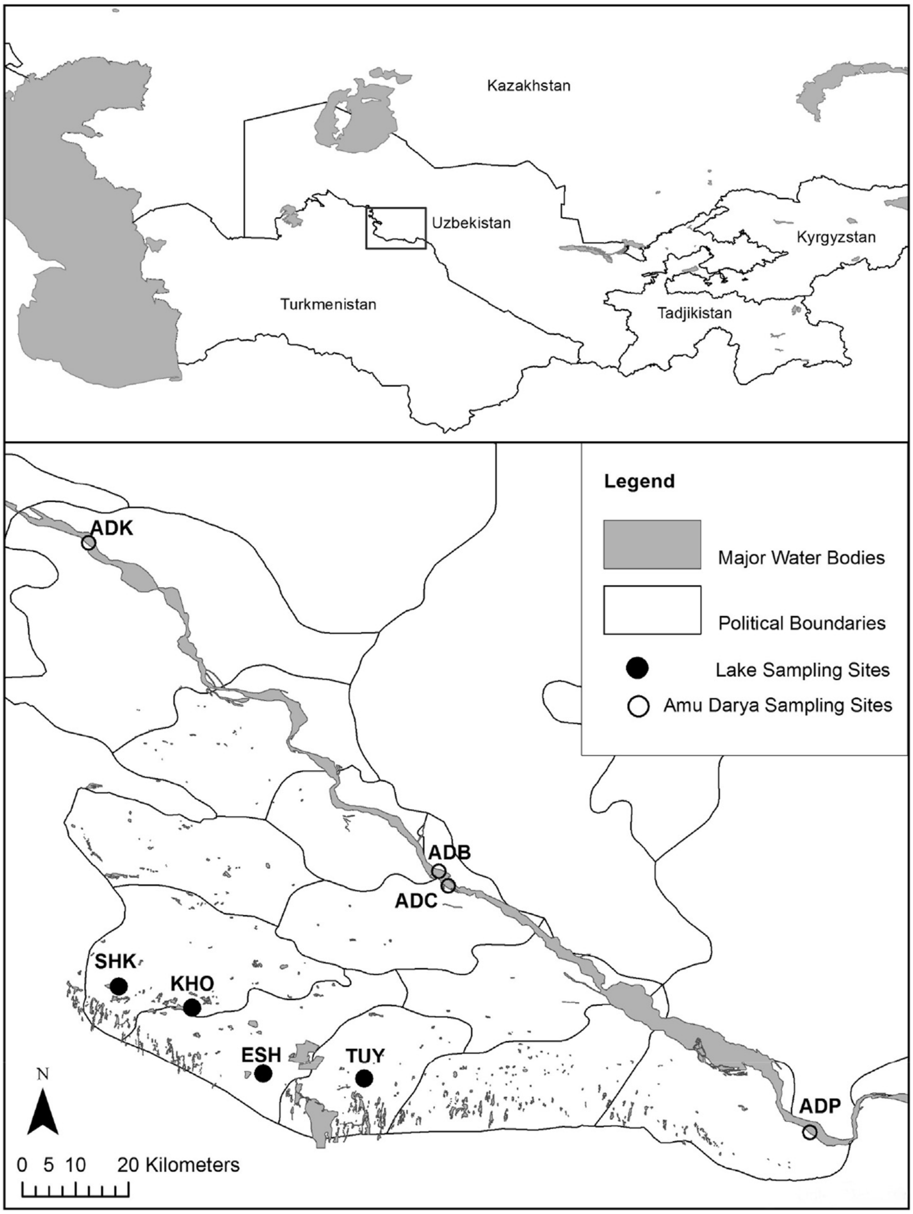

Fig. 1. Location of Eshanrabat (ESH), Khodjababa (KHO), Shur (Koshkopir) (SHK), and Tuyrek (TUY) lake sample sites and Amu Darya river sample sites Pitnyak (ADP); Cholish (ADC); Beruni (ADB); and Kypchak (ADK) within the Khorezm region of Uzbekistan, Central Asia.

Table 1
Characteristics of 4 study lakes: Eshanrabat (ESH), Khodjababa (KHO), Shur (Koshkopir) (SHK), and Tuyrek (TUY).

Lake	Surface area[a] (km^2)	Maximum depth (m)	Clarity (m)	Phytoplankton present	Macrophytes present	Zooplankton present
ESH	1.22	1.5	2	Yes	Yes	Yes
KHO	0.21	2.0	1	Yes	No	Yes
SHK	0.38	3.0	2	Yes	Yes	Yes
TUY	0.08	3.0	2	Yes	No	Yes

[a] Surface area estimated using satellite images in Google Earth from 2002 (ESH), 2005 (KHO, SHK), and 2006 (TUY).

were averaged for each sampling date. Logistical issues prevented the lakes from all being sampled at the same time each month, so the time of day and the day of the month samples were collected varied. Some of the lakes were not sampled in November, December, and/or January due to extremely low water levels and/or freezing conditions (Saito et al., 2010). Four sites on the Amu Darya were also sampled from June 2006 to May 2007: Pitnyak (ADP; most upstream site located where canal water leaves the Amu Darya to Khorezm); Cholish (ADC); Beruni (ADB); and Kypchak (ADK; most downstream site).

One water sample was taken from 0.3 m below the surface at each *in situ* sampling location on each sampling date to measure nutrient (nitrogen and phosphorus species), and pesticide concentrations (ΣDDT and ΣHCH) in the lakes. All water quality analyses were conducted at the Hydrometeorological Research Institute (NIGMI) in Tashkent, Uzbekistan. Nitrogen was analyzed by testing for nitrite (NO_2^-), nitrate (NO_3^-), and total ammonia nitrogen (TAN; sum of NH_3 and NH_4^+) according to modified U.S. Environmental Protection Agency (USEPA) 350.1 and 353.1 methods. Water samples were passed through a 0.45 μm filter before analysis. Method detection limits (MDL) for nitrite, nitrate and TAN were 0.001, 0.0005, and 0.005 mg/L, respectively (Shanafield et al., 2010). Total dissolved phosphorus (TDP) was analyzed at NIGMI based on USEPA 365.3 methods using the photometric method with ascorbic acid and a MDL of 1 μg/L. Replicates were completed on 10% of the samples and 72% of the replicates were within 15% of each other. Thirteen percent of the samples were field duplicates, and 50% of the duplicates were within 15% of one another. Water samples collected from October 2006 to October 2008 were analyzed for ΣDDT and ΣHCH using an Agilent 6890 chromatograph that has detection limits of 0.002, 0.002, 0.005, 0.010, and 0.020 μg/L for α-HCH, γ-HCH, DDE, DDD, and DDT, respectively. For pesticides, 7% and 26% of the samples were replicates and field duplicates, respectively. Sixty percent of the pesticide replicates and 26% of the pesticide duplicates were within 25% of one another. Because many of the results were near the MDL, this degree of replicate and duplicate performance is expected.

Semipermeable membrane devices (SPMDs) are passive organic samplers that were used to mimic biological tissue to explore the overall toxicity of the lake water (see Huckins et al. (2006) for more details about how SPMDs are used to assess toxicity). The SPMDs are composed of lay-flat tubing that is filled with a thin film of the chemical compound triolein. Triolein adsorbs substances that would likely accumulate in the fat tissue of fish. Compounds with log octanol–water partition coefficients (K_{ow}) greater than 3.0 (hydrophobic compounds) are most easily accumulated in SPMDs. General classes of hydrophobic compounds sampled by SPMDs include polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), organochlorine pesticides, chlorinated dioxins and furans, pyrethroids, alkylphenols, and certain heterocyclic aromatics (Goodbred et al., 2009). In this study, SPMDs with 15.2 cm of triolein-filled tubing were used for ease of transport and cost effectiveness. Goodbred et al. (2009) have shown that the sensitivity of the 15.2 cm SPMDs is statistically sufficient to quantify individual organic compounds at an order of magnitude below aquatic health benchmarks.

SPMDs were deployed near the center of all four lakes for approximately one month in July 2006 during high lake levels, and in November 2006 during lower lake levels. The SPMDs were suspended from buoys at approximately mid-lake depth. In addition, three SPMDs were placed vertically in the water column near the center of the lake in ESH, KHO, and SHK in June 2007: one SPMD near the mid-depth point of the lake, one just above the sediment–water interface; and one just below the sediment–water interface under a brick or weight that kept the SPMDs in a vertical layout. A blank sample opened during deployment and retrieval of each sample was tested to determine if atmospheric contamination was present. Nitrile gloves were worn by all personnel and changed frequently to prevent cross contamination. The SPMDs were collected and kept in a freezer until shipped to the United States for analysis. During analysis in the laboratory, SPMDs were cleaned and the triolein extracted following procedures outlined in Rosen et al. (2006). The P450RGS test (CYP1A) was performed by the US Army Corps of Engineers (Vicksburg, MS) to determine toxicity equivalents (TEQs) which indicate a toxicity response to organochlorine pesticides (i.e., DDT and HCH) as well as PAHs (Rosen et al., 2006). Details of the specific CYP1A test that was used, P450RGS, can be found in Rosen et al. (2006). In general, the P450RGS test is useful for determining toxicity from AhR hydrophobic compounds and has been used extensively to assess toxicity in urban streams in the United States (Bryant and Goodbred, 2009) and by the U.S. Army Corps of Engineers to test suitability and toxicity of dredged sediment in waterways, including organochlorines and PAHs (Inouye and McFarland, 2000).

3.2. Aquaculture guidelines

While aquaculture guidelines are available for some countries, they are not available for Uzbekistan or the Khorezm region. Thus, a literature review was conducted in which reviewed sources included: 1) water quality data compiled by staff at the World Bank for aquaculture in Zweig et al. (1999); 2) United States Government organizations (e.g., ATSDR, 2002; USEPA, 2009; USEPA, 1980); and 3) books and journal articles about aquaculture water quality (e.g., Boyd, 1990; Mara and Cairncross, 1989). Table 2 summarizes guidelines from government agencies and scientific literature that are pertinent for lakes in Khorezm. Particular focus in the literature review was placed on fish species found in Khorezm and fish found in brackish warm water environments. Native grass carp (*C. idella*) and naturalized channel catfish (*Ictalurus punctatus*) are two such species that have accessible aquaculture guidelines. Although channel catfish were not found in the four lakes, these fish are known to be present in Khorezm and are included in Table 2.

Aquaculture guidelines presented indicate values that will generally provide the most favorable environmental conditions for optimal fish growth. Tolerable levels for aquaculture are also presented; these guidelines can encompass a greater range of values and although fish growth may not be maximized, the environmental conditions will not likely have a major impact on fish growth. When applicable, approximate lethal limits for fish are also shown in Table 2. In accordance with Zweig et al. (1999), we categorized physical and chemical lake characteristics as well as pesticide concentrations within “optimal” ranges (having little or no effect on growth and development), “tolerable” ranges (corresponding to chronic or sub-lethal toxicity) and “lethal” ranges (corresponding to acute toxicity).

3.3. Biota

Zooplankton, macroinvertebrate, and fish samples were collected throughout 2006–2008 to provide information about the local species in the four lakes. To collect zooplankton, a clean conical net (diameter 18 cm, length 35 cm, mesh size No. 76) was pulled in the water behind a row boat for 10 min in the center of the lake. Zooplankton were placed in clean bottles and kept cold. Macroinvertebrates were collected with a net along the bottom of each lake in the littoral zone and placed in vials with alcohol for preservation. Some fish were selected from the gill nets of local fishermen for tissue samples to determine toxin loads in native and naturalized fishes already living in the lakes. The study team also deployed gill nets of size 15, 22, 30, 40, 50, 60, 70, and 80 mm, although fish were only caught using the 22 and 30 mm gill nets. Between 2006 and 2008, a total of 47, 106, 45, and 79 fish were caught at ESH, KHO, SHK and TUY lakes, respectively. Fish were identified according to Omonov and Mirzaev (1993), weighed and placed on a fish board to measure the standard fish length, and scales from behind the pectoral fin were put in an envelope for age analysis. A small number ($n = 10$) of dorsal muscle samples from fish caught in KHO, SHK and TUY were analyzed for ΣDDT and ΣHCH concentrations. The pesticide analysis was completed at NIGMI using an Agilent 6890 chromatograph with capillary columns (Rovinsky, 1986).

To determine fish age and growth rates, fish scales were

Table 2
Recommended aquaculture guidelines from Zweig et al. (1999) unless otherwise noted. All units are in mg/L unless otherwise noted.

	General	Freshwater fish	Grass carp	Channel Catfish
Temperature	Species dependent	Lethal <0 °C	Optimal 25–30 °C	Optimal 27–29 °C
Turbidity	Tolerable <80; Species dependent			Behavior change >20,000
Salinity	Species dependent	Optimal <0.5 g/L	Optimal <10–14 g/L	Optimal 0.5–3 g/L Tolerable <0.5–14 g/L
Alkalinity	Optimal >100; tolerable 20–400	Poor buffering <30	Optimal >100 or 150	
pH	Optimal 6.5–9	Lethal <4 or >11; reduced growth 4–6.5 & 9–11		
Hardness	Optimal waters will have equal magnitude as alkalinity			
Dissolved Oxygen	Optimal >4–5; dependent on other variables	Optimal >5; can survive a few days >1.5; few hours >1; lethal <0.3	Tolerate 3–4; prefer >5	Slow growth <5
Total Gas Pressure (TGP)	Optimal <100%			
Nitrogen Gas (N_2)	Optimal 10–20			
Ammonia (NH_3)	Many variables affect concentrations (toxic between 0.6 and 2)	Optimal <0.05		
Nitrite (NO_2^-)	Optimal <0.1	Optimal <0.1 (hard and soft); reduced growth >0.5		
Nitrate (NO_3^-)	Optimal <100; tolerable <3		Optimal <80	
Total Ammonia Nitrogen (TAN)		Optimal <1.0		
Iron (Fe)	Optimal <0.01[a]		Optimal <0.2	Tolerable 20–50 for ferrous iron
Manganese (Mn)	Optimal <0.01			
Hydrogen Sulfide (H_2S)	Avoid			
Methane (CH_4)	Optimal <65			
Total HCH		Optimal <0.98 μg/L[b]		
Total DDT		Optimal <0.001 μg/L; tolerable <1.1 μg/L[b]		
Toxicity Equivalent (TEQ)	Optimal <300 pg TEQ/mL[c]; Tolerable 500–1500 pg TEQ/mL[c]			
Fecal Coliform	Ideal <1000/100 mL[d]			

[a] Boyd (1990) states that some aquaculture systems can tolerate concentrations of ferrous iron up to 100 mg/L.
[b] USEPA (1980).
[c] Rosen et al., 2006.
[d] Mara and Cairncross 1989.

examined in the laboratory at the Institute for Water Problems in Tashkent by placing 3 to 4 scales in a petri dish with water. A drop of ammonia was added to remove dirt from the scales, and they were examined under a microscope to determine age by counting the number of annual rings. The rate of growth was defined according to Dahl-Lea formula (Pravdin, 1966). Growth analysis was only completed for fish from KHO, SHK, and TUY.

To assess phytoplankton density, a liter of water from 0.3 m below the surface of the lake was collected and analyzed. Phytoplankton concentrations were estimated based on the sedimentary method (Kiselev, 1969; Usachev, 1961). Quantitative processing of algae was done microscopically using a BIOLAM microscope (Soviet Union) with standard algology technique using Fuchs-Rosenthal cell counting chambers (volume 3.2 mm^3).

4. Results and discussion

4.1. Water quality

Warm water fish species generally thrive in water with temperatures between 20 and 28 °C, while temperatures <0 °C are generally considered to be lethal (Zweig et al., 1999, Table 2). Seasonal trends in water temperature were observed in all four lakes between June 2006 and October 2008 (Fig. 2a). Summer (June–August) temperatures were generally between 25 and 30 °C, while winter temperatures (December–February) were generally between −1.0 and 10 °C. ESH had the only measured temperature below 0 °C, but ESH did not freeze when this occurred in January 2008 because of its high salinity concentrations. During an extremely cold spell in December 2007 all four lakes were partially frozen.

Local fish species such as grass carp and Wels catfish (*Silurus glanis L*) grow well in brackish waters because they can tolerate high salinity concentrations. Grass carp can tolerate salinities ranging from <10 to 14 g/L (Zweig et al., 1999). Wels catfish prefer salinities of 0.5–3 g/L, although they can survive at salinities between <0.5 and 14 g/L (Table 2). Salinity levels >14 g/L are above the maximum tolerable levels for channel catfish and grass carp (Table 2). Salinity in the investigated lakes ranged between 1.5 and 49 g/L (Fig. 2b). Salinity in KHO, SHK, and TUY lakes never exceeded the maximum tolerable level (14 g/L) and typically ranged from 2 to 3 g/L. KHO, SHK and TUY had maximum salinity concentrations of 11.5, 5.7, and 5.0 g/L, respectively, in the fall of 2008, which corresponded with low lake levels. ESH consistently had higher salinity levels and displayed higher salinity variability compared to the other three lakes (Fig. 2b). The highest measured salinity concentration in ESH was 49.8 g/L in July 2008. The higher salinity values observed in ESH are likely a result of its location and hydrology. ESH is a terminal lake with no outflow. High evaporative rates and low incoming flows can cause the lake level to decline and salinity to increase. Also, local agricultural practices influence water supply for all of the lakes (Scott et al., 2011). In early spring (February–March) and to some extent in fall (September–October) agricultural fields are leached, increasing groundwater levels and salinity concentrations in groundwater. The volume of water and salinity concentration supplied to the study lakes during this process of leaching is unknown; however, they may substantially influence lake hydrochemistry.

DO concentrations >5.0 mg/L are recommended for warm water fish species including carp and channel catfish (Table 2; Lloyd, 1992). These species can usually survive DO concentrations >1.5 mg/L for several days and >1.0 mg/L for several hours. Lethal

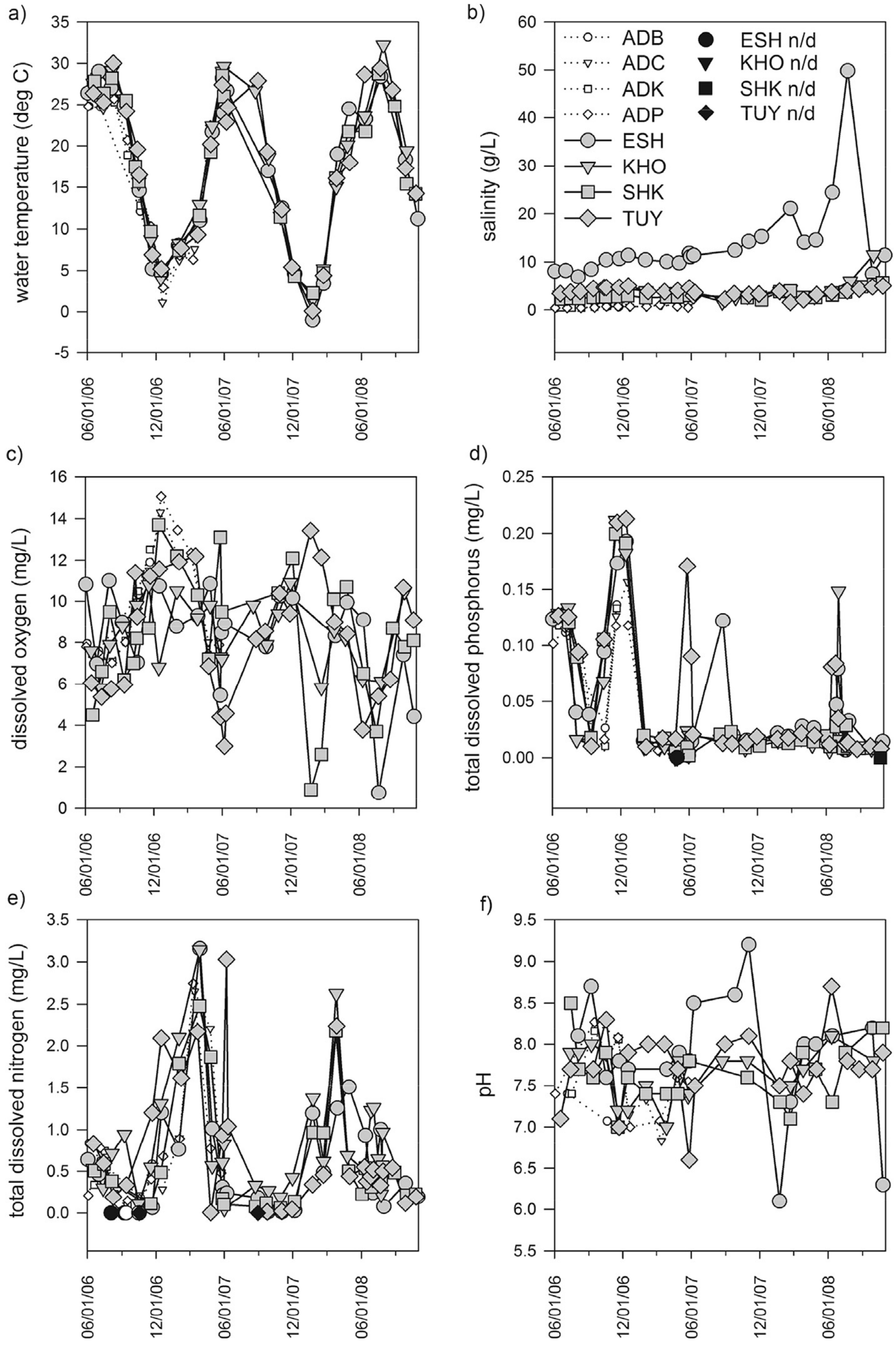

Fig. 2. Measured a) water temperature (°C); b) salinity (g/L); c) dissolved oxygen (mg/L); d) total dissolved phosphorus (mg/L); e) total dissolved nitrogen (mg/L); and f) pH over time for Amu Darya sampling sites (Beruni (ADB), Cholish (ADC), Kypchak (ADK), and Pitnyak (ADP)) and lakes (Eshanrabat (ESH); Khodjababa (KHO); Shur (Koshopir) (SHK); Tuyrek (TUY)). "n/d" refers to measurements of "not detected."

DO levels occur at <0.3 mg/L (Table 2). The majority of measured DO values in the four lakes were between 5.0 and 12.0 mg/L (Fig. 2c). ESH and SHK had low DO concentrations in January 2008; values reached lows of 1.13 and 0.94 mg/L, respectively. Another low DO value of 0.76 mg/L was observed in ESH in July 2008. DO concentrations in the lakes corresponded to Amu Darya DO concentrations (Fig. 2c).

Local sources of important nutrients for productivity are likely entering the lakes via input water from the Amu Darya (Shanafield et al., 2010) as well as from livestock, sediment, fertilizers, household sewage, and drains (Nikanarova, 1988). Nitrogen and phosphorus concentrations in the four lakes were similar to concentrations found in the Amu Darya (Fig. 2d, e; Shanafield et al., 2010). TDP concentrations varied between lakes and ranged from below detection limits to 0.21 mg/L (Fig. 2d). All four lakes had maximum TDP concentrations during the winter of 2006 (Fig. 2d). Nitrogen values were similar between the four lakes (Fig. 2e). TDN was dominated by TAN, which varied between 0.04 and 2.97 mg/L and appeared to have seasonal fluctuations, with lower concentrations measured in fall and higher concentrations measured in spring, which corresponded with seasonal agricultural leaching (Shanafield et al., 2010). Of particular concern for aquaculture is unionized ammonia concentration, which is a toxic form of nitrogen to aquatic species (Filova, 1989). Unionized ammonia concentrations ranged from below detection limits to 0.144 mg/L (Shanafield et al., 2010). TAN concentrations were occasionally above recommended levels for aquaculture; however, the majority of unionized ammonia concentrations were within the optimal range (Shanafield et al., 2010). Nitrite and nitrate concentrations were all <0.06 mg/L and <0.5 mg/L, respectively. The highest nitrate values occurred during the spring of 2006, 2007, and 2008 and generally correlated with higher concentrations of nitrite.

Values of pH were usually within the optimal range (6.5–9.0) for raising warm water fish and were not measured in the lethal range (<4 or >11; Table 2; Fig. 2f). KHO, SHK, and TUY had pH values that were in the same basic range as the Amu Darya values. ESH had the greatest variability in pH, which ranged from 6.1 to 9.2.

The pesticides DDT and HCH were used extensively from the 1950s through 1991. In the late 1970s, the total amount of pesticides used in Central Asia was between 30 and 35 kg/ha, almost 30 times higher than in the former Soviet Union during this time (UNESCO, 2000); as a result, DDT and HCH are still being detected in soil, water, plants, animals and human breast milk in the Aral Sea region (Ataniyazova et al., 2001; Bragin et al., 2001; Bogdasarov et al., 2001; Galiulin and Bashkin, 1996; Muntean et al., 2003; Nishonov et al., 2009). Although other pesticides and herbicides have been used in Uzbekistan for agriculture, few or no data are available on their occurrence and use. Due to the low solubility of these compounds and their resistance to breaking down completely (Loganathan and Kannan, 1994), their presence in the water and fish can be used as a marker for anthropogenically-derived organic compound occurrence in the lakes.

Both DDT and HCH were found in all of the lakes. With the exception of a few values below detection limits in 2006, all water samples had DDT concentrations greater than the optimal maximum of 0.001 μg/L (Zweig et al., 1999) for rearing fish for human consumption (Fig. 3a; Table 2). ΣDDT concentrations ranged from below detection limits to 0.14 μg/L and were all below the maximum tolerable or acute toxicity concentration of 1.1 μg/L for aquaculture water (Fig. 3a). The highest observed lake ΣDDT concentration was in TUY in June 2007. ΣHCH concentrations in all lake samples never exceeded 0.05 μg/L, which was far below the optimal maximum of 0.97 μg/L (Zweig et al., 1999) for aquaculture (Fig. 3b; Table 2).

Although the water sampled in the lakes showed that DDT and HCH were present, SPMD results indicated these pesticides did not appear to be eliciting a comparable toxic response in biologic tissue samples taken from the lakes and Amu Darya. Toxicity equivalent (TEQ) concentrations measured from SPMD extracts were predominately within maximum optimal concentrations (<300 pg TEQ/mL; Table 2) at our study sites, despite higher than optimal concentrations of measured DDT in the water. The P450RGS assay results of SPMD extracts showed that the two blanks that represent background conditions ranged from 56 to 120 TEQ. TEQ measurements in the lakes were all within optimal and occasionally within the background condition range. Toxicity measurements in the lakes ranged from 82 TEQ in SHK to 241 TEQ in TUY (Table 3). SPMD results from the Amu Darya were similar to results from the lakes, with the maximum and only measured toxicity above the optimal range at 328 TEQ at ADP in June 2006. The other two SPMD results from the Amu Darya, ADK and ADB, were 69 and 140 TEQ, respectively.

The lakes also showed a narrow range in toxicity, with ESH samples showing virtually no toxicity relative to background conditions, KHO and SHK having low toxicity (maximum 152 and 205 TEQ, respectively), and TUY showing a slightly higher toxicity, with four out of five samples measuring 140-241 TEQ. Even though toxicity was found in the water in this study, the highest toxicity value from the Amu Darya is comparable to the TEQ values (range 95–599) from reference (undeveloped watershed) streams used to study effects of urbanization in six different metropolitan areas of the United States, and an order of magnitude lower than the highest TEQ value of 9158 from all 164 streams (Bryant and Goodbred, 2009). It is interesting that TUY had both the most samples with toxicity and the highest toxicity of the four lakes, and also had the highest ΣDDT and some of the highest ΣHCH concentrations. Because SPMDs sample other hydrophobic compounds, not just DDT and HCH, the higher toxicity in TUY might be due to other compounds not measured in this study. Even though toxicity in TUY is still low enough that it most likely would not affect aquaculture, it might be prudent to occasionally monitor toxicity to assure it is not increasing.

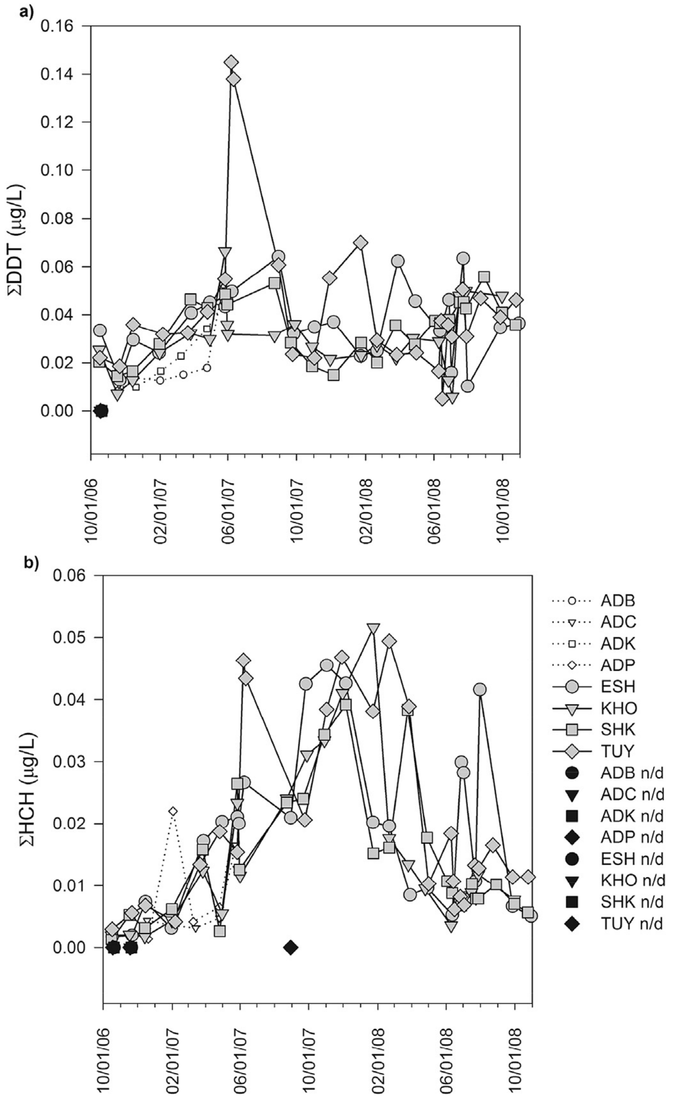

Fig. 3. Measured a) total DDT (μg/L); and b) total HCH (μg/L) for Amu Darya sampling sites (Beruni (ADB), Cholish (ADC), Kypchak (ADK), and Pitnyak (ADP)) and lakes (Eshanrabat (ESH); Khodjababa (KHO); Shur (Koshopir) (SHK); Tuyrek (TUY)). "n/d" refers to measurements of "not detected." Samples collected through September 2006 were analyzed with a Fractovap chromatograph, after which they were analyzed with an Agilent chromatograph that had a lower detection limit.

Our limited fish tissue ΣDDT concentrations for KHO, SHK, and

Table 3
SPMD results for deployments in 2006 and 2007 for Amu Darya sampling sites (Beruni (ADB), Cholish (ADC), Kypchak (ADK), and Pitnyak (ADP)) and lakes (Eshanrabat, Khodjababa, Shur (Koshopir), Tuyrek). All units are toxic equivalents (TEQ) in pg/mL. Three replicates of each sample were analyzed in the lab, and values shown are averages of the replicates with the standard deviation in parentheses. See Table 1 for a list of lake abbreviations.

Site	Location	June 2006	October 2006	June 2007
ADP	Water column	327.6 (18.8)		
ADB	Water column	140.1 (26.0)		
ADK	Water column		68.6 (21.2)	
ESH	Water column	119.8 (26.8)	121.7 (7.9)	
ESH	Surface			105.4 (11.5)[a]
ESH	Middle			126.4 (16.8)
ESH	Bottom			109.3 (14.5)
ESH	Buried			106.7 (22.0)
KHO	Water column	124.6 (14.9)	152.1 (21.7)	
KHO	Middle			122.1 (17.4)[a]
KHO	Above bottom			83.3 (12.7)[a]
KHO	At bottom			105.2 (11.4)[a]
SHK	Water column	205.1 (30.6)[a]	81.7 (3.1)	
SHK	Surface			111.8 (16.7)
SHK	Middle			89.1 (6.5)
SHK	Bottom			84.8 (1.3)
TUY	Water column	142.4 (12.2)	96.4 (29.8)	
TUY	Surface			241.0 (11.4)
TUY	Middle			198.9 (19.4)
TUY	Bottom			205.0 (3.4)
Blank 1[b]		77.5 (35)	56.0 (6.2)	119.5 (15.1)
Blank 2[c]		96.6 (27.7)	92.3 (2.8)	89.6 (12.9)

[a] Replicate field samples were taken; average of replicate results shown.

[b] Blank 1 was used for deployments only for June 2006, October 2006, and June 2007.

[c] Blank 2 was used for retrievals only for June 2006, October 2006, and June 2007 with the exception that it was also used for one deployment in June 2007.

TUY lakes were well below US Food and Drug Administration guidelines of <5.0 mg/kg wet weight for DDT (USDHHS, 2002). ΣDDT concentrations were greater than ΣHCH in sampled fish, with average ΣDDT concentrations of 0.0074 mg/kg and a range of 0.0018–0.0349 mg/kg, while average ΣHCH values were 0.0016 mg/kg with a range of 0.0006–0.0025 mg/kg.

4.2. Biota

The investigated lakes can be categorized as macrophyte-dominated (ESH and SHK) and phytoplankton-dominated lakes (KHO and TUY). SHK was dominated by *Myriophyllum aquaticus*, whereas ESH was dominated by *Chara* spp. The dominant complex of phytoplankton communities included bacillophyta, blue-green and green alga. Zooplankton species composition of the lakes was relatively non-diverse and consisted of 29 species: 13 species of rotifera, 7 species of cladocera and 9 species of copepoda. Dominant species of SHK, KHO, and TUY lakes were rotifers *Brachionus plicatilis* and *Keratella quadrata*, cladocerans *Diaphanosoma mongolianum*, and cyclop copepods *Thermocyclops vermifer* and *Cyclops vicinus*. Zooplankton of ESH lake, which is notably more saline than the other lakes, were represented by the rotifer *B. plicatilis*, calanoid copepods *Arctodiaptomus salinus*, cyclop copepods *Apocyclops dengizikus* and *Harpacticoida* spp, and a cladoceran *Moina salina*. Zooplankton communities of all four lakes were dominated mostly by the number of copepods (cyclop, calanoida, and harpacticoida), but the percent of copepods varied depending on lake characterization and level of salinity. SHK, a macrophyte-dominated lake with salinity less than 3 g/L, tended to develop zooplankton communities of *Simocephalus vetulus*, whereas ESH developed mostly cladocera *A. salinus* and rotifera *B. plicatilis*.

In the investigated lakes, 17 species of fish were identified. Ten of the observed fish species were commercial. Dominant commercial fish species included snakehead (*Channa argus warpachowskii* (Berg.)), goldfish (*Carassius auratus gibelio* (Bloch)), aral roach (*Rutilus rutilus aralensis* (Berg.)), common carp (*Cyprinus carpio* L.), and grass carp (*Ctenopharyngodon idella* (Valenciennes)). Because of the brackish waters, these durable species are well-suited for lakes in Khorezm.

Environmental conditions for fish growth varied between the lakes. Our growth-rate results indicated that growth of one-year-old snakehead and goldfish were greater in SHK than in TUY and KHO, whereas carp growth barely differed between these three lakes (Fig. 4). Although we did not measure fish population numbers, the abundance of aquatic plants in SHK may make this lake well-suited for herbivorous fish such as grass carp. The populations of goldfish should also make this lake suitable for predatory snakehead. For TUY, we observed large numbers of planktonic organisms in the lake, suggesting it may be suitable to raise plankton-eating species of fish such as bighead carp and silver carp. In addition, both SHK and TUY have well developed benthic macroinvertebrate communities, which could provide an ample source of food for bottom-feeders such as goldfish and carp.

5. Conclusions

Our results suggest that hydroecological conditions in KHO and SHK are likely to successfully support healthy fish populations for aquaculture. Variable water levels in ESH and possible ΣDDT contamination in TUY make these lakes potentially less desirable for aquaculture. Further research on TUY should confirm whether or not ΣDDT found in the water is accumulating in fish tissue at a level hazardous for human consumption before proceeding with aquaculture at this site.

During the sampling period from June 2006 to October 2008, ESH regularly had low water levels that contributed to low and sometimes lethal winter water temperatures, and high salinity not tolerable to most freshwater fish species. Throughout the study period all of the lakes supported phytoplankton and zooplankton, but only KHO, SHK, and TUY consistently had warm water fish species present. Without intensive intervention, ESH will likely not have the environmental conditions to support healthy fish populations. Lake management techniques could enhance the viability

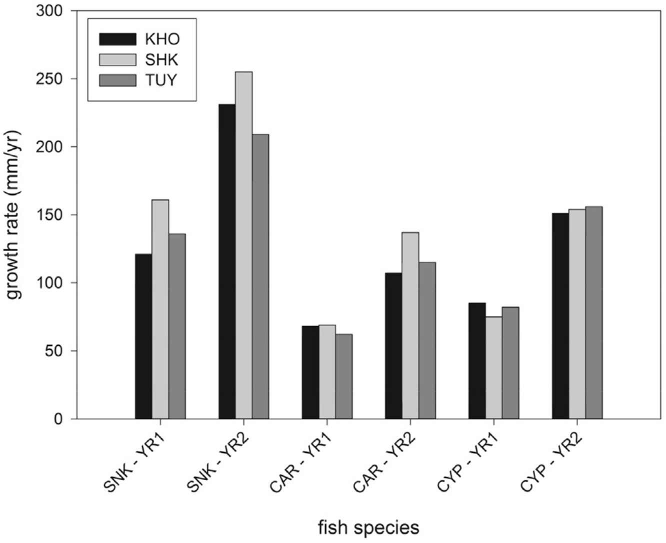

Fig. 4. Calculated fish growth rates for year-1 (YR1) and year-2 (YR2) snakehead (SNK), goldfish (CAR), and carp (CYP) in Khodjababa (KHO), Shurkul (Koshkopir) (SHK), and Tuyrek (TUY) lakes.

of developing aquaculture in lakes such as ESH, but pursuing this option would likely be resource intensive.

Further research of ΣDDT pathways in Khorezm lakes is also important. Although ΣDDT in the water was above optimal concentrations based on World Bank aquaculture guidelines (Zweig et al., 1999), both SPMD results and fish tissue results showed concentrations within tissues to be well within USEPA optimal ranges (Table 2). ΣDDT concentrations in fish tissue samples were all below 0.035 mg/kg and ΣHCH concentrations were all below 0.0025 mg/kg, although the sample size ($n = 10$) was likely too small to adequately capture the species-specific or trophic- or age-related variability of pesticide concentrations in Khorezm fish.

Low DO concentrations were occasionally observed in ESH, SHK and TUY (Fig. 2c), however it is difficult to determine the potential impact on fish without knowing the duration of these low DO concentrations because the lakes were only monitored monthly. The persistence of existing fish communities suggests the low DO conditions were not extreme or lethal. DO concentrations can be improved with simple, low-cost techniques to promote well-aerated waters, so the possibility of low DO concentrations should not discourage farmers from pursuing aquaculture in Khorezm lakes.

In assessing other lakes in the region that may be suitable for aquaculture, variability in lake level (and hence salinity) would need to be considered: lakes can initially be screened by examining lake depth and volume, and by determining the reliability of source water. Additionally, resident fishes should also be tested for ΣDDT concentrations in their tissue. Because ΣDDT bioaccumulates and biomagnifies, bottom-feeding fishes and older fish should be part of this analysis. Lakes that are currently being used to raise fish should be prioritized before this assessment is expanded to other lakes. With over 400 small lakes in Khorezm, developing water resources to provide a local food supply could increase consumption of fish, a traditional Uzbek food, while also supporting the local economy.

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References

Ataniyazova, O.A., Baumann, R.A., Liem, A.K., Mukhopadhyay, U.A., Vogelaar, E.F., Boersma, E.R., 2001. Levels of certain metals, organochlorine pesticides and dioxins in cord blood, maternal blood, human milk, and some commonly used nutrients in the surroundings of the Aral Sea, (Karakalpakstan, Republic of Uzbekistan). Acta Paediatr. 90, 801–808.

[ATSDR] Agency for Toxic Substances and Disease Registry, 2002. Toxicological Profile for DDT, DDE, DDD. U.S. Department of Health and Human Services, Public Health Service, Atlanta, GA [2011-03-17]. http://www.atsdr.cdc.gov/ToxProfiles/tp35.pdf (retrieved March 15, 2011).

Bogdasarov, V., Sergeeva, I., Bolshakovaa, L., Zubkov, D., 2001. Mapping of the degree of pollution by pesticides of agricultural irrigated areas in the Aral Sea regions. In: Ecological Research and Monitoring of the Aral Sea Deltas. A Basis for Restoration. Book 2. UNESCO Aral Sea Project. Final Scientific Report, pp. 225–230.

Boyd, C.E., 1990. Water Quality in Ponds for Aquaculture. Auburn University Press, Birmingham, AL.

Bragin, B.I., Sokolov, S.B., Jashenko, R.V., 2001. Accumulation of heavy metals and chlorine organic pesticides in components and trophic chains of water areas of the Syr-Dar'ya river delta and human diet. In: Ecological Research and Monitoring of the Aral Sea Deltas. A Basis for Restoration. Book 2. UNESCO Aral Sea Project. Final Scientific Report, pp. 55–72.

Bryant Jr., W.L., Goodbred, S.L., 2009. The response of hydrophobic organics and potential toxicity in streams to urbanization of watersheds in six metropolitan areas of the United States. Environ. Monit. Assess. 157, 419–447.

Filova, V.A., 1989. Harmful Chemical Substances: Inorganic Connections of Groups V-VIII. Gydrometizdat, Leningrad (In Russian).

Food and Agricultural Organization (FAO) Fisheries and Aquaculture Department, 2009. The State of World Fisheries and Aquaculture 2008. Italy, Rome.

Goodbred, S.L., Bryant, W.L., Rosen, M.R., Alvarez, D., Spencer, T., 2009. How useful are the "other" semipermeable membrane devices (SPMDs); the mini-unit (15.2 cm long)? Sci. Total Environ. 407, 4149–4156.

Galiulin, R.V., Bashkin, V.N., 1996. Organochlorinated compounds (PCBs and insecticides) in irrigated agrolandscapes of Russia and Uzbekistan. Water, Air, Soil Pollut. 89, 247–266.

Huckins, J.N., Petty, J.D., Booij, K., 2006. Monitors of Organic Chemicals in the Environment —Semipermeable Membrane Devices. Springer, New York, p. 223.

Ibrakhimov, M., Khamzina, A., Forkutsa, I., Paluasheva, G., Lamers, J.P.A., Tischbein, B., Vlek, P.L.G., Martius, C., 2007. Groundwater table and salinity: spatial and temporal distribution and influence on soil salinization in Khorezm region (Uzbekistan, Aral Sea basin). Irrigation Drainage Syst. 21 (3–4), 219–236.

Ibrakhimov, M., Martius, C., Lamers, J.P.A., Tischbein, B., 2011. The dynamics of groundwater table and salinity over 17 years in Khorezm. Agric. Water Manag. 101, 52–61. http://dx.doi.org/10.1016/j.agwat.2011.09.002.

Inouye, L.S., McFarland, V.A., 2000. Biomarker Based Analysis for Contaminants in Sediment/soil: Review of Cell-based Assays and cDNA Arrays. DOER Technical Notes Collection (ERDC TN-DOER-C19). U.S. Army Corps of Engineer Research and Development Center, Vicksburg, MS. http://www.wes.army.mil/el/dots/doer.

Karimov, B., Kamilov, B., Upare, M., van Anrooy, R., Bueno, P., Shokhimardonov, D., 2009. Inland Capture Fisheries and Aquaculture in the Republic of Uzbekistan: Current Status and Planning. Food and Agricultural Organization (FAO) Fisheries and Aquaculture Circular No. 1030/1. FAO, Rome, Italy.

Karimov, B., Lieth, H., Kurambaeva, M., Matsapeva, I., 2005. Mitigation and Adaptation Strategies for Global Change, vol. 10, 87–1-3.

Kiselev, I.A., 1969. Introduction and general questions on planktology. In: Plankton of the Seas and Continental Waterbodies, vol. 2. Nauka, Leningrad (in Russian).

Lloyd, R., 1992. Pollution and Freshwater Fish. West Byfleet, Fishing New Books. Oxford, UK, p. 192.

Loganathan, B.G., Kannan, K., 1994. Global organochlorine contamination trends: an overview. Ambio 23, 187–191.

Mara, D., Cairncross, S., 1989. Guidelines for the Safe Use of Wastewater and Excreta in Agriculture and Aquaculture. World Health Organization [2011-03-15]. http://www.who.int/water_sanitation_health/wastewater/wasteuse/en/ (Retrieved March 15, 2011).

Micklin, P., 2007. The aral sea disaster. Annu. Rev. Earth Planet. Sci. 35, 47–72.

Muntean, N., Jermini, M., Small, I., Falzon, D., Fürst, P., Migliorati, G., Scortichini, G., Forti, A.F., Anklam, E., von Holst, C., Niyazmatov, B., Bahkridinov, S., Aertgeerts, R., Bertollini, R., Tirado, C., Kolb, A., 2003. Assessment of dietary exposure to some persistent organic pollutants in the Republic of Karakalpakstan of Uzbekistan. Environ. Health Perspect. 111, 1306–1311.

Nikanarova, A.M. (Ed.), 1988. The Directory on Hydrochemistry. Gidrometeoizdat, Leningrad (In Russian).

Nishonov, B., Rosen, M.R., Fayzieva, D., Saito, L., Lamers, J., 2009. Organochlorine Pesticides Residue in Lakes of Khorezm, Uzbekistan. 10th International HCH and Pesticide Forum Proceedings Book of Papers, 6 – 10 September, 2009. Brno, Czech Republic, pp. 157–161.

Oberkircher, L., Tischbein, B., Hornidge, A.-K., Schorcht, G., Bhaduri, A., Awan, U.D., Manschadi, A.M., 2010. Rethinking Water Management in Khorezm, Uzbekistan: Concepts and Recommendations. Working Paper Series 54. Department of Political Cultural Change. Center for Development Research, University of Bonn [2010-08-15]. http://www.zef.de/fileadmin/webfiles/downloads/zef_wp/WP54_Oberkircher_et_al.pdf (retrieved August 15, 2010).

Omonov, A., Mirzaev, U., 1993. Fishes of Uzbekistan. Fan, Tashkent, Uzbekistan, p. 28 (in Uzbek).

Pravdin, I.F., 1966. Study of Fishes (Mainly Fresh-water), Book 4. Food Industry, Moscow, p. 376.

Rosen, M.R., Rowe, T.G., Goodbred, S.L., Shipley, D.O., Arufe, J.A., 2006. Importance of land use, streamflow, and water quality on toxicity of SPMD extracts deployed in streams from the Lake Tahoe and Truckee River Watersheds. In: Hughes, R.M., Wang, L., Seelbach, P.W. (Eds.), Influences of Landscapes on Stream Habitats and Biological Assemblages. American Fisheries Society, Symposium 48, pp. 125–149.

Rovinsky, F. (Ed.), 1986. Unified Methods of the Monitoring of Background Pollution of the Environment. Gidrometeoizdat, Moscow, p. 182 (in Russian).

Saito, L., Fayzieva, D., Rosen, M.R., Nishonov, B., Lamers, J., Chandra, S., 2010. Final Report: Using Stable Isotopes, Passive Organic Samplers and Modeling to Assess Environmental Security in Khorezm, Uzbekistan. NATO Science for Peace Project No. 982159.

Scott, J., Rosen, M.R., Saito, L., Decker, D.L., 2011. The influence of irrigation water on the hydrology and lake water budgets of two small arid-climate lakes in Khorezm, Uzbekistan. J. Hydrology 410 (1–2), 114–125.

Shanafield, M., Rosen, M.R., Saito, L., Chandra, S., Lamers, J., Nishonov, B., 2010.

Identification of nitrogen sources to four small lakes in the agricultural region of Khorezm, Uzbekistan. Biogeochemistry 101 (1–3), 357–368.

Tischbein, B., Awan, U.K., Abdullaev, I., Bobojonov, I., Conrad, C., Forkutsa, I., Ibrakhimov, M., Poluasheva, G., 2012. Water management in Khorezm: current situation and options for improvement (hydrological perspective). In: Martius, C., Rudenko, I., Lamers, J.P.A., Vlek, P.L.G. (Eds.), Cotton, Water, Salts and Soums - Economic and Ecological Restructuring in Khorezm, Uzbekistan. Springer, Dordrecht, Heidelberg, London, New York, pp. 69–92.

Usachev, P.I., 1961. Quantitative technique of gathering and processing phytoplankton. Works VGBO 11, 411–415.

[UNESCO] United Nations Educational, Scientific, and Cultural Organization, 2000. Water Related Vision for the Aral Sea Basin for the Year 2025 [2013-03-20]. http://unesdoc.unesco.org/images/0012/001262/126259mo.pdf (retrieved March 20, 2013).

[USDHHS] U.S. Department of Health and Human Services, Public Health Service, 2002. Toxicological Profile for DDT, DDE, and DDD, Agency for Toxic Substances and Disease Registry (retrieved March 15, 2011). http://www.atsdr.cdc.gov/ToxProfiles/tp35.pdf.

[USEPA] U.S. Environmental Protection Agency, 2009. Draft 2009 Update Aquatic Life Ambient Water Quality Criteria for Ammonia-freshwater. EPA/822-D-09-001. Office of Water, Washington, DC.

[USEPA] United States Environmental Protection Agency, 1980. Ambient Water Quality Criteria for DDT. Report No. EPA-440/5-80-038. USEPA, Washington, DC, p. 174 [2012-09-07]. http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm#cmc (retrieved September 7, 2012).

Veldwisch, G.J.A., 2008. Cotton, Rice and Water. The Transformation of Agrarian Relations, Irrigation Technology and Water Distribution in Khorezm, Uzbekistan. PhD dissertation. University of Bonn, Germany.

Wecker, B., Karimov, B., Kamilov, B., Waller, U., Matthies, M., Lieth, H., 2007. Sustainable Aquaculture in Recirculating Systems-feasibility Study for the Catchment Area of the Aral Sea. Institute of Environmental Systems Research, University Osnabrück, Germany. http://www.usf.uos.de:8880/projects/AquacultureUzbekistan/pdf/feasibility_study_final.pdf.

Wehrheim, P., Schoeller-Schletter, A., Martius, C. (Eds.), 2008. Continuity and Change: Land and Water Use Reforms in Rural Uzbekistan: Socio-economic and Legal Analyses from the Region Khorezm. Leibniz-Institut für Agrarentwicklung in Mittel- und Osteuropa (IAMO), Halle/Saale, Germany [2011-02-23]. http://www.iamo.de/dok/sr_vol43.pdf.

Zweig, R.D., Morton, J.D., Stewart, M., 1999. Source Water Quality for Aquaculture: a Guide for Assessment. The World Bank, Washington, D.C. [2011-12-12]. http://www-wds.worldbank.org/servlet/WDSContentServer/WDSP/IB/2002/03/15/000094946_02030704010886/Rendered/PDF/multi0page.pdf