Journal of Fisheries and Aquatic Science, 2011
ISSN 1816-4927 / DOI: 10.3923/jfas.2011.

Hydroacoustic Study of Spatial and Temporal Distribution of *Poblana alchichica* (de Buen, 1945) in Lake Alchichica, Mexico

[1]E. Arce, [2]J. Alcocer, [3]X. Chiappa-Carrara and [4]L. Zambrano
[1]Graduate Program in Marine Sciences and Limnology, National Autonomous University of Mexico, Ciudad Universitaria, Mexico DF 04510, Mexico
[2]Tropical Limnology Research Proyect, FES Iztacala, National Autonomous University of Mexico, Av. de los Barrios No. 1, Los Reyes Iztacala, 54090 Tlalnepantla, Estado de Mexico
[3]Multidisciplinary Unit of Teaching and Research Sisal, National Autonomous University of Mexico, Puerto de Abrigo S/N, Sisal, 97355 Yucatan, Mexico
[4]Department of Zoology, Biology Institute, National Autonomous University of Mexico, Ciudad Universitaria, Mexico DF 04510, Mexico

Corresponding Author: J. Alcocer, Tropical Limnology Research Proyect, FES Iztacala, National Autonomous University of Mexico, Av. de los Barrios No. 1, Los Reyes Iztacala, 54090 Tlalnepantla, Estado de Mexico Tel: (52) 555623.1333/39719 Fax: (52) 55 5390.7604

ABSTRACT
The present study analyses the distribution and abundance of *Poblana alchichica*, an atherinidae fish endemic to Lake Alchichica. Fish were sampled using hydroacoustic surveys, carrying out equidistant transect performed on a perpendicular grid that covered the entire surface of the lake on a seasonal basis to take into account the four hydrodynamic stages of Lake Alchichica. Results indicate that vertical distribution of fish varies in time and is limited by the availability of dissolved oxygen in deeper layers. Prey distribution and the zone in which reproduction occurs (i.e., the littoral) limit the horizontal distribution of the fish. Abundance of *P. alchichica* varied from 12,510 fish in early stratification up to 29,200 fish in the well-established stratification. Spatially, the average abundance in the littoral zone was 13,973±2,040 fish while in the pelagic zone abundance reached 7,088±1.395 fish. Density of *P. alchichica* fluctuated from 0.000015 individuals per m^3 in the pelagic zone during the early stratification to 0.019 individuals per m^3 in the littoral zone during the well-established stratification. Mean density estimates was 0.009±0.002 individuals per m^3. Hydroacoustic technique allowed understanding effectively fish density and distribution. These values are lower than those found in comparable environments and highlight the importance of the littoral zone and consequently the water level reduction, for the conservation of the species in the ecosystem.

Key words: *Poblana alchichica*, hydroacoustic survey, abundance, distribution, Tropical lake

INTRODUCTION
The Alchichica silverside, *Poblana alchichica*, is the only fish species inhabiting Lake Alchichica, one of the few deep Mexican lakes (maximum depth 62 m). Since, its distribution is restricted to this lake, even small habitat variations impose a threat of extinction to the population (Alcocer *et al.*, 2009).

The extinction risk of Mexican native species (MER) is calculated through the evaluation of 4 criteria regarding the taxon (Tambutti *et al.*, 2002): (1) distribution extent in Mexico, (2) habitat condition, (3) intrinsic biological vulnerability and (4) human impact on the species; each criterion is independent from the others and the addition comes to be an accumulative evaluation of risk. It is evident that the extinction risk is correlated not only with the extension of the distribution range -which in this case is very limited (microendemism)- but also with the size of the population. What is the minimum size population for a fish species to be considered threatened or endangered? What is the amount that guarantees a healthy and self-sustained population? In spite of their relevance, these issues are not addressed in the criteria described in the Mexican Official Norm.

In recent decades, multiple factors (such as decline in precipitation, increasing temperature and evaporation, decreasing water level, pollution, etc.) have led to a decrease in the abundance of the silverside according to local fishermen. Recently, this endemic fish has been declared as state-protected threatened species and listed in the NOM-059-ECOL-2001 (SEMARNAT, 2002). Therefore, understanding the biology and life history of this fish will greatly help to set up a series of conservation measures for the ecosystem of Lake Alchichica which holds other endemic species like the salamander *Ambystoma taylori* (Brandon *et al.*, 1982) and the isopod *Caecidotea williamsi* (Escobar-Briones and Alcocer, 2002).

Since its description, research efforts have concentrated on taxonomic aspects of *P. alchichica* (Miller, 1986). Limnological aspects of the lake have been described by Alcocer *et al.* (2000), Filonov and Alcocer (2002) and Filonov *et al.* (2006) and few studies evaluating the lake resources have been published (Lugo *et al.*, 1999; Oliva *et al.*, 2001; Adame *et al.*, 2008). Other than the accounts of local fishermen there is not a single study on the abundance and distribution of *P. alchichica*. Hydroacoustic offers an opportunity to adequately describe spatial and temporal patterns of fish distributions in freshwater habitats (Rose, 1992; Chen *et al.*, 2009). Hydroacoustic techniques have the advantage of a rapid, economic and extensive coverage of the water cross section (Coll *et al.*, 2007; Guillard and Verges, 2007).

The bucket-like morphology of Lake Alchichica precludes the application of standard methodologies (i.e., nets) to study the abundance and distribution of the fish; hence, hydroacoustic becomes a reliable alternative. Hydroacoustic techniques are rapid, cost-effective, non-invasive and less selective than gillnetting (Busch and Mehner, 2009) and have the advantage of extensive coverage of the water cross-section without increasing fish mortality or affecting fish behavior (Guillard and Verges, 2007).

Most hydroacoustic studies with similar objectives to this investigation have been conducted in marine environments (Lawson and Rose, 1999; Benoit-Bird *et al.*, 2001; Cardinale *et al.*, 2003) and in a much lesser extent in lakes (Brabrand, 1991; Baroudy and Elliott, 1993; Diachok *et al.*, 2001; Mehner *et al.*, 2003; Wanzenbock *et al.*, 2003; Chen *et al.*, 2009). In recent years hydroacoustic studies are increasingly being used in all kinds of aquatic ecosystems in order to acquire detailed information about aquatic life and particularly about fish (Guillard and Verges, 2007). However, technical improvements in these methods and their greater precision have contributed to their extensive use in fresh water (Wanzenbock *et al.*, 2003; Cech *et al.*, 2005; Mehner, 2006).

The aim of the present study was to provide the scientific basis for the protection of the *P. alchichica* through the analysis of the data obtained from four hydroacoustic surveys covering an annual cycle to assess the spatial and temporal distribution and abundance of this endemic species and to evaluate the limnological characteristics related to the distribution of the fish.

MATERIALS AND METHODS

Lake Alchichica (19°24.7' N; 97°24.0' W, 2,345 m a.s.l.) is nearly circular (surface area 2.3 km^2, maximum length 1,733 m), bucket-shaped with maximum and mean depth of 62 and 40.9 m, respectively (Filonov *et al.*, 2006). The lake is groundwater fed; the water is hyposaline (~ 8.5 g L^{-1}) and alkaline (pH ~ 9, 37 meq L^{-1}); sodium and chloride are the dominant ions but bicarbonates and carbonates are also important (Vilaclara *et al.*, 1993). Alchichica is considered oligotrophic (Adame *et al.*, 2008) based on the low chlorophyll a (<5 µg L^{-1}) and nutrient (<4 µmol L^{-1}) concentrations in the mixing zone and clear waters (euphotic zone = 13-38 m).

Instrument: A flat-bottom aluminum boat 10' in length and 36" beam width was used for the study. It had a draft of 15 cm and a transom-mount electric trolling motor of 30 lb thrust. The fish detection was carried out with a GARMIN GPSMAP 168 Sounder equipped with a remote (external) antenna to improve reception of the GPS signals. The depth sounder has a precision of 95%, speed register of 0.5 m sec^{-1}, frequency of 200 kHz, 8° cone angle and transmitting power of 150 watts (RMS), 1200 watts (peak to peak). The navigation courses were based on transects to detect fish abundance and distribution by using echoing signals which were downloaded to a portable computer. Collected data were analyzed with MapSource version 8.0.

Detection itinerary and frequency: Equidistant transects were conducted on a perpendicular grid and covered the entire surface of the lake (Fig. 1). The total number of transects was 22 (11 parallel to the main axis and 11 across it). They were repeated four times during a one-year period (2004) to characterize the main hydrodynamic seasons of the warm-monomictic Lake Alchichica recognized by Alcocer *et al.* (2000): Circulation (January) and early (March), well-established (July) and late (November) stratification.

Calibration of detection precision: The transducer was calibrated to recognize the capability of the instrument to distinguish individual fish from fish schools. A 750 L aquarium holding 100 fish with sizes ranging from 10 to 50 mm total length was used to evaluate the minimum detectable fish-size. This size range is similar to the one commonly observed in the field. The results of the calibration confirmed the sounder's capacity to record each fish individually. However when two or more fish were schooling, the transducer detected them as a single large-sized organism. This is considered to be an underestimation factor of fish abundance.

Calculation of fish density: The number of individual fish was estimated based on the number of signals received by the transducer. The volume of water in the lake was calculated by computing the volume of each horizontal stratum as limited by the contours on the bathymetric chart and adding the volumes of all strata. The shape of each stratum was approximated as an inverted truncated cone according to the following formula:

$$V = h / 3 \left(A_1 + A2 + \sqrt{A_1 A_2}\right)$$

where, V is volume of the stratum, h is vertical depth of each stratum, A_1 is the area of the upper surface and A_2 is area of the lower surface of the stratum whose volume is to be determined.

The density of fish was expressed in volume (individuals per m^3) and in area (individuals per m^2). To calculate the abundance of *P. alchichica* in the lake it was necessary to calculate the number of fish found in the sampled volume and to extrapolate the results to the total volume of the lake.

Fish densities in the lake in the sampled area were grouped to perform an ANOVA test to compare the fish distribution per season (circulation and early, well-established and late stratification). A t-test was used to assess differences among lake's zone (littoral and pelagic). The data were analyzed using Statistic 7.

RESULTS

Abundance and density: The abundance of *P. alchichica* varied from 12,510 individual acoustic records, from now on considered as individual fish, during the early stratification to 29,200 individuals in the well-established stratification; total average = 21, 060±6,842.72 individuals; littoral zone average = 13, 973±4, 081 individuals; pelagic zone average = 7, 088±2,790 individuals (Table 1).

The density of *P. alchichica* fluctuated from 0.000015 individuals per m^3 in the pelagic zone during the early stratification to 0.019 individuals per m^3 in the littoral zone during the well-established stratification. In the littoral zone, the yearly average density was 0.014±0.004 individuals per m^3 while in the pelagic zone density values were 0.0047±0.0033 individuals per m^3.

Horizontal distribution: Lake Alchichica's basin is bucket-shaped so it reaches deep waters near the littoral zone. The water depth on the tufa ring lakeward reaches around 40 m while on the inner side, towards the lake's edge, the water is no more than 5 m deep.

Fish abundance and density were analyzed by grouping data into two zones: Littoral and pelagic (Fig. 1). Results show that *P. alchichica* displays a general trend to congregate on the littoral zone, mostly associated to the tufa ring lakeward, since significant differences between fish density and abundance were found. The horizontal distribution pattern was similar in all sampling periods ($F_{(3,4)} = 0.96$; $p>0.05$). Organisms were clustered close to the littoral zone reaching up to 66.3% of the total abundance, while those fish found in the central or pelagic zone of the lake, constituted a minor percentage of the population (33.7%). Fish abundance and fish density in the littoral zone were greater than estimates obtained in the pelagic zone regardless of the sampling period ($t_{(abundance)} = 9.6$, $p<0.01$; $t_{(density)} = 13.0$, $p<0.001$).

Bathymetric distribution: During the circulation period, although fish were distributed throughout the whole water column (0-62 m), most of them were found in the upper 40 m; 29.8% of the total number of records was obtained within the first 10 m of the water column and 26.8% of the records were obtained in the 31 to 40 m depth range. Only 0.5% of the records were obtained in depths greater than 50 m (Fig. 2a).

Table 1: Abundance (ind) and density (ind m^{-3}) of *P. alchichica* during the different hydrodynamic stages of Lake Alchichica

	Littoral zone		Pelagic zone		Total	
Season	Abundance	Density	Abundance	Density	Abundance	Density
Circulation	14.070	0.014[a]	7.910	0.0060[b]	21.980	0.020
Early stratification	9.030	0.009[a]	3.480	0.000015[b]	12.510	0.009
Well-established stratification	19.020	0.019[a]	10.180	0.0078[b]	29.200	0.027
Late stratification	13.770	0.014[a]	6.780	0.0051[b]	20.550	0.019
Average (± standard deviation)	13.973±4.081	0.014±0.004	7.088±2.790	0.0047±0.0033	21.060±6.843	0.019±0.007

Different letters indicate statistical differences of fish density between zones ($t_{(density)} = 13.0$, $p<0.001$) and seasons ($F_{(3,4)} = 0.96$, $p>0.05$)

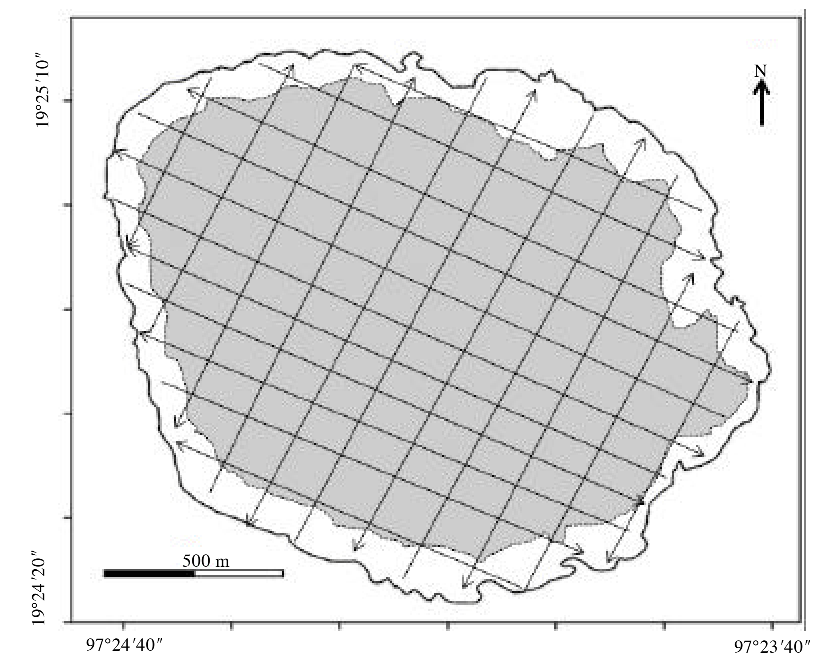

Fig. 1: Geographical locations of the hydroacoustic transects in Alchichica Lake, Puebla. The dotted line indicates the 40 m isobaths and the littoral area is in white and the pelagic zone in grey

In early stratification, *P. alchichica* was mainly found in depths up to 30 m (Fig. 2b) and 32.9% of the records were obtained within the first ten meters. The number of registers that were obtained in the pelagic zone in depths greater than 50 m was small (0.6%).

A similar situation was observed during the well-established stratification with most fish found in the first 30 m (Fig. 2c). There were two preferential depths at which *P. alchichica* was located: The 0 to 10 m layer, associated with the tufa ring (accounting for the 37.7% of the records) and from 21 to 30 m in the pelagic zone (with 39% of the records).

In the late stratification, *P. alchichica* was typically found in depths not greater than 40 m (Fig. 2d). The fish were found especially in the upper ten meters (39%), particularly associated with the tufa ring.

DISCUSSION

Echosounding proved to be a useful sampling technique to obtain abundance estimates of fish in this particular lake where traditional fishing techniques are not suitable. This sampling method allowed establishing the horizontal and bathymetric abundance and distribution fish of the Alchichica silverside that helped to identify its preferred habitat. Moreover, this technique is suitable to be used in studies concerning small species: In spite of the fact that *P. alchichica* maximum size was below 12 cm, the instrument was able to detect individuals greater than 1 cm Total Length (TL) as well as schooling fish. In similar systems fish abundance values are higher but with a similar distribution, in which most of the fish are closer to the littoral zone.

There are several factors that influence the distribution of fish within a lake such as water depth, distance from the shore, presence of aquatic vegetation, plankton distribution, substrate

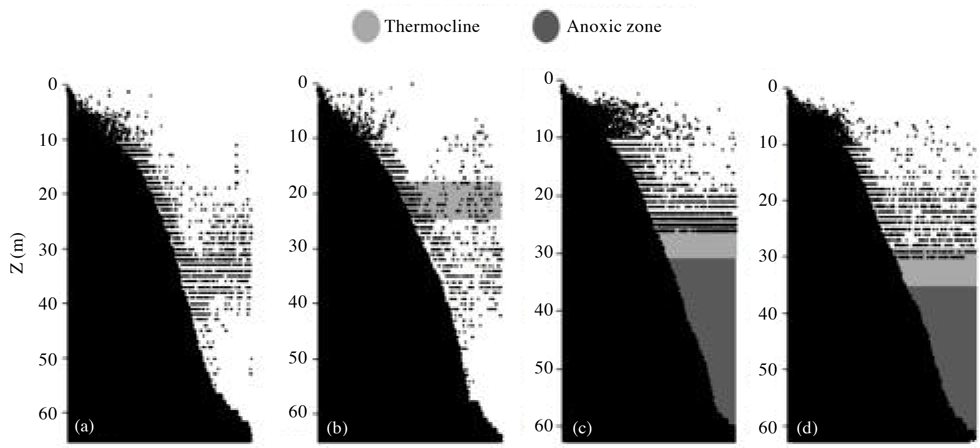

Fig. 2: Bathymetric distribution of *P. alchichica* (each dot represents one fish) in the different seasons (a = circulation, b = early stratification, c = well-established stratification, d = late stratification). The light grey area indicates the thermocline and the dark grey area the anoxic zone

characteristics, water quality and strength and direction of wind (Liu, 1990; Tameishi *et al.*, 1996; Heng *et al.*, 2006). In Lake Alchichica, the tufa ring found in the littoral zone of the basin provides the unique habitat that *P. alchichica* takes advantage of in order to find food, protection and in which reproduction takes place. The tufa ring offers a large variety of food items when compared to the limnetic zone where only zooplankton, composed by one copepod (*Leptodiaptomus garciai*) and two rotifer species (*Brachionus plicatilis* and *Hexarthra jenkinae*), is available (Lugo *et al.*, 1999). Preliminary data indicate that *P. alchichica* (>50 mm) feed preferentially on benthic prey distributed in the tufa ring, while smaller individuals (<30 mm) consumed zooplankton. Also reproduction takes place in the tufa ring. Oviposition takes place in the littoral area where *P. alchichica* eggs are usually found attached either to *Ruppia maritima* or directly on tufa deposits since atherinid eggs need to be adhered to the vegetation or other substrates (Martinez-Palacios *et al.*, 2004). *P. alchichica* does not exhibit parental care and larval and juvenile stages remain in the littoral zone of the lake amongst the macrophytes and tufa.

P. alchichica tends to be located close to the bottom of the lake (Fig. 2) as far as the dissolved oxygen concentration allows it, since below the 40 m isobath the hypolimnion becomes anoxic. During the well-established and late stratification, the potential habitat available to fish reduces down to 63 and 56% of the total volume of the lake.

A phylogenetically related species (*Chirostoma jordani*) which is an endemic atherinid of Lake Chapala, shows a preferential distribution close to the shore as *P. alchichica* but occupying the surface layers (Moncayo-Estrada *et al.*, 2010). The trophic preference of *C. jordani* for pelagic zooplankton accounts for its bathymetric distribution.

It is to be expected that fish abundance in oligotrophic lakes to be low according to the trophic (primary production) status. But fish densities in other oligotrophic lakes attain values ten times higher than those found for *P. alchichica*. For example, *Salmo trutta* reaches values in the range from 0.026 to 0.053 individuals per m^2 in Lake Paasivesi, Finland (Jurvelius *et al.*, 1984) and mean values of 0.060 individuals per m^2 in Lake Redó, Spain (Encina and Rodriguez-Ruiz, 2003).

Coregonus lavaretus in the Wahnbach Reservoir (Brenner *et al.*, 1987) has densities varying from 0.010 to 0.050 individuals per m^2. Maximum length of species may account to this general behavior. For instance, *S. trutta* (TL = 30 to > 60 cm) and *C. lavaretus* (TL > 27 cm) are considerably larger than *P. alchichica* (TL = average 6-7 cm, maximum 11-12 cm). Hence, the estimated population abundance of *P. alchichica* is between 16,000 and 21,000 organisms >1 cm TL.

Extinction risk is correlated with the size of the population and the extension of the distribution range (Gardenfors *et al.*, 2001). This study shows that the population of *P. alchichica* is reduced in its only habitat. Historical aerial photographs revealed a reduction in Alchichica's water level and the high-water level marks are now far above today's shoreline. Over extraction of groundwater for irrigation and water supplies to towns and cities is mostly responsible of the lake's desiccation process, although climate change should not be overlooked (Alcocer *et al.*, 2009). The consequence is that the littoral zone in which large portions of the tufa deposits where formerly submersed (stromatolites) and where most of these organisms are located are now exposed to sunlight, dry and devoid of aquatic life (Alcocer *et al.*, 2010). The habitat in which Alchichica silverside adults find food and complete the reproductive process is shrinking fast.

The present findings demonstrate that management actions to preserve this species must include avoid further level decline that will cause the disappearance of one critical habitat of *P. alchichica* and protect the littoral zone from any human perturbation.

CONCLUSION

Echosounding proved to be a useful sampling technique to obtain abundance and distribution estimates of fish where traditional fishing techniques are not suitable. The use of this technique is appropriate in studies concerning small species (>1 cm total length). The preferred distribution of the fish to remain close to the littoral area is associated to feeding, reproduction and protection against predators. This species has lower density values than native species of other similar systems. To guarantee the persistence of *P. alchichica*, actions must consider water-use management policies to preserve the littoral area, a crucial habitat for this and the other endemic species of the lake. The present findings are pertinent to other species inhabiting lakes in similar threat.

ACKNOWLEDGMENTS

This study was supported by the Consejo Nacional de Ciencia y Tecnología through the project 103332 Dinámica Ecológica a Largo Plazo del Lago Alchichica, Puebla and the Dirección General de Asuntos del Personal Académico, Universidad Nacional Autónoma de México (UNAM), through the project IN221009 "Estudios Ecológicos a Largo Plazo en Lagos Mexicanos: Lago Alchichica, Puebla." Field and laboratory assistance by Aramis Flores, Erik Ramos, Jorge Luna, Jorge Castro, José Figueroa, Laura Peralta, Luis Oseguera and Marco Ramírez is much appreciated.

REFERENCES

Adame, M.F., J. Alcocer and E. Escobar, 2008. Size-fractionated phytoplankton biomass and its implications for the dynamics of an oligotrophic tropical lake. Freshwater Biol., 53: 22-31.

Alcocer, J., A Lugo, E. Escobar, R. Sanchez and G. Vilaclara, 2000. Water column stratification and its implications in the tropical warm monomictic Lake Alchichica, Puebla, Mexico. Verh. Int. Verein. Limnol., 27: 3166-3169.

Alcocer, J., X. Chiappa-Carrara, E. Arce and L. Zambrano, 2009. Threatened fishes of the world: *Poblana alchichica* (de Buen, 1945) (Atheriniformes: Atherinopsidae). Environ. Biol. Fish., 85: 317-318.

Alcocer, J., E. Arce, L. Zambrano and X. Chiappa-Carrara, 2010. *Poblana alchichica*: A threatened silverside species? Verh. Int. Verein. Limnol., 30: 1429-1432.

Baroudy, E. and J.M. Elliott, 1993. The effect of large-scale spatial variation of pelagic fish on hydroacoustic estimates of their population density in Windermere (northwest England). Ecol. Freshwater Fish, 2: 160-166.

Benoit-Bird, K., W.L. Whitlow, R.E. Brainard and M.O. Lammers, 2001. Diel horizontal migration of the Hawaiian mesopelagic boundary community observed acoustically. Mar. Ecol. Prog. Ser., 217: 1-14.

Brabrand, A., 1991. The estimation of pelagic fish density, single fish size and fish biomass of Artic charr (*Salvelinus alpinus*) by ecosounding. Nord. J. Freshwater Res., 66: 44-49.

Brandon, R.A., E.J. Maruska and W.T. Rumph, 1982. A new species of neotenic Ambystoma (Amphibia, Caudata) endemic to Laguna Alchichica, Puebla, Mexico. Bull. Southern California Acad. Sci., 80: 112-125..

Brenner, T., J. Clasen, K. Lange and T. Lindem, 1987. The whitefish (*Coregonus laveretus* L.) of the Wahnbach reservoir and their assessment by hydroacoustic methods. Schweiz. Z. Hydrol., 49: 363-372.

Busch, S. and T. Mehner, 2009. Hydroacoustic estimates of fish population depths and densities at increasingly longer time scales. Int. Rev. Hydrobiol., 1: 91-102.

Cardinale, M., M. Casini, F. Arrhenius and N. Hakansson, 2003. Diel spatial distribution and feeding activity of herring (*Clupea harengus*) and sprat (*Sprattus sprattus*) in the Baltic Sea. Aquat. Living Resour., 16: 283-292.

Cech, M., M. Kratochvil, J. Kubecka, V. Drastik and J. Matena, 2005. Diel vertical migrations of bathypelagic perch fry. J. Fish Biol., 66: 685-702.

Chen, D., X. Zhang, X. Tan, K. Wang, Y. Qiao and Y. Chang, 2009. Hydroacoustic study of spatial and temporal distribution of Gymnocypris przewalskii (Kessler, 1876) in Qinghai Lake, China. Environ. Biol. Fish., 84: 231-239.

Coll, C., L.T. De Morais, R. Lae, A. Lebourges-Dhaussy and M. Simier *et al.*, 2007. Use and limits of three methods for assessing fish size spectra and fish abundance in two tropical man-made lakes. Fish. Res., 83: 306-318.

Diachok, O., B. Liorzou and C. Scalabrin, 2001. Estimation of the number density of fish from resonance absorptivity and echo sounder data. J. Mar. Sci., 58: 137-153.

Encina, L. and A. Rodriguez-Ruiz, 2003. Abundance and distribution of a brown trout (*Salmo trutta*, L.) population in a remote high mountain lake. Hydrobiologia, 493: 35-42.

Escobar-Briones, E. and J. Alcocer, 2002. *Caecidotea williamsi* (Crustacea: Isopoda: Asellidae), a new species from a saline crater-lake in the eastern Mexican Plateau. Hydrobiologia, 477: 93-105.

Filonov, A. and J. Alcocer, 2002. Internal waves in a tropical crater lake: Alchichica, Central Mexico. Verth. Int. Verein. Limnol., 28: 1857-1860.

Filonov, A., I. Tereshchenko and J. Alcocer, 2006. Dynamic response to mountain breeze circulation in Alchichica, a crater lake in Mexico. Geophys. Res. Lett., 33: 1-4.

Gardenfors, U., C. Hilton-Taylor, G. Mace, M. Rodriguez and P. Jon, 2001. The application of IUCN Red List criteria at regional levels. Conser Biol., 15: 1206-1212.

Guillard, J. and C. Verges, 2007. The repeatability of fish biomass and size distribution estimates obtained by hydroacoustic surveys using various sampling strategies and statistical analyses. Int. Rev. Hydrobiol., 92: 605-617.

Heng, L.Y., L.N. Chukong, R.B. Stuebing and M. Omar, 2006. The water quality of several oxbow lakes in Sabah, Malaysia and its relation to fish fauna distribution. J. Boil. Sci., 6: 365-369.

Jurvelius, J., T. Lindem and J. Louhimo, 1984. The number of pelagic fish in Lake Paasivesi, Finland, monitored by hydroacoustic methods. Fish. Res., 2: 273-283.

Lawson, G.L. and G.A. Rose, 1999. The importance of detectability to acoustic surveys of semi-demersal fish. ICES J. Mar. Sci., 56: 370-380.

Liu, J.K., 1990. Researches on the Ecology of the Donghu Lake (A). Academic Press, Beijing, pp: 152-164.

Lugo, A., M.E. Gonzalez, M.R. Sanchez and J. Alcocer, 1999. Distribution of *Leptodiaptomus novamexicanus* (Copepoda: Calanoida) in a Mexican hyposaline lake. Rev. Biol. Trop., 47: 141-148.

Martinez-Palacios, C.A., J.C. Morte, J.A. Tello-Ballinas, L.G. Toledo-Cuevas and L.G. Ross, 2004. The effects of saline environments on survival and growth of eggs and larvae of Chirostoma estor estor Jordan 1880 (Pisces: Atherinidae). Aquaculture, 238: 509-522.

Mehner, T., 2006. Prediction of hydroacoustic target strength of vendace *(Coregonus albula)* from concurrent trawl catches. Fish. Res., 79: 162-169.

Mehner, T., H. Gasner, H.M. Schulz and J. Wanzemboeck, 2003. Comparative fish stock estimates in Lake Stechlin by parallel split-beam ecosounding with 120 kHz. Adv. Limnol., 58: 227-236.

Miller, R.R., 1986. Composition and derivation of the freshwater fish fauna of Mexico. An. Esc. Nac. Cienc. Biol. Mex., 30: 121-153.

Moncayo-Estrada, R., O.T. Lind and C. Escalera-Gallardo, 2010. Trophic partitioning of sympatric zooplanktivorous silverside in a tropical shallow lake: Fish morphometry and diet composition. Copeia, 3: 431-436.

Oliva, M.G., A. Lugo, J. Alcocer, L. Peralta and M.R. Sanchez, 2001. Phytoplankton dynamics in a deep, tropical, hyposaline lake. Hydrobiologia, 466: 299-306.

Rose, G.A., 1992. A review of problems and new directions in the application of fisheries acoustics on the Canadian East coast. Fish. Res., 14: 105-128.

SEMARNAT, 2002. Mexican official norm NOM-059-ECOL-2001, Environmental protection-flora and fauna native species of Mexico -risk categories and specifications for its inclusion, exclusion or change-list of species in risk. Diario Oficial, 6 March 2002. http://www.aida-americas.org /en/node/1684.

Tambutti, M., A. Aldama, O. Sanchez, R. Medellin and J. Soberon Mainero, 2002. Determination of the extinction risk of wildlife species in Mexico. Gaceta Ecologica, 61: 11-21.

Tameishi, H., H. Shinomiya, I. Aoki and T. Sugimoto, 1996. Understanding Japanese sardine migrations using acoustic and other aids. ICES J. Mar. Sci., 53: 167-171.

Vilaclara, G., M. Chavez, A. Lugo, H. Gonzalez and M.L. Gaytan, 1993. Comparative description of crater-lakes basic chemistry in Puebla State Mexico. Verh. Int. Ver. Limnol., 25: 435-440.

Wanzenbock, J., T. Mehner, M. Schulz, H. Gassner and I. Winfield, 2003. Quality assurance of hydroacustic surveys: The repeatability of fish-abundance and biomass estimates in lakes within and between hydroacustic systems. ICES J. Mar. Sci., 60: 486-492.