Exploitation and evaluation of the tilapia fishery (*Oreochromis* spp.) in the Fernando Hiriart Balderrama "Zimapám" Reservoir, Hidalgo, Mexico

Explotación y evaluación de la pesquería de tilapia (*Oreochromis* spp.) en la represa Fernando Hiriart Balderrama "Zimapám", Hidalgo, México

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ABSTRACT

Oreochromis spp. fishing in the Fernando Hiriart Balderrama Reservior began in 1997 and its effects had never been studied before. Schaefer and Fox's biomass dynamic model were used in order to obtain the first evaluation of this resource and to analyze the presence of record errors (or observation errors) in the annual total catch data set. The number of fishermen was used as the fishing effort unit. Schaefer´s model proved to be statically reliable: *Oreochromis* spp. was estimated at the maximum population size value of k = 9 000 tons and reproduction rate value at annual r = 0.730. Considering those ecological and biological strategies, Schaefer´s model showed that great biomass levels (predicted biomass) have been produced in the Zimapán reservior; however, only a small part of this biomass was exploited during the analyzed period. The results indicate that tilapia fishery in the Zimapán Reservoir was at equilibrium or was not over-fished between 1997 and 2006 because historical tilapia records observed in Schaefer´s model were far from the k parameter and below the MSY value. With this exploitation type, the fishing effort can increase to up to 7 203 fishermen (level of fishing effort at which the maximum sustainable yield is achieved (f_{MSY})). However, in order to avoid an increase of the non-controlled fishing effort a similar analysis is recommended with recent data.

Keywords: Dynamic models, evaluation, biomass, tilapia, exploitation.

RESUMEN

La pesca de la tilapia *Oreochromis* spp. en la presa hidroeléctrica Fernando Hiriart Balderrama comenzó en 1997, esta pesquería nunca ha sido evaluada. Fueron utilizados los modelos dinámicos de biomasa de Schaefer y Fox para obtener la primera evaluación de este recurso y para analizar la presencia de errores de registro (errores de observación) en la captura anual total. El número de pescadores fue usado como la unidad de esfuerzo de pesca. El modelo de Schaefer resultó estadísticamente confiable y para *Oreochromis* spp. fueron estimados el tamaño máximo de población en k = 9 000 tons y la tasa de reproducción en r = 0.730 anual. Considerando estas estrategias ecológicas y biológicas, el modelo de Schaefer sugirió que grandes niveles de biomasa (biomasa predicha) fueron producidas en la presa Zimapán, pero solo una pequeña parte de esta biomasa fue explotada durante el periodo analizado. Los resultados indicaron que la pesquería de la tilapia en la presa Zimapán estuvo en equilibrio o no fue sobreexplotada entre 1997 y el 2006, porque los registros históricos en el modelo de Schaefer fueron observados muy lejos del parámetro k y por debajo del valor MSY. Con este tipo de explotación, el esfuerzo de pesca podría incrementarse hasta alcanzar 7 203 número de pescadores (nivel de esfuerzo de pesca en el cual se activa el rendimiento máximo

sostenible (f_{MSY})), pero para evitar un incremento no controlado del esfuerzo de pesca, se recomienda hacer un análisis similar integrando datos recientes.

Palabras claves: Modelos dinámicos, evaluación, biomasa, tilapia, explotación.

INTRODUCTION

Water reservoirs have been used to provide and store water, control flooding, generate electricity, produce food, provide jobs and sport fishing (López-Hernández *et al*. 2007). The Mexican government built the Fernando Hiriart Balderrama Hydroelectric Reservoir (Zimapán Reservoir) in 1995 to produce an average of 1 292.40 GW/year in the state of Hidalgo (Fig. 1). The Zimapán Reservoir is located in the Infiernillo Canyon between the states of Hidalgo and Queretaro and its reservior has a total area of 22.9 km². The main water sources are the Tula, Moctezuma, Alfajayucan, San Francisco and San Juan rivers (López-Hernández *et al*. 2007).

Although tilapia fishing in the Zimapán Reservoir began as a small scale activity in the states of Hidalgo and Queretaro, it was formalized in 1997, increasing tilapia production. Fishing has recently been considered a very important economic activity to provide food and jobs (Hernández-Montaño & Orbe, 2002; López-Hernández *et al*. 2007).

CONAPESCA (2009) reported a 20.45% increase in tilapia production in the states of Hidalgo and Queretaro compared to the one reported in other landlocked Mexican states. *Oreochromis* spp. is caught in the Zimapán Reservoir with small four meter long fiberglass boats with 15 to 25 horsepower outboard engines. Fishermen use gillnets made of nylon monofilament with a diameter of 0.3 mm or less, minimum mesh size of 11.43 cm, maximum length of 60 m, fall or maximum height of 5 m, and an overlapping between 52% and 65%.

To the best of our knowledge, no other studies about tilapia exploitation have been conducted in the states of Hidalgo and Queretaro. The only reports available discuss water quality in the Zimapán Reservoir (Hernández-Montaño & Orbe, 2002; López-Hernández *et al*. 2007; Gómez-Ponce *et al*. 2011). In the present study, tilapia fishing is evaluated from 1997 to 2006, being the first research conducted in the reservoir. Results obtained may be used as a historical point of reference to describe recent biomass changes of *Oreochromis* spp.
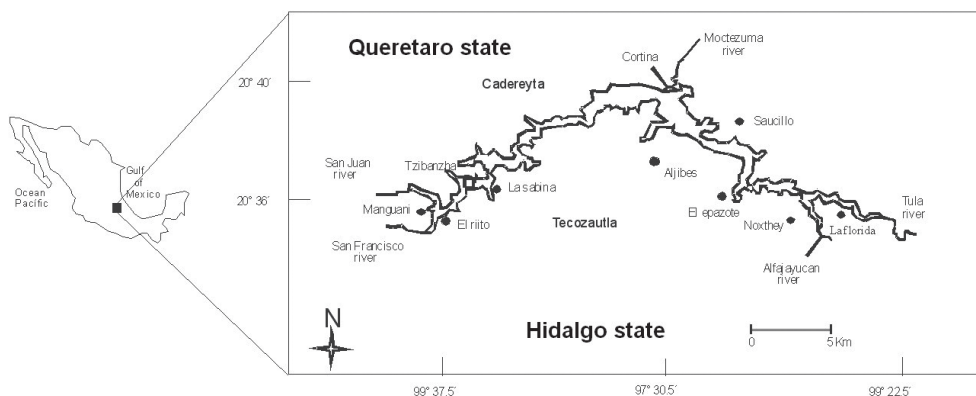

Fig. 1. Study area and communities around the Fernando Hiriart Zimapán hydroelectric reservoir at Hidalgo

Fig. 1. Área de estudio y comunidades alrededor de la presa hidroeléctrica Fernando Hiriart Zimapán, Hidalgo

The Schaefer (1954) and Fox (1970) biomass dynamic models (with the observation error) were used in order to evaluate the exploitation (over-fished or non-over-fished) and estimate annual biomass changes. According to Punt & Hilborn (1996), both objectives were developed based on the description of the following parameters: maximum sustainable yield (MSY), level of fishing effort at which the maximum sustainable yield is achieved (f_{MSY}), maximum population size (k), intrinsic growth rate (r), and the catchability coefficient (q).

MATERIALS AND METHODS

The Zimapán Reservoir (20° 35' - 20° 40' N and 99° 22' - 99° 37' W) has an average surface area of 2 600 ha of water surface, is located at an altitude of 1 870 m above sea level and is fed primarily by the San Juan and Tula rivers. The reservoir is bordered by the municipalities of Zimapán, Tasquillo, and Tecozautla on the western part the State of Hidalgo and by the municipality of Cadereyta Montes within the State of Querétaro. The reservoir has a load capacity of 1.5 million m^3 and is considered by the National Fisheries Institute to have great potential for developing tilapia fishing due to its physicochemical conditions and natural and artificial availability of food (López-Hernández *et al.* 2007).

Total annual catch data sets for *Oreochromis* spp. were used to estimate catch per unit of effort (CPUE, tons per number of fishermen). This information was obtained during 10 fishing seasons in the Zimapán Reservoir and recorded in the states of Hidalgo and Querétaro between 1997 and 2006. Data sets were provided to the Institute of Maritime and Limnological Sciences (*Instituto de Ciencias del Mar y Limnología*) from the National Autonomous University of Mexico (UNAM) by the Secretariat of Agriculture, Livestock, Rural Development, Fisheries, and Food

from the state of Hidalgo through the records from fishing cooperatives working in the vicinity of the reservoir (SAGARPA).

According to Punt & Hilborn (1996), the Schaefer and Fox models are $B_{t+1} = [B_t + r \cdot B_t \cdot (1 - (B_t/k) - C_t] \cdot V_t$ and $B_{t+1} = [B_t + r \cdot B_t \cdot (1 - (\ln B_t / \ln k) - C_t] \cdot V_t$, respectively, where B_{t+1} = predicted annual biomass; B_t = present biomass; C_t = present catch; V_t = observation error; k and r are defined as before). $V_t = [\ln I_t - \ln U_t]$ (I_t = present catch per unit of effort; U_t = predicted catch per unit of effort). B_{t+1} is "virtial" biomass value (or predicted annual biomass changes) that was available in the Zimapán Reservoir in the year t+1, and on this "virtual" biomass, each year fishermen obtained a real catch value (C_t), which them recorded.

According to Malcolm (2001), the k and r parameters were estimated using the minimum likelihood of logarithmic normal distribution ($-\ln (k, r/It)$), this is:

$$-\ln \ell (k, r/I_t)), \text{ this is: } -\ln \ell (k, r/I_t) = \sum_{t=1}^{n} [\ln SD_V + (1/2) \cdot \ln 2\pi + V_t^2/2 \cdot SD_V^2].$$

$$SD_V = \sqrt{[(1/n) \cdot \sum_{t=1}^{n} (V_t^2)]},$$

where SD_V is the standard deviation of V_t and n is the total number of fishing seasons analyzed. The catchability coefficient was estimated with:

$$q = EXP [(1/n) \cdot \sum_{t=1}^{n} \ln (I_t/B_t)].$$

The SD_V values obtained were used to evaluate the statistic fit between the I_t and U_t in both Schaefer´s and Fox´s models. According to Ludwing & Walters (1989), SD_V takes values between zero and one. A SD_V value near zero guarantees a good statistical fit between I_t and U_t values; this means that the observation error was not present in all the analyzed fishing seasons or was present only in some of them. Therefore, predicted annual biomass changes of

Oreochromis spp. in the Zimapán Reservoir are statistically reliable. A SD_V value near one suggests a bad statistic fit between I_t and U_t values; this means that the observation error was present in all or almost all the analyzed fishing seasons. Therefore, predicted annual biomass changes of *Oreochromis* spp. in the Zimapán Reservoir are not statistically reliable.

The maximum sustainable yield value and the level of fishing effort at which the maximum sustainable yield is achieved were estimated with: $MSY = r \cdot k/4$; $f_{MSY} = r/2 \cdot q$. The relationship between fishing effort and tilapia catches was estimated.

According to Chien-Hsiung (2004), the relationships between equilibrium and non-equilibrium in fishery were considered in order to describe the exploitation and the annual biomass changes of *Oreochromis* spp. The relationships are:

a) When the biomass changes oscillate below MSY value, the system is not over-fished because the level of fishing effort is relatively low. This relationship allows for an increase in the net production without affecting the equilibrium between birth and death rates (the biomass is at equilibrium). Both rates were considered in the r parameter.

b) When the biomass changes have reached or surpassed the MSY value, fishery is generally over-fished by an increase of the fishing effort. This relationship will break the equilibrium between birth and death rates (the biomass is not at equilibrium).

c) The MSY value cannot be greater or equal than the k value.

RESULTS

Historical records of tilapia fishing showed that the fishing effort from 1997 to 2000 was equivalent to approximately 200 fishermen while catches decreased from 800 tons captured in 1997 to less than 200 tons. Starting that year, the catch and fishing effort gradually increased to 400 fishermen and 450 tons in 2003, and in 2004 they substantially increased reaching a maximum amount of fishermen at 2 400 and a maximum production of 1 600 tons.

Using the number of fishermen, Schaefer's model generated a standard deviation value of 0.1788 (Table 1). I_t and U_t values resulted in a good statistic fit in the 1997, 1998, 2001, 2003, 2004, 2005 and 2006 fishing seasons (70% without recording errors) (Fig. 2). The 1999, 2000 and 2002 fishing seasons showed a bad statistic fit (30% with recording errors) (Fig. 2).

Table 1. Estimated parameter for *Oreochromis* spp. from 1997 to 2006. MSY is the maximum sustainable yield, f_{MSY} is the level of fishing effort at which the maximum sustainable yield is achieved, q is the catchability coefficient, k is the maximum population size, r is the intrinsic growth rate and SD_V is the standard deviation of the observation error

Cuadro 1. Parámetros estimados para *Oreochromis* spp., de 1997 hasta el 2006. RMS es el rendimiento máximo sostenible, f_{RMS} es el nivel de esfuerzo de pesca en el cual se activa el rendimiento máximo sostenible, q es el coeficiente de capturabilidad, k es el tamaño máximo de la población, r es la tasa intrínseca de crecimiento y DS_V es la desviación estándar del error de observación

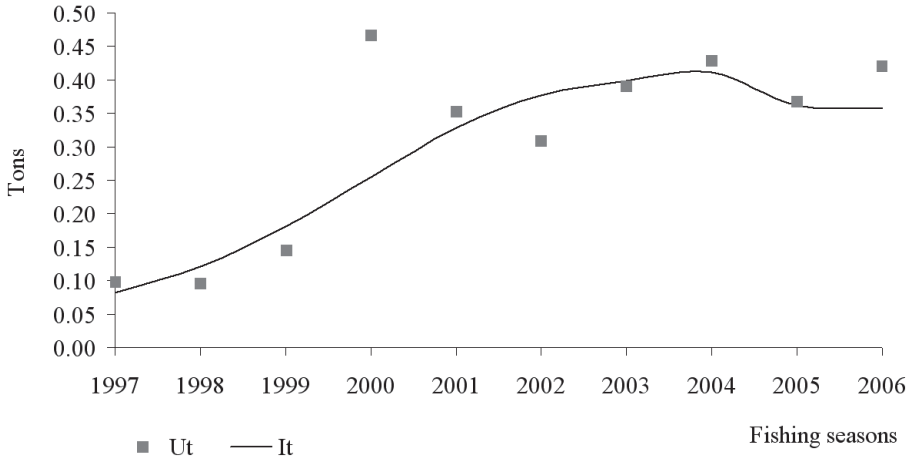| Model	MSY tons	f_{MSY} number of fishermen	q	k tons	r annual	SD_v
Schaefer	1 643	7 203	0.0005	9 000	0.730	0.1788
Fox	5 934	10 899	0.0001	10 063	2.359	0.3022

Fig. 2. Schaefer's model with the number of fishermen and statistic fit between observed catch per unit of effort (I_t) and predicted catch per unit of effort (U_t)

Fig. 2. Modelo de Schaefer con el número de pescadores y ajuste estadístico entre la captura por unidad de esfuerzo observada (I_t) y la captura por unidad de esfuerzo esperada (U_t)

Using the number of fishermen, Fox's model generated a standard deviation value of 0.3022 (Table 1). The I_t and U_t values resulted in a good statistic fit in the 1997, 1998, 2001, 2003, 2004, 2005, and 2006 fishing seasons (70% without recording errors) (Fig. 3). The 1999, 2000, 2002 fishing seasons showed a bad statistic fit (30% with recording errors) (Fig. 3).

Both objectives were described following Schaefer's model: $B_{t+1} = [B_t+0.730·B_t·(1-(B_t/90\ 000)-C_t]·V_t$ (Table 1 and Fig. 4).

Schaefer's model showed that predicted annual biomass changes were observed between the MSY and k values (Fig. 4) and that these "virtual" biomass values were never greater than the tilapia
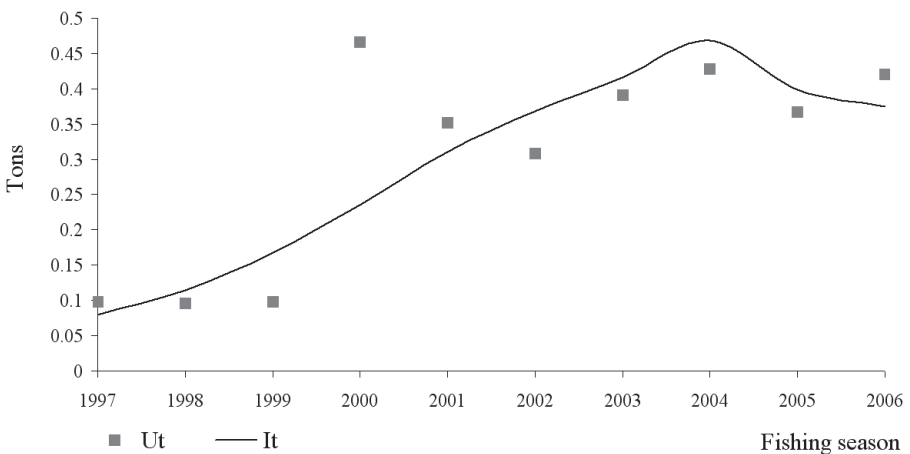

Fig. 3. Fox's model with the number of fishermen and statistic fit between observed catch per unit of effort (I_t) and predicted catch per unit of effort (U_t)

Fig. 3. El modelo de Fox con el número de pescadores y el ajuste estadístico entre la captura por unidad de esfuerzo observada (I_t) y la captura por unidad de esfuerzo esperada (U_t)
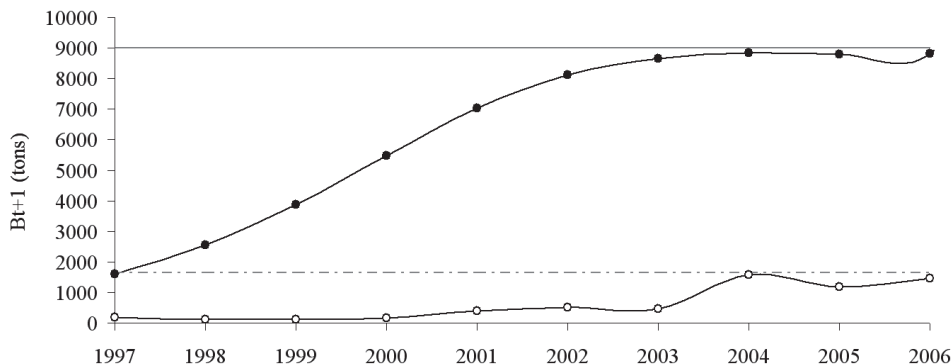
Fig. 4. Predicted annual biomass changes (Bt+1, black circles with a continuous line) and tilapia catch values recorded (Ct, white circles with a continuous line) for the fishery of Oreochromis spp. in the Zimapan Reservoir between 1997 and 2006; the continuous gray line is the maximum population size (k); the discontinuous gray line is the maximum sustainable yield (MSY)

Fig. 4. Cambios de la biomasa anual modelada (Bt+1, círculos negros con una línea continua) y va¬lores de captura registrados de tilapia (Ct, círculos blancos con una línea continua) para la pesquería de Oreochromis spp. en la presa Zimapán entre 1997 y el 2006; la línea gris continua es el tamaño máximo de la población (k); la línea gris discontinua es el rendimiento máximo sostenible (RMS)

catches recorded between 1997 and 2006 (Fig. 4). This result indicates that the Zimapán Reservoir recorded a greater tilapia production, but only a small portion was exploited between 1997 and 2006 (Fig. 4). Following tilapia catch records, two periods of exploitation were observed between 1997 and 2006. In the first period (from 1997 to 2003), tilapia catch was not higher than 600 tons (Fig. 5). In the second period (from 2003 to 2006), tilapia catch increased with a maximum record of 1 573 tons during 2004 (Fig. 5). The end tendency of the fishing effort (number of fishermen) resulted in an equal amount to the one described for tilapia catches (Fig. 5). A directly proportional relationship between the fishing effort and tilapia catches was obtained (r = 0.9310, $P = 0.00003$).

DISCUSSION

The assessment of fishing resources is critical for managing all fisheries (Penn & Caputi, 1986; Cervantes-Hernández et al. 2006; 2010) since length-cohort and age-cohort data can be carefully analyzed (Jiménez-Badillo, 2004); however, when data is not available, as in the case of a preliminary assessment, the study can be conducted with holistic models, subject to different time scales (Cervantes-Hernández et al. 2006).

The method used to estimate parameters for Schaefer and Fox´s holistic models is the least squares (Sparre & Venema, 1995); however, an increase in the dynamic versions of those parameters (Hilborn & Walters, 1992) has limited their usefulness to manage fisheries, in a way that their application serves only as background (Pérez, 2005; Ibaibarriaga et al. 2008). The least squares method is limited to estimate more than two parameters (Cervantes-Hernández et al. 2006); however, to estimate dynamic parameters, bayesian statistics has been effective in some cases (Morales-Bojórquez et al.
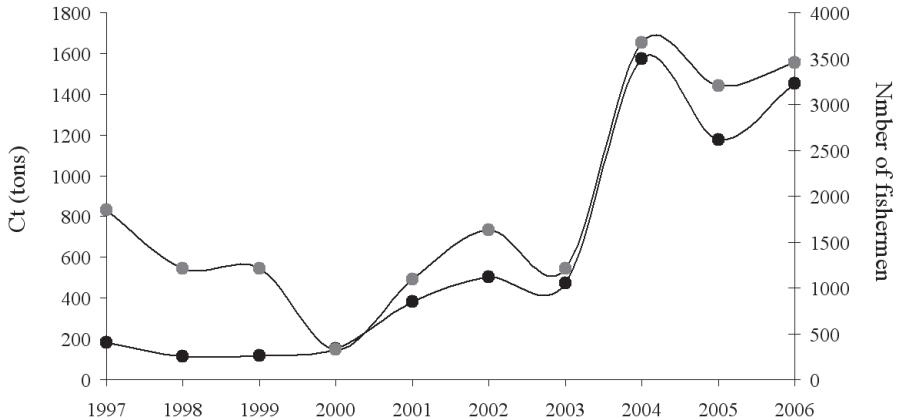
Fig. 5. Tilapia catch values recorded (C_t, black circles with a continuous line) and number of fishermen (gray circles with a continuous line) for the fishery of *Oreochromis* spp. in the Zimapán reservoir between 1997 and 2006

Fig. 5. Valores de captura registrados de tilapia (C_t, círculos negros con una línea continua) y el número de pescadores (círculos grises con una línea continua) para pesquería de *Oreochromis* spp. en la presa Zimapán entre 1997 y 2006

2001; Cervantes-Hernández *et al.* 2010). For this reason, this investigation has used the minimum plausibility method for obtaining the precise estimation of dynamic parameters r-k-q.

The observation error has in order to evaluate record errors in annual total catch data sets (Punt, 1988) and to generate a reliable statistic fit between the I_t and U_t (Ludwig & Walters, 1989). The analysis of these errors resulted in an important strategy because the commercial catch-at-age data available for *Oreochromis* spp. fishery at the Zimapán Reservoir. Based on the results obtained for SD_V (Table 1 and Figures 2, 3), Schaefer's model proved to be statistically reliable and could be used to evaluate exploitation and to estimate annual biomass changes of *Oreochromis* spp. in the Zimapán Reservoir between 1997 and 2006.

With Schaefer's model and the observation error, we obtained a reliable statistic fit between the I_t and U_t (Fig. 2). Standard deviation value of this fit was estimated at 0.1788, suggesting that the predicted annual biomass changes of *Oreochromis* spp. were statistically reliable than the predicted annual biomass changes obtained with Fox's model (SD_V = 0.3022) (Fig. 3).

We are not aware of other evaluation studies for *Oreochromis* spp. with this method in Mexico. However, we have gained experience in developing and understanding biomass dynamic models with observation and process errors with other species such as shrimp (Morales-Bojórquez *et al.* 2001; Cervantes-Hernández *et al.* 2006). In particular, this study used the experience gained assessing shrimp from the South Pacific to demonstrate how observation errors can affect the evaluation of another type of fishing, in this case, *Oreochromis* spp. fishing.

Morales-Bojórquez *et al.* (2001) used the process error in a biomass dynamic model and reported that analyzed commercial catch data had no record errors (or observation errors) but tehy never estimated or demonstrated it. With process error, these authors could not evaluate shrimp fisheries

from the Gulf of California, Mexico, because they obtained a "stochastic" behavior in catch per unit of effort records. When catch per unit of effort is "stochastic", records can not follow a specific trajectory because fishing seasons were not related and an evaluation is not easy to obtain.

According to Hilborn & Walters (1992), the observation error was used in this study to demonstrate that recording errors were present in the annual total catch of *Oreochromis* spp. and that this error was also considered in the predicted annual biomass changes. A "deterministic" behavior in catch per unit of effort records was observed in Schaefer's model (Fig. 2). Consequently, the catch per unit of effort records could follow a specific trajectory (statistic fit) where all fishing seasons were related (Fig. 2). With this behavior, fishery was evaluated more easily. Nevertheless, this evaluation showed a bad statistic fit (30% with recording errors) during the 1999, 2000, 2002 fishing seasons (Fig. 2).

In the Zimapán Reservoir, tilapia catch values recorded were never greater than the predicted annual biomass changes of *Oreochromis* spp. between 1997 and 2006 (Fig. 4). This suggests that the fishing effort never reached an important exploitation level to obtain a point of capture significantly greater than the MSY value obtained. For this reason, we mentioned that this fishery was not over-fished during the studied period. The level of fishing effort at which the maximum sustainable yield is achieved was estimated at 7 203 fishermen (Table 1); however, during all the fishing seasons the total number of fishermen near to the f_{MSY} value was never recorded; the maximum f_{MSY} value was estimated at 1 573 during 2004.

The intrinsic growth rate estimated for *Oreochromis* spp. resulted at 0.730 annual (Table 1), this value suggested that

in the Zimapán Reservoir these species had a fast reproduction rate between 1997 and 2006 (Fig. 4). This result was consistent with fecundity studies reported by Granados-Flores (2006) in the Zimapán Reservoir, this author showed that female tilapia between 17.9 and 25.9 cm of total length had an average production of 2 123 eggs. The reproduction rate of the tilapia life cycle has been described by several authors as high. There have been fertility values ranging between 200 and 3 000 eggs per female depending on the species and the region. Morales (1974) indicated that tilapia females between 31 and 33 cm of total length in the Temascal Miguel Alemán Reservoir, Oaxaca, Mexico, had total oocytes for fish from 1 000 to 1 800. In the Chila lagoon, Basurto (1995) reported that tilapia females between 29 and 34 cm of total length had oocytes for fish production from 888 to 2 945. Jiménez-Badillo (1999) reported that *Oreochromis aureus* (Steindachner, 1864) females between 13.9 and 28 cm of total length laid or produced an average of 2 123 oocytes in the Adolfo López Mateos Reservoir, Michoacan, Mexico. In the Emiliano Zapata Reservoir, Morelos, Mexico, Peña-Mendoza *et al.* (2005) observed tilapia females with total length smaller than other females in Mexican Reservoirs (between 15 and 25 cm), which showed a production of oocytes between 243 and 847 (Granados-Flores, 2006). In the case of African tilapias, Anene & Okorie (2008) reported for *Tilapia mariae* a production of 424 to 2,781 eggs with an average of 1 705 eggs per female, whereas Shalloof-Kariman & Hanan (2008) reported from 289 to 1456 eggs per female for *Oreochromis niloticus* in a lake in Egypt. Alamilla (2001) reported that *Oreochromis* spp. is very resistant to live in places with high population density, with severe changes of temperature, salinity and low oxygen concentrations. Bocek (2003) indicated that Tilapia can feed on a wide range of natural and

artificial food. Considering these ecological aspects and reproductive strategies, we can understand the high values of the k parameter (9 000 tons) present in the Zimapán Reservoir (Table 1 and Fig. 4). Several authors have reported an ecological relationship between the k and r parameters (Krebs, 1985; Beltrán-Álvarez *et al.* 2009).

Based on the results from this study, we conclude that tilapia fishing in the Zimapán Reservoir was at equilibrium or was not over-fished during the analyzed period (1997 to 2004) because in all fishing seasons, tilapia catches recorded in Schaefer´s model were observed far from the k parameter and below the MSY value.

ACKNOWLEDGEMENTS

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