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Preliminary demographic analysis of shortfin mako shark (*Isurus oxyrinchus*) in the Mexican Pacific Ocean[1]

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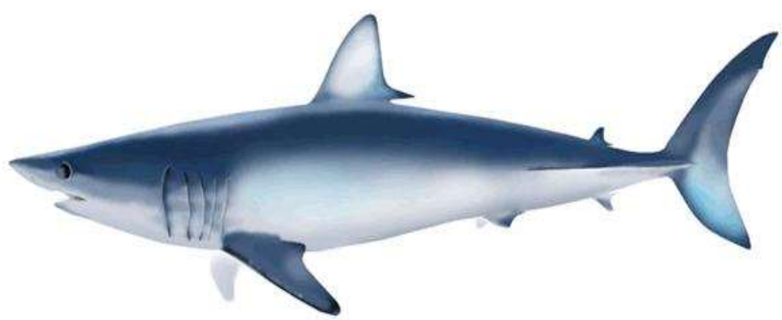

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Abstract

Demographic analyses are commonly used to obtain information about the population dynamics of sharks. For shortfin mako shark (*Isurus oxyrinchus*) such studies have been undertaken mainly in the Western Pacific Ocean. The objective of this study was to explore in a preliminary way the demography of *I. oxyrinchus* population caught in the Mexican Pacific, incorporating new available information on age and growth for the region, as well as the catch composition obtained from the Mexican observer´s program on board industrial longline shark fishing vessels during the last decade. The basic demographic parameters were estimated using life tables and age-based matrices. Elasticity matrices were used to determine the contribution of each age group to the population growth rate and the effect of different fishing mortality rates (F) evaluated. In addition, the rebound potential was calculated. The analyses indicated increasing population rates of the species in the Mexican Pacific Ocean under natural conditions for different scenarios of longevity and breeding seasonality. The juveniles produced the biggest change in population growth rates (r and λ), followed by the adults. However, the influence of the age groups commonly caught by the Mexican fishery (2–4 years) to r and λ was considerably lower than that from the rest of the juveniles and adults, suggesting that the fishery may not have such a serious impact on the population of *I. oxyrinchus* if the rates of fishing mortality are adequate. The population tolerate up to an F=0.5 if catches focus on 2–4 age groups. Our results demonstrate that the recovery capacity for the species after being subject to F was lower than that reported previously. The impact of management measurements adopted to date in Mexico on the demography of the species need to be addressed in the future. The full understanding of the population dynamics of the species in Mexican waters is necessary to achieve sustainability.

Introduction

Population dynamics depends on the growth, mortality and reproduction of individuals (Heppell et al. 1999). Demographic analysis (life tables and matrix models) can be used to gain insight into the population dynamics of sharks under a variety of scenarios, and to assess their productivity and vulnerability to varying exploitation rates (Cortés 1998, Chen and Yuan 2006, Cortés 2007). Age and stage-based demographic models have been very popular for elasmobranchs, providing a more realistic view of the dynamics of some populations (Mollet and Cailliet 2002).

The study of shortfin mako shark (*Isurus oxyrinchus*) fisheries has been recently a subject of international interest (Clarke et al. 2015, ISC 2017), as well as national for Mexico, due to the importance of the species in the catches of both artisanal and industrial fisheries (González-Ania et al. 2017, Sosa-Nishizaki et al. 2017). However, studies of population dynamics of the species have been undertaken mainly in the Western Pacific Ocean, evaluating the impact of uncertainty in the biological parameters used in demographic models to estimate population growth rates. Such studies included the development of a two-sex stage-based matrix model that takes account of sexual dimorphism and mating mechanism, considering that this shark is sexually dimorphic in vital rates (Joung and Hsu 2005), that the reproduction involves both males and females, and that births depend on the relative abundance of both sexes through an appropriate mating function, whereas the lack of suitable mates can affect population growth and viability (Iannelli et al. 2005, Tsai et al. 2015 and Yokoi et al. 2017) (Table 1).

The results of the evaluation of the population status of *I. oxyrinchus* in the Northwest Pacific showed that the young individuals have experienced higher fishing pressure in recent years, appearing to be at a relatively high risk of overfishing. The abundance is also likely to be dropping under current fishing conditions (Chang and Liu 2009, Tsai et al. 2015). The objective of this study was thus to explore in a preliminary way the demography of *I. oxyrinchus* population that is caught in the Mexican Pacific, incorporating the new available information on age and growth for the region (Rodríguez-Madrigal et al. 2017) and reproduction for the species (Semba et al. 2011, Semba et al. 2017). The demographic analysis is also used to determine through elasticity analysis a base line for fishing mortality, as well as the effects of the Mexican fishery on the productivity of the species, using the information on catches from an observer program on board Mexican shark fishing vessels during the last decade.

Table 1. Demographic parameters reported for *Isurus oxyrinchus* captured north of the Pacific Ocean.

Finite population growth rate (λ)	*Natural mortality (M)*	*Fishing mortality (F)*	*Total mortality (Z)*	Reference
	F: 0.077−0.244 M: 0.091−0.203	Of ages 6−10 years (0.036−0.145; 0.08). The average *F* increased from 0.020 to 0.046 at ages 3−5 years.	F: 0.210 M: 0.244	Chang and Liu 2009
	F: 0.077−0.242, 0.107 M: 0.093−0.200, 0.119	F: 0.288 M: 0.227		Tsai et al. 2011
Without *F* F: 1.069 and 1.047 (2yr and 3 yr) M: 1.088 and 1.056 Under current F F: 0.954 and 0.943 M: 0.938 and 0.918	F: 0.091−0.124 M: 0.119−0.141	F: 0.287−0.296, 0.291 M: 0.226−0.234, 0.231		Tsai et al. 2014
1.0300±0.0763				Liu et al. 2015
Whitout F F: 1.047, 1.051 monogamous, 1.010 polyandrous, 1.082 polygynous. Current F F:0.943, 0.930 and 0.955				Tsai et al. 2015
1.007–1.374, 1.107*				Yokoi et al. 2017

*Calculated from values of *r* reported (0.102, 0.007–0.318)

Materials and methods

The basic demographic parameters such as the intrinsic rate of population increase (r), finite rate of population increase (λ), net reproductive rate (R_0), generation time (G) and population doubling rate (t_{x2}), were estimated using life tables based on the Euler-Lotka equation and age-based matrices (Leslie matrices) (Krebs 1985, Hoenig and Gruber 1990, Simpfendorfer 2005). We preferred to use an age-based model rather than stage-based one to determine the elasticity of each age group, considering that the catches of the Mexican shark vessels focus on a particular proportion of the population and not in a whole stage.

Both life tables and matrices were solved with the PopTools 3.2.5 software (Hood 2011) (Appendix 1).

All models here considered only the female parameters, as far as it has been stated that single-sex models can be appropriate as indicators of total population dynamics if females and males in each age group in the population have similar sizes and mortality rates (Tsai et al. 2014), and differences in growth of females and males of *I. oxyrinchus* have not been found in Mexican waters (Rodríguez-Madrigal unpublished data) We also used the one-sex traditional methodology of demographic studies considering that females are the component of the population that contributes directly to increase a population (Caswell 2001), as well as a base line for future comparisons with two-sex models.

Due to the lack of conclusive length-at-maturity estimations for the Mexican Pacific (Conde-Moreno and Galván-Magaña 2006), the age at maturity of females was estimated based in the L_{50} reported by Semba et al. (2017) (233 cm of precaudal length, PCL), transformed to total length (TL) with the equation TL=PCL+2.13/0.84 (Semba et al. 2009), and the inverse von Bertalanffy growth equation using the parameters estimated for the part of the stock from Mexican waters (L_{inf}= 345.3, k= 0.12 and L_0=68.9, n= 130) (Rodríguez-Madrigal unpublished data). A sex ratio of embryos 1:1 was considered ($x^2_1 = 0.91$, P= 0.34) as reported by Semba et al. (2011). Two scenarios were developed considering a breeding periodicity of two and three years due to the uncertainty that remains on such reproductive strategy for the species (Table 2).

Three scenarios were calculated considering possible longevities: 31 years according to validated studies of specimens collected in the Northwest Atlantic Ocean (Ardizzone et al. 2006), besides 29 and 41 years estimated with the equations of Taylor (1958) and Fabens (1965) from the k of females estimated by Rodriguez-Madrigal (unpublished data). Though Tsai et al. (2014) demonstrate that longevity had a lower effect on population growth rate in comparison to other life history parameters such as survival rate and fecundity in a stage-based model, we considered important to determine if this might be the same in an age-based model.

The natural mortality (M) was taken from the procedures of Kai and Yokoi (2017) with an empirical equation of Hoenig (1983) M= exp(0.941)$a_{max}^{-0.873}$, considering the length-at-age of von Bertalanffy growth curve.

Table 2. Reproductive parameters of shortfin mako considered in the present study.

Size at maturity (cm of TL)	Gestation period (months)	Litter size	Size at birth (cm of TL)	Sex ratio of embryos (F:M)	Litter size increases with maternal size	Reproductive cycle (years)	Region	Reference
*2.98 and 2.73	15−18	4−25	70	1:1	LS=0.810 $TL^{2.346}$ (n=24, P=0.013, r^2= 0.25)	3	Arround the world	Mollet et al. 2000
F: 278 M: 210	23−25	4−15	74	1:1	Litter size did not increase with maternal size.	3	Northwestern Pacific	Joung and Hsu 2005
M: 180							Baja California	Conde-Moreno and Galván-Magaña 2006
F: 256** M: 156	9−13	8−17, 11.8	59–60**	1:1	LS= 0.12 x PCL – 21.4 ($F_{1,7}$ =0.12, P=0.008)	Is shorter than previously thought.	Western and central North Pacific	Semba et al. 2011

*The median TL at maturity, ** cm of PCL.

Effects of fishing

The age composition of the catches of shark fishing vessels in the Mexican Pacific was estimated from the TL of 3,296 females recorded during 2006–2016 by onboard observers, using the von Bertalanffy growth equation estimated for the species in the region (Rodríguez-Madrigal unpublished data).

To determine where the management or conservation actions might produce the greatest benefits to the population, elasticity matrices were estimated (Heppell et al. 2000), considering the biological parameters described previously. The elasticity of the sharks commonly caught by the fisheries was estimated by adding the elasticities of each age group that compose the main catch.

The effect of fishing mortality (*F*) on the main age groups captured by the Mexican longline industrial fleets in the Mexican Pacific Ocean (2–4 years), was evaluated taking into account two breeding periods, longevity of 31 years, average litter size of 12 embryos (Stevens 2008) and sex ratio of embryos of 1:1. The effect of *F* on ages 1–5 was also explored (corresponding to 90% of total catches), as well as on all juveniles (1–11 years).

Rebound potential

The measure of how fast a population would recover from fishing mortality (rebound potential, r_{2M}), was estimated with the technique implemented by Au and Smith (1997) and Smith et al. (1998), considering a longevity of 29, 31 and 41years, age at maturity of 12 years, average litter size of 12 embryos (Stevens 2008), the sex ratio of embryos 1:1 and target-*M* of Kai and Yokoi (2017). Values of total mortality $Z= 1.5M$ and $1.25M$ were used as alternative scenarios, as these have been suggested as more appropriate levels to achieve maximum sustainable yield (MSY) for sharks (Simpfendorfer 2005).

Results

The demographic parameters for *I. oxyrinchus* in the Mexican Pacific Ocean indicated increasing population rates (*r* and λ) under natural conditions (Without fishing mortality), for all scenarios of longevity and breeding seasonality considered. The population can increase from 6 to 8% per year. The total number of female offspring produced per individual in a single cohort can be from three to five organisms. The mean period between birth of a parent and the birth of her offspring can be from 18 to 20 years. Likewise, the population would take from eight to 16 years to double.

For all the scenarios juvenile produced the biggest change in population growth rate, followed by the adult stage (Table 4). Given that the shortfin mako shark fishery in the Mexican Pacific mainly affects juvenile organisms from 2 to 4 years (Fig. 1), it can be observed that the contribution to *r* by these organisms is considerably lower than that from the rest of the juveniles and adults. It could be interpreted thus that the fishery carried out in the study area may not have such a serious impact on the population of *I. oxyrinchus* if the rates of fishing mortality are adequate.

Table 3. Estimated demographic parameters for *I. oxyrinchus* in the Mexican Pacific Ocean with two different breeding periodicities and three possible longevities.

Longevity (years)	Intrinsic rate of population increase (r)	Finite rate of population increase (λ)	Net reproductive rate (R_0)	Generation time (G)	Population doubling rate (t_{x2})
		2 years breeding period			
29	0.082	1.085	4.059	17.966	8.458
31	0.083	1.086	4.211	18.417	8.380
41	0.084	1.087	4.658	20.082	8.241
		3 years breeding period			
29	0.057	1.059	2.706	17.966	12.072
31	0.058	1.060	2.807	18.417	11.860
41	0.061	1.062	3.106	20.082	11.450

Table 4. Contribution of survival (Elasticity) of each stage to population growth of *I. oryrinchus* in the Mexican Pacific Ocean and the proportion of juveniles caught by the Mexican fishery, considering two different breeding periodicities and three possible longevities.

	2 years breeding periodicity			3 years breeding periodicity		
Stage	29	31	41	29	31	41
Newborns (< 1 yr old)	0.06	0.06	0.06	0.06	0.06	0.06
Juveniles (1-11 yrs old)	0.67	0.67	0.65	0.66	0.65	0.63
Adults (>12 yrs old)	0.26	0.27	0.29	0.28	0.29	0.32
Juveniles (2–4 yrs old) (69% of the catches)	0.18	0.18	0.18	0.18	0.18	0.17
Juveniles (1–5 yrs old) (90 % of the catches)	0.31	0.30	0.30	0.30	0.29	0.28

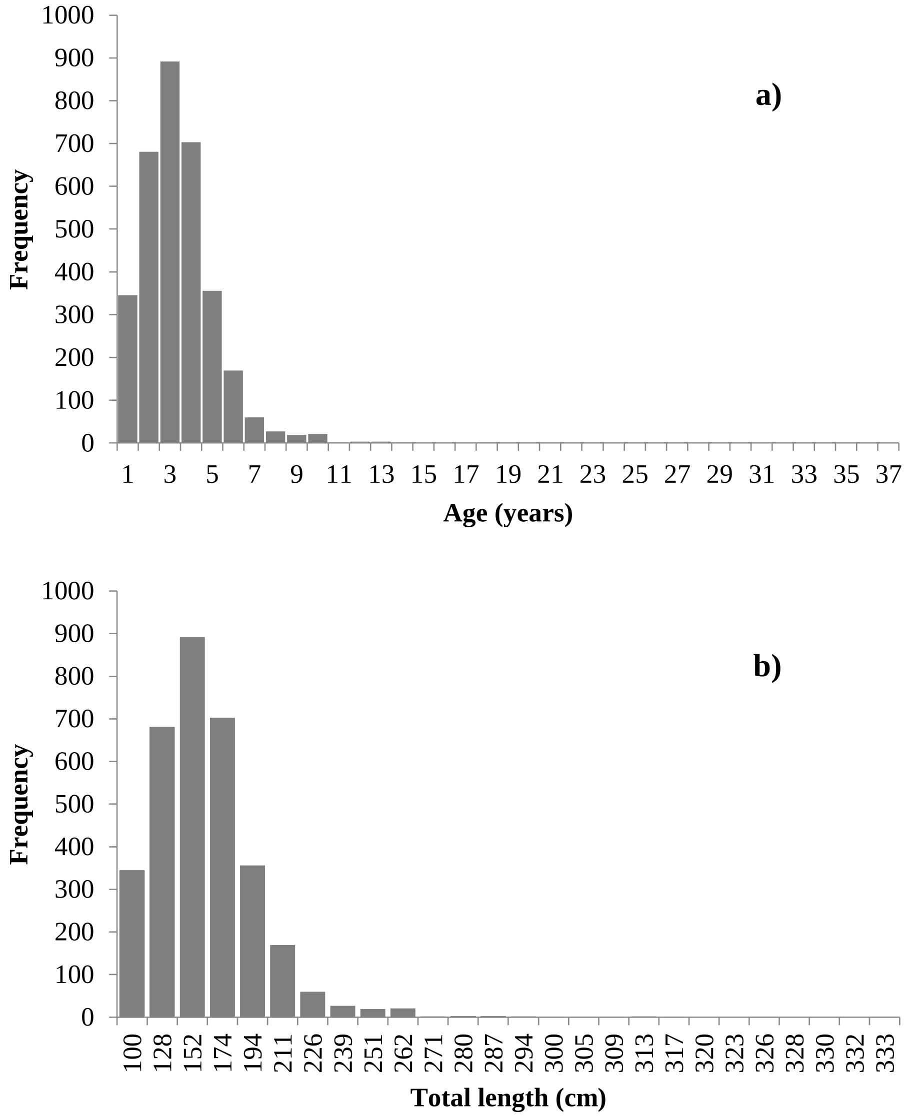

Figure 1. a) age and b) size distribution of females *Isurus oxyrinchus* caught by the industrial fishery in the Mexican Pacific Ocean, based on 3,296 individuals sampled by onboard observers.

The response of λ to different levels of F depended of the age groups caught and the breeding periodicity as expected. It was observed that the population tolerate up to a F=0.5 if catches focus on 2–4 age groups, whereas the population is highly sensitive even to the lowest F values if all juveniles would be caught (1-11 years old) (Table 5).

The relative ability of *I. oxyrinchus* to recover from fishing pressure was considerably higher when Z equals $2M$ (r_{2M}) to reach MSY than at levels of Z= 1.5 and 1.25 of M. On the other hand, different longevities had little effect on r_{2M} (Table 6).

Table 5. Finite population growth rate of *Isurus oxyrinchus* in the Mexican Pacific Ocean under different exploitation scenarios applied at specific age groups. BP= Breeding periodicity. Gray values indicate population decreases.

	2–4 years		1–5 years		1–11 years	
F	2 years BP	3 years BP	2 years BP	3 years BP	2 years BP	3 years BP
0.05	1.076	1.051	1.070	1.045	1.051	1.027
0.10	1.067	1.042	1.054	1.030	1.019	0.996
0.15	1.057	1.033	1.039	1.016	0.989	
0.20	1.048	1.024	1.024	1.002	0.961	
0.25	1.039	1.016	1.010	0.988		
0.30	1.030	1.007	0.997			
0.35	1.022	0.999				
0.40	1.013					
0.45	1.005					
0.50	0.997					

Table 6. Rebound potential of *Isurus oxyrinchus* in the Mexican Pacific Ocean with different longevity.

	r_{2M}		
Longevity	2*M*	1.5*M*	1.25*M*
29 yr	0.032	0.018	0.010
31 yr	0.032	0.018	0.010
41 yr	0.034	0.017	0.009

Discussion

The preliminary demographic parameters obtained for females of *I. oxyrinchus* in the Mexican Pacific Ocean were different to those reported by Tsai et al. (2014) in the Northwest Pacific. These authors used, however, a two sex model influenced by mating mechanisms, though considering the same different reproductive cycles and longevities of 31 to 41 years. Like in the mentioned study, λ obtained in the present study decreased as the reproductive cycle is larger but not as the longevity increases.

The preliminary elasticity analyses for the shortfin mako shark in the Mexican Pacific Ocean were similar to the results obtained by Yokoi et al. (2017), showing that the survival rate of juveniles plays an important role in the proportional changes of the population growth rate. Thus, it would be possible to achieve sustainable utilization of the stock if juveniles would be protected, establishing a capture size limit for example. The vulnerability of juvenile sharks has been reported in other shark demographic studies too (Smith et al. 1998, Heppell et al. 2000).

The effect of different *F* on λ for the different age groups extracted in the Mexican Pacific Ocean suggest a relatively high tolerance to fishing rates, however it would be necessary to consider the different fishing rates of each age groups since Tsai et al. (2014) and Tsai et al. (2015) reported important decreases in λ. It has also been pointed out that some populations can sustain certain levels of exploitation when fishing targeted a small proportion of the age-classes, as in the case of *Carcharhinus obscurus* in Southwestern Australia, which is a long-lived, late-maturing, slow-growing and slow-reproducing species and has achieves a sustainable exploitation aiming at the youngest age-classes. On the other hand, even small catches over a wide range of ages may make this strategy unsustainable (Simpfendorfer 1999).

Regarding the recovery potential observed for *I. oxyrinchus* in the Mexican Pacific Ocean, it should be considered that as other long-lived, slow-growing with low fecundity and productivity species, mako sharks are highly susceptible to overfishing if no adequate management measures are implemented. Our results demonstrate that the recovery capacity for the species after being subject to fishing mortality was lower than that reported previously by Smith et al. (1998) (r_{2M}= 0.051), considering an age at maturity of females close to 7 years, maximum age of 28 years and average fecundity of four (female pups per adult female). In addition, it has been pointed out that species with low values (r_{2M} <0.04) tend to be late-maturing medium- to large-sized coastal sharks, whereas those with the high values (r_{2M} > 0.08) were small coastal, early-maturing species.

Chang and Liu (2009) suggested a management measure of 32% reduction of current fishing effort for the shortfin mako stock in the Northwest Pacific, whereas Tsai et al. (2011) mentioned that the stock status should be closely monitored to ensure sustainable utilization. Estimates of abundance, movements and direct measurements of natural mortality are also important to achieve sustainability of shark populations (Tsai et al. 2014). The understanding of the population dynamics of the species in Mexican waters is thus necessary to achieve sustainability, highlighting the importance of carry out management measures such as for example the release of blue and shortfin mako sharks less than 100 cm of total length, being implemented since 2013 approximately. Likewise, as of 2018 observers on board of Mexican longline industrial fleets have begun to quantify the number of sharks released per set and per trip, another strategy that will allow to reach an adequate fishing management for the population of interest.

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Appendix 1

Life table for *Isurus oxyrinchus* in the Mexican Pacific Ocean, with two years of breeding period. Age interval x, survivorship l_x, fecundity m_x, age-specific reproductive rate l_x*m_x.

x	l_x	m_x	l_x*m_x	$x*l_x*m_x$
0	1	0	0	0
1	0.76	0	0	0
2	0.61	0	0	0
3	0.51	0	0	0
4	0.43	0	0	0
5	0.37	0	0	0
6	0.32	0	0	0
7	0.28	0	0	0
8	0.25	0	0	0
9	0.22	0	0	0
10	0.19	0	0	0
11	0.17	0	0	0
12	0.16	3	0.47	5.61
13	0.14	3	0.42	5.46
14	0.13	3	0.38	5.28
15	0.11	3	0.34	5.10
16	0.10	3	0.31	4.91
17	0.09	3	0.28	4.72
18	0.08	3	0.25	4.52
19	0.08	3	0.23	4.32
20	0.07	3	0.21	4.13
21	0.06	3	0.19	3.93
22	0.06	3	0.17	3.74
23	0.05	3	0.15	3.55
24	0.05	3	0.14	3.37
25	0.04	3	0.13	3.19
26	0.04	3	0.12	3.02
27	0.04	3	0.11	2.85
28	0.03	3	0.10	2.69
29	0.03	3	0.09	2.53
30	0.03	3	0.08	2.39
31	0.02	3	0.07	2.24

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1	0	0	0	0	0	0	0	0	0	0	0	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29	2.29
2	0.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0.83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0.85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0.86	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0.87	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0.88	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0.88	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0.89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0.89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0.89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.91	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.91	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.91	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.91	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.91	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.91	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.91	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.91	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.91	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.91	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.91	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.91	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.91	0

Projection matrix of *Isurus oxyrinchus* in the Mexican Pacific Ocean, with two years of breeding period.

Life table for *Isurus oxyrinchus* in the Mexican Pacific Ocean, with three years of breeding period. Age interval x, survivorship l_x, fecundity m_x, age-specific reproductive rate l_x*m_x.

x	l_x	m_x	l_x*m_x	$x*l_x*m_x$
0	1	0	0	0
1	0.76	0	0	0
2	0.61	0	0	0
3	0.51	0	0	0
4	0.43	0	0	0
5	0.37	0	0	0
6	0.32	0	0	0
7	0.28	0	0	0
8	0.25	0	0	0
9	0.22	0	0	0
10	0.19	0	0	0
11	0.17	0	0	0
12	0.16	2	0.31	3.74
13	0.14	2	0.28	3.64
14	0.13	2	0.25	3.52
15	0.11	2	0.23	3.40
16	0.10	2	0.20	3.28
17	0.09	2	0.19	3.15
18	0.08	2	0.17	3.01
19	0.08	2	0.15	2.88
20	0.07	2	0.14	2.75
21	0.06	2	0.12	2.62
22	0.06	2	0.11	2.49
23	0.05	2	0.10	2.37
24	0.05	2	0.09	2.24
25	0.04	2	0.09	2.13
26	0.04	2	0.08	2.01
27	0.04	2	0.07	1.90
28	0.03	2	0.06	1.79
29	0.03	2	0.06	1.69
30	0.03	2	0.05	1.59
31	0.02	2	0.05	1.50

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1	0	0	0	0	0	0	0	0	0	0	0	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.53	1.53
2	0.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0.83	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0.85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0.86	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0.87	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0.88	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0.88	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0.89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0.89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0.89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.91	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.91	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.91	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.91	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.91	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.91	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.91	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.91	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.91	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.91	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.91	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.91	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.91	0

Figure 2. Projection matrix of *Isurus oxyrinchus* in the Mexican Pacific Ocean, with three years of breeding period.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1	0	0	0	0	0	0	0	0	0	0	0	0.011	0.009	0.007	0.006	0.005	0.004	0.003	0.003	0.002	0.002	0.002	0.001	0.001	1E-03	8E-04	7E-04	6E-04	5E-04	4E-04	3E-04
2	0.061	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0.061	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0.061	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0.061	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0.061	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0.061	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0.061	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0.061	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0.061	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0.061	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0.061	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0.042	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0.034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.028	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.023	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.019	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.016	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.013	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.011	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.009	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.007	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.005	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.004	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.003	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.002	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.002	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7E-04	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3E-04	0

Elasticity matrix of *Isurus oxyrinchus* in the Mexican Pacific Ocean, with two years of breeding period.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1	0	0	0	0	0	0	0	0	0	0	0	0.009	0.008	0.007	0.006	0.005	0.004	0.003	0.003	0.003	0.002	0.002	0.002	0.001	0.001	1E-03	9E-04	7E-04	6E-04	5E-04	5E-04
2	0.059	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0.059	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0.059	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0.059	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0.059	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0.059	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0.059	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0.059	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0.059	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0.059	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0.059	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0.042	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0.036	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.025	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.021	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.018	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.015	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.012	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.008	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.007	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.005	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.004	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.003	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.002	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.002	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5E-04	0

Elasticity matrix of *Isurus oxyrinchus* in the Mexican Pacific Ocean, with three years of breeding period.