



*Journal of Fish Biology* (2012) **80**, 1213–1226

doi:10.1111/j.1095-8649.2011.03164.x, available online at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)

## Reproductive biology of *Zearaja chilensis* (Chondrichthyes: Rajidae) in the south-east Pacific Ocean

C. BUSTAMANTE\*†‡, C. VARGAS-CARO†, M. C. ODDONE§, F. CONCHA||,  
H. FLORES†, J. LAMILLA† AND M. B. BENNETT\*

\*School of Biomedical Sciences, The University of Queensland, St Lucia, Queensland 4072, Australia, †Laboratorio de Elasmobranchios (ELASMOLAB), Instituto de Ciencias Marinas y Limnológicas, Universidad Austral de Chile, Casilla 567, Valdivia, Chile, §Universidade Federal de Rio Grande, Instituto de Oceanografia, Laboratório de Histologia, Instituto de Ciências Biológicas, Avenida Itália, km 8 s/n, Caixa Postal 474, 96201-900, Rio Grande, RS, Brazil and ||Laboratorio de Ecología e Impactos Ambientales, Facultad de Ciencias del Mar y de Recursos Naturales, Universidad de Valparaíso, Chile

Between 2000 and 2002, three artisanal landing sites were sampled in southern Chile, with data on population structure and reproductive development collected from 5477 yellownose skates *Zearaja chilensis*. Total length ( $L_T$ ) ranged from 33 to 158 cm for females and 34 to 155 cm for males. No sexual dimorphism was evident in disc size (length or width) or in  $L_T$ –mass relationships. The smallest mature female was 95 cm  $L_T$  and the size at which 50% were mature ( $L_{T50}$ ) was 109 cm. Males matured between 80 and 90 cm  $L_T$  with a  $L_{T50}$  of 88 cm. Although the largest *Z. chilensis* captured by the artisanal fishery was 155 cm  $L_T$ , 89% of landings comprised relatively small, immature fish. This situation may compromise the stock integrity if intrinsic vulnerability and probable long-life span of *Z. chilensis* are considered. Consequences for the survival of the species and possible signs of a fishery collapse must be reviewed by management authorities by consideration of both artisanal and industrial landings in Chile.

© 2011 The Authors

*Journal of Fish Biology* © 2011 The Fisheries Society of the British Isles

Key words: fishery management; size-at-maturity; yellownose skate.

### INTRODUCTION

Skates are cartilaginous benthic fishes that occupy the same spatial niche as demersal teleosts, such as flatfishes, hakes and eels (Walker & Hislop, 1998). Unlike the majority of bony fishes, however, skates have intrinsic life-history patterns that make them highly susceptible to commercial over-exploitation (Dulvy *et al.*, 2000; Dulvy & Reynolds, 2002; Frisk, 2010). Skates present unique challenges for fishery management (Stevens *et al.*, 2000) and conservation (Roberts & Hawkins, 1999; Dulvy & Reynolds, 2002) due to their low fecundity, late age at sexual maturity and relatively high longevity (Holden, 1977; Frisk *et al.*, 2001). Over the last decade, evaluation of the conservation status of skates and rays in several geographic areas has established that commercially exploited species could be seriously threatened (Dulvy &

‡Author to whom correspondence should be addressed. Tel.: +61 7 33467975; email: carlos.bustamantediaz@uqconnect.edu.au

Reynolds, 2002) or even extirpated (Dulvy *et al.*, 2003) from a given fishing area. For example, large declines in populations and local extinctions of North Atlantic Ocean skates, such as the common skate *Dipturus batis* (L. 1758), the barndoor skate *Dipturus laevis* (Mitchill 1818), the white skate *Rostroraja alba* (Lacépède 1803) and thornback ray *Raja clavata* L. 1758, have resulted from commercial fishing activities (Dulvy & Forrest, 2010). Resilience to fishing pressure varies among skate species, however, and while some populations have decreased dramatically (Brander, 1981; Iglésias *et al.*, 2009), others have not, and, in some cases, may even have increased because of reorganization of ecological niches (Walker & Hislop, 1998; Dulvy *et al.*, 2000; Dulvy & Forrest, 2010). The vulnerability of batoid populations is mostly assessed through the examination of fisheries catch trends (Dulvy *et al.*, 2000), but in many South American countries, including Argentina (Massa & Hozbor, 2003), Brazil (M. C. Oddone, pers. obs.) and Chile (Lamilla *et al.*, 2005), skates and rays have generally been recorded as a single unidentified category (*e.g.* rays, including rajoids and Myliobatiformes) in official fisheries records for several decades. From 2003, however, landings of the target species [the yellownose skate *Zearaja chilensis* (Guichenot 1848)] and by-catch (a combination of six other skate species) in the Chilean skate fishery have been recorded separately.

*Zearaja chilensis* is the most commercially valuable batoid that inhabits the continental slope of southern South America from Uruguay (south-western Atlantic Ocean) to central Chile (south-eastern Pacific Ocean) (Menni & López, 1984) and to the east of the Falkland Islands (Agnew *et al.*, 2000). The first recorded landings of *Z. chilensis* in Chile were made in the early 1970s (Bahamonde *et al.*, 1996). Since then, the catch effort for this species has gradually intensified especially in the small-scale coastal fleet located between Valdivia (40° S) and Aisén (45° S), which is considered an artisanal fishery by local management authorities (Licandeo *et al.*, 2006). In addition to this target fishery, *Z. chilensis* is caught as by-catch in two industrial trawl fisheries: the southern hake *Merluccius australis* (Hutton 1872) fishery that operates south of 41° 28-6' S (Quiroz *et al.*, 2009) and the common hake *Merluccius gayi* (Guichenot 1848) bottom trawl fishery that operates between 34° 28' S and 41° 28-6' S (Gálvez *et al.*, 1998). These artisanal and industrial fishing grounds do not overlap due to local management measures which restrict the target catch of *Z. chilensis* for industrial vessels to south of 41° 28-6' S and 9.26 km (5 nautical miles) out into Chilean waters. According to official records, the annual national landing (from artisanal and industrial fleets) of *Z. chilensis* has increased from 1317 in 1990 to 3010 in 2007, with an average landing of 2663 for this period (SERNAP, 2007). After a biological closure was imposed on the artisanal fisheries in 2008, the annual landing by industrial fleets has averaged 1727 for 2008 and 2009 (SERNAP, 2009). Despite this closure, a fishing quota of 2307 and 642 were granted to the artisanal fishery during 2009 and 2010.

Although size at maturity (Fuentealba *et al.*, 1990; Bahamonde *et al.*, 1996) and the life history of this species (Licandeo *et al.*, 2006; Quiroz *et al.*, 2009) have been determined previously, based on landings in southern bottom longline fishery grounds, there is a lack of information about the northern coastal artisanal fishery population. In order to provide additional information on the reproductive biology of *Z. chilensis*, sexual dimorphism was assessed and size at maturity was determined from the artisanal exploited stock. Further details of the sexual development of both males and females, as well as estimates of fecundity are also presented.

## MATERIALS AND METHODS

*Zearaja chilensis* landings were sampled from three localities in southern Chile: Queule (39.4° S), Corral (39.8° S) and Bahía Mansa (40.5° S) (Fig. 1), between September 2000 and December 2002. All specimens were caught by artisanal vessels of 6–15.5 m length using bottom-set longlines of 300–400 hooks (M/K No. 7). Total length ( $L_T$ ), disc width ( $W_D$ ) and length ( $L_D$ ) were recorded for each specimen following Hubbs & Ishiyama (1968) and Last *et al.* (2008), along with sex and left clasper post-cloacal length ( $L_C$ ). Measurements were made to the nearest cm. Total body mass ( $M_T$ ) and liver mass ( $M_L$ ) were determined for all *Z. chilensis* and recorded to the nearest gram. The hepato-somatic index ( $I_H$ ) was calculated as:  $I_H = 100 (M_L M_T^{-1})$ . Ovary and oviducal-gland mass and maximum ovarian-follicle diameters were measured for females, while testes and epigonal organ mass were determined for males. All measurements are presented as the mean  $\pm$  s.d.

The  $\chi^2$  goodness of fit (Sokal & Rohlf, 1987) was used to test whether the ratio of males to females varied significantly from a 1:1 ratio. Linear relationships between  $L_T$ , partial lengths ( $L_D$  and  $W_D$ ) and  $M_T$  were fitted separately for sex and tested for sexual dimorphism using ANCOVA. Regressions were fitted to raw data, except for  $L_T$  and  $M_T$ , which were  $\log_{10}$

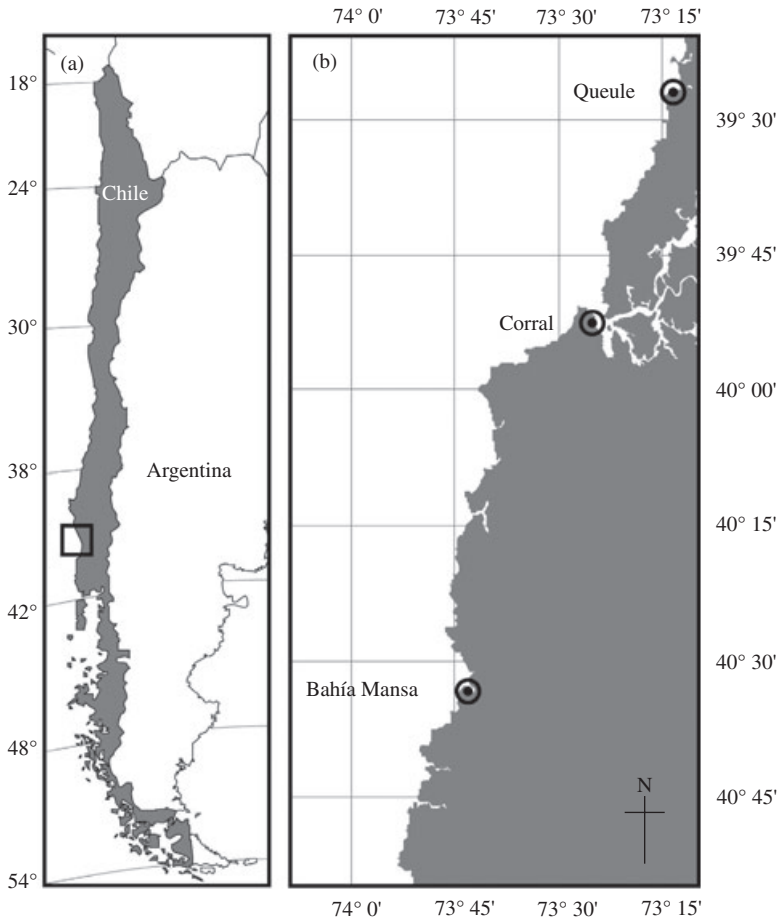


FIG. 1. Map of Chile (a) showing location of study area (inset box), and (b) three *Zearaja chilensis* landings sites (⊙).

transformed. A *t*-test was used to evaluate differences between the  $I_H$  of mature and immature *Z. chilensis* according to sex. Paired *t*-tests were performed to explore possible differences in left *v.* right ovary mass, oviducal-gland mass and ovarian-follicle size and number, and differences between epigonal organ and testes mass. Relationships between ovary–oviducal-gland mass and  $L_T$ , and between  $L_C$  and  $L_T$  were used to further assess the onset of maturity (Capapé & Quignard, 1974; Restrepo & Watson, 1991). One-way ANOVA was used to test for significant differences in mean maximum ovarian-follicle diameter and  $I_H$  in available months (September to December).

Binomial maturity data (immature 0, mature 1) were determined by sex at 10 cm intervals. Size at maturity in both sexes were calculated by fitting the following logistic curve (by minimization of the least squares), to the relationship between the fraction of mature males or females as a function of  $L_T$ ,  $Y = [1 + e^{-(a+bX)}]^{-1}$ , where  $Y$  is the fraction of mature individuals in  $L_T$  class  $X$ , and  $a$  and  $b$  are the model coefficients. The ratio  $a:b$  represents the size at which 50% of the fish were mature (Mollet *et al.*, 2000; Oddone *et al.*, 2005). Females were considered mature when vitellogenic (yellow) ovarian follicles and egg capsules were present (Chen *et al.*, 1997; Oddone *et al.*, 2005). Individual males with sperm in their seminal vesicles and calcified, rigid claspers were considered mature (Sosebee, 2005). All data analyses were performed using the freeware software PAST (Hammer *et al.*, 2001), with significance accepted at  $P < 0.05$ .

## RESULTS

### CATCH COMPOSITION

A total of 5477 specimens were examined (2356 females and 3121 males). The catch composition sex ratio of 1:0.75 had a significant bias towards males ( $\chi^2 = 53.692$ , d.f. = 1,  $P > 0.001$ ). Body size of females caught ranged between 33 and 158 cm  $L_T$  ( $75.4 \pm 12.6$  cm); males ranged between 34 and 155 cm  $L_T$  ( $85.4 \pm 7.2$  cm) (Fig. 2). The  $L_T$  and  $M_T$  relationship was influenced by sex ( $M_T = 1e-05 L_T^{2.9165}$  in females and  $M_T = 3e-05 L_T^{2.6614}$  in males), but no significant differences were observed between slopes (ANCOVA,  $F_{1,5202} = 0.293$ ;  $P > 0.05$ ) [Fig. 3(a)]. Size-related sexual dimorphism was not obvious despite significant differences when comparing slopes between  $L_T$  and  $L_D$  [ANCOVA,  $F_{1,5254} = 12.14$ ;  $P < 0.001$ ; Fig. 3(b)] or  $W_D$  [ANCOVA,  $F_{1,4848} = 4586$ ;  $P < 0.001$ ; Fig. 3(c)]. The overall mass of catches was 24.6 tonnes with mean  $\pm$  s.d. of  $4530 \pm 3625$  g with a minimum of 800 g and maximum of 3800 g.

### LIVER MEASUREMENTS

The mean  $\pm$  s.d.  $I_H$  was  $5.135 \pm 1.443$  for males, and  $5.157 \pm 1.254$  for females, with no significant differences observed between months ( $F_{4,244} = 10.17$ ,  $P > 0.05$ ) for either sex (Fig. 4). Significant differences were observed between  $I_H$  of mature and immature males ( $t = -3.524$ , d.f. = 2802,  $P < 0.001$ ) and between mature and immature females ( $t = -3.939$ , d.f. = 2064,  $P < 0.001$ ), with relatively heavier livers present in mature specimens. There was no significant difference between overall mature male and female  $I_H$  ( $t = 1.916$ , d.f. = 4074,  $P > 0.05$ ).

### FEMALE REPRODUCTIVE BIOLOGY

Asymmetry of the reproductive tract was not observed in mature *Z. chilensis*, with no significant differences between the mass of the left ( $127.08 \pm 52.22$  g) and right

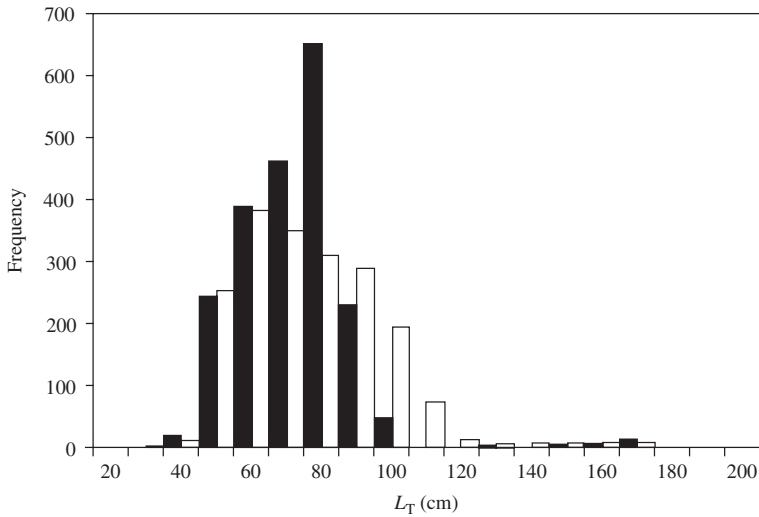


FIG. 2. Total length ( $L_T$ ) absolute frequency distribution of *Zearaja chilensis* ( $n = 5477$ ) [■, males ( $n = 3121$ ) and □, females ( $n = 2356$ )].

( $130.57 \pm 48.03$  g) ovaries ( $t = 0.588$ , d.f. = 2084,  $P > 0.05$ ). Similarly, there were no significant differences between left ( $43.57 \pm 38.65$  g) and right ( $44.44 \pm 40.24$  g) oviducal-gland masses ( $t = 0.187$ , d.f. = 2132,  $P > 0.05$ ). Significant differences were detected, however, in ovarian-follicle counts between left ( $142.91 \pm 48.73$ ) and right ( $163.26 \pm 62.39$ ) ovaries ( $t = 3.145$ , d.f. = 2368,  $P < 0.001$ ). Ovarian follicles were 0.3–4.1 cm in diameter and 0.04–19.21 g in mass. No significant differences ( $t = 1.730$ , d.f. = 2110,  $P > 0.05$ ) were observed between maximum diameters of ovarian follicles in left ( $3.38 \pm 0.35$  cm) and right ( $3.50 \pm 0.43$  cm) ovaries. The minimum size at first maturity occurred at c. 95 cm  $L_T$  based on ovary and oviducal-gland mass [Fig. 5(a), (b)]. Substantial variations in ovarian-follicle mass were observed for follicles of the same diameter as a result of differences in yolk consistency [Fig. 5(c)]. Mean maximum ovarian-follicle diameter ranged from  $3.45 \pm 0.24$  cm in September to  $4.10 \pm 0.43$  cm in December, although no significant differences were observed between months [ANOVA,  $F_{3,273} = 4.0$ ,  $P > 0.05$ ; Fig. 4(a)]. The size at which 50% of the fish were mature ( $L_{T50}$ ) was 109 cm  $L_T$  [Fig. 5(d)], and mature females represented only 8% of the female catch at this size.

## MALE REPRODUCTIVE BIOLOGY

The  $L_C$  varied markedly between mature specimens with the smallest mature male recorded at 62 cm  $L_T$ , whereas some individuals were immature at c. 95 cm  $L_T$  [Fig. 6(a)]. No significant differences were found between left ( $11.2 \pm 5.6$  g, range = 0.08–26.5 g) and right ( $11.4 \pm 4.8$  g, range = 0.09–27.57 g) testis masses ( $t = 0.245$ , d.f. = 2214,  $P > 0.05$ ). No significant differences were found between left ( $38.8 \pm 14.2$  g, range = 2.39–82.44 g) and right ( $38.7 \pm 10.4$  g, range = 1.83–81.28 g) epigonal-organ masses ( $t = 0.075$ , d.f. = 2214,  $P > 0.05$ ). Based on

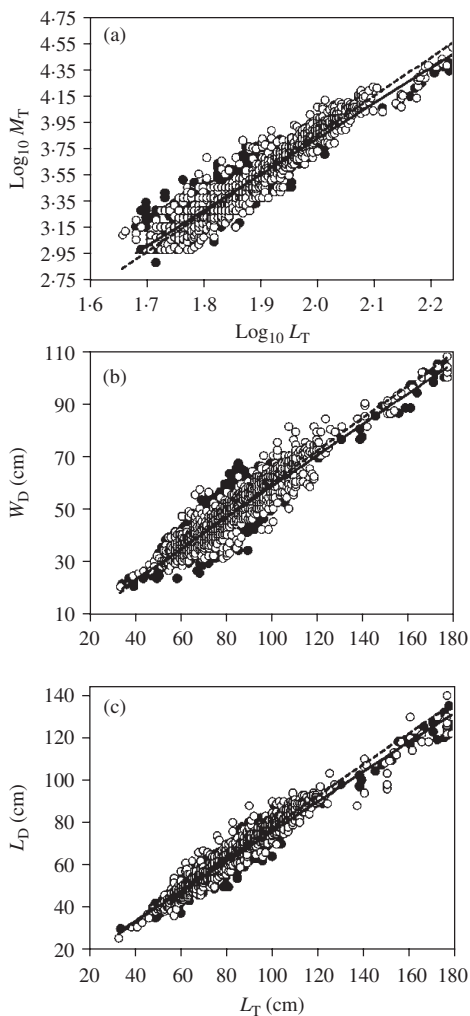


FIG. 3. Relationships between total length ( $L_T$ ) and (a) total body mass ( $M_T$ ), (b) disc width ( $W_D$ ) and (c) disc length ( $L_D$ ) of male (●) and female (○) *Zeoraja chilensis*. The curves were fitted by (a) male  $y = 2.706x - 1.572$  and female  $y = 2.951x - 2.036$ , (b) male  $y = 0.596x - 1.263$  and female  $y = 0.628x - 3.185$  and (c) male  $y = 0.708x + 5.094$  and female  $y = 0.748x + 2.641$ .

the calculated  $L_{T50}$  of 88 cm  $L_T$  for males [Fig. 6(b)], 13.6% of males in the catch were mature.

## DISCUSSION

The sex ratio in *Z. chilensis* was biased towards males, which suggests some sexual segregation in the study area although the reason for this is not known. Differences in sexual composition may be a consequence of behaviour, and many deep-sea skates are known to segregate by sex, size and maturity (Ebert *et al.*, 2008).

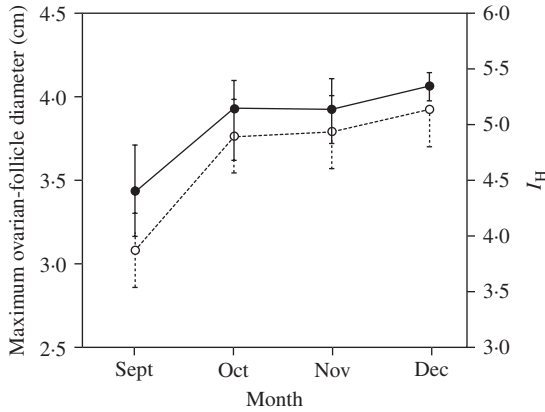


FIG. 4. Monthly variation of maximum ovarian-follicle diameter (●) and hepato-somatic index ( $I_H$ ; ○) of *Zearaja chilensis*. Values are mean  $\pm$  s.d.

In elasmobranchs, size is commonly regarded as a major secondary sexual characteristic, with females often larger and heavier than males (Cortés, 2000). This characteristic seems to be common in rajoid species (Lamilla *et al.*, 1984; Smith & Merriner, 1986; Martin & Cailliet, 1988), but while the size-frequency distribution

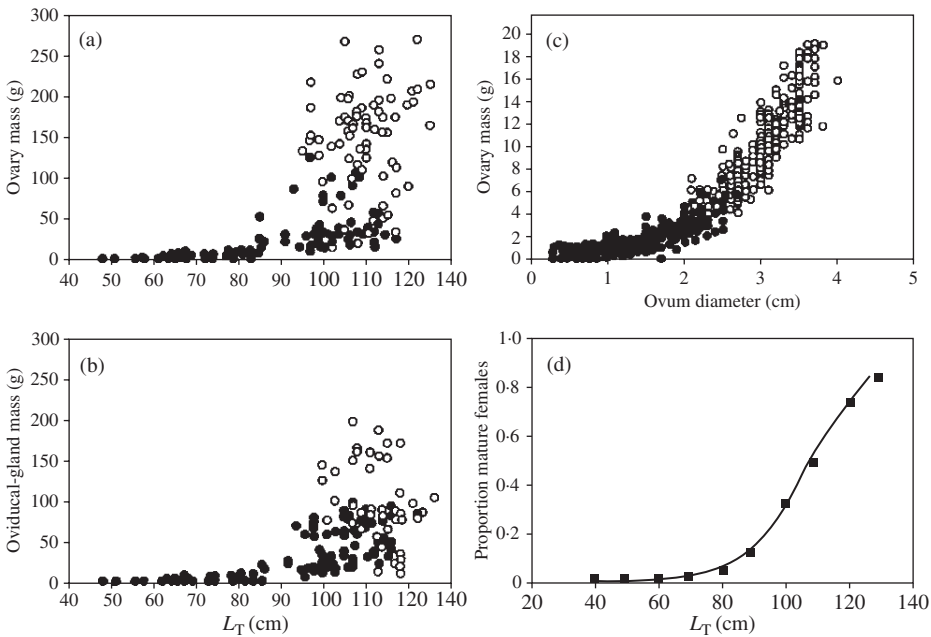


FIG. 5. Relationships between total length ( $L_T$ ) and (a) ovary mass and (b) oviducal-gland mass, (c) ovum diameter and ovum mass and (d) logistic model (—) fitted for the relationship between  $L_T$  and proportion of mature female *Zearaja chilensis*. (●, immature; ○, mature; ■, the observed proportion of mature individuals in each size interval) (d) The curve was fitted by:  $y = [1 + e^{-(8.185+0.075x)}]^{-1}$ .

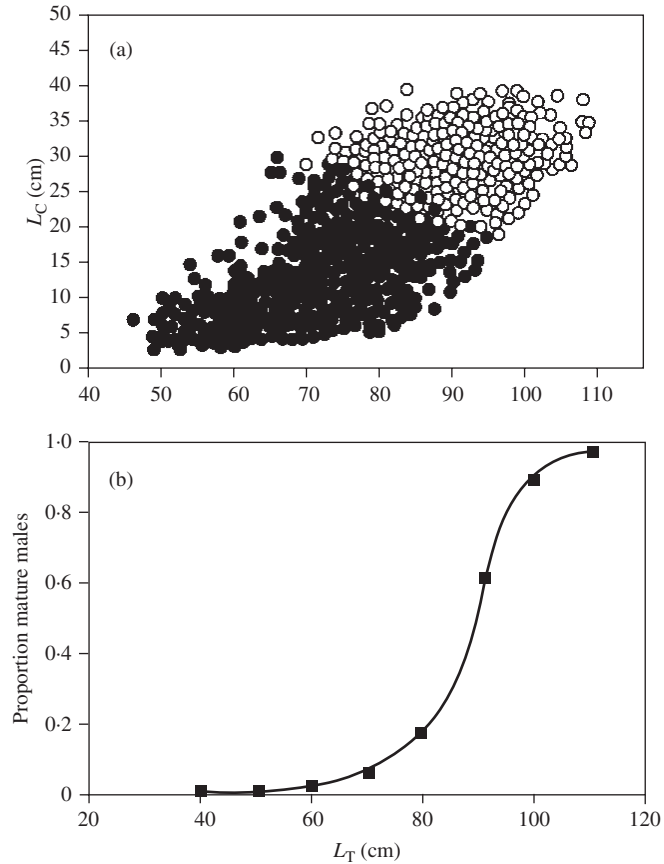


FIG. 6. Relationships between (a) total length ( $L_T$ ) and clasper length ( $L_C$ ) and (b) logistic model (—) fitted for the relationship between  $L_T$  and proportion of mature males of *Zearaja chilensis*. (●, immature; ○, mature; ■, the observed proportion of mature individual in each size interval. (b) The curve was fitted by:  $y = [1 + e^{-(11.649+0.132x)}]^{-1}$ .

in the current study indicated that *Z. chilensis* >100 cm  $L_T$  were predominantly female, in absolute terms, it appeared that males and females attained similar maximum sizes. There may be a selective advantage for female *Z. chilensis* to grow to a larger size than males (Licandeo *et al.*, 2006) in order to accommodate relatively large ova (that mature at *c.* 41 mm in diameter) and the associated reproductive tract. A large body size would in itself provide a large energy reserve to draw upon for egg production and may also influence the diet, by allowing larger and possibly different species of prey to be taken as seen in other skate species (Brickle *et al.*, 2003; Kyne *et al.*, 2008). In some species, however, such as the ovoviviparous apron ray *Discopyge tschudii* Heckel 1846, the length–mass relationship and body size (measured as disc width) indicate that males grow larger than females (García, 1984; Pequeño *et al.*, 1988). A similar situation has also been reported for *Bathyraja interrupta* (Gill & Townsend 1897), *Bathyraja minispinosa* Ishiyama & Ishihara 1977 and *Bathyraja parmifera* (Bean 1881) (Ebert, 2005), as well as for *Leucoraja wallacei*



(Hulley 1970), *Raja straeleni* Poll 1951, *Raja barnardi* (Norman 1935) and *Raja leopardus* (von Bonde & Swart 1923) (Ebert *et al.*, 2008). Pequeño *et al.* (1988) argued that this could be an adaptation to activities such as mating or swimming behaviour in those species that undergo significant migrations. It is also common to find that size-at-maturity varies according to sex, with males commonly reaching maturation at smaller sizes than the females (Wetherbee, 1996; Ellis & Shackley, 1997; Girard & Du Buit, 1999). In *Z. chilensis*, males matured at *c.* 80% of the size at maturity of females, but Mabragaña *et al.* (2002) suggest that this dimorphism could be due to local ecological characteristics rather than to biological peculiarity.

The  $I_H$  was significantly larger in mature fish compared to immature specimens in both sexes, which is presumably correlated with larger energy reserves in animals in which growth has slowed. Interestingly, while female elasmobranchs often have larger livers than males, due to requirements for egg and yolk development (Quiroz *et al.*, 2011), these differences are not reflected in the present findings. Unlike mature males, the liver of mature females produces vitellogenin, the precursor protein molecule of vitellogenic material during the oocyte maturation. But according to the  $I_H$ , there are not significant differences between both mature males and females despite females needing to store great amounts of lipids in their livers during previtellogenic and gestation phases. This is consistent with mature females of the Aleutian skate *Bathyraja aleutica* (Gilbert 1896) reported by Ebert (2005). Mabragaña *et al.* (2002) and Oddone & Velasco (2006) described similar observations in the smallnose fanskate *Sympterygia bonapartii* Müller & Henle 1841 and the eyespot skate *Atlantoraja cyclophora* (Regan 1903) from the south-west Atlantic ocean.

While many elasmobranchs have a single functional ovary (Dodd *et al.* 1983; Hamlett & Koob, 1999; Musick & Ellis, 2005), ovarian symmetry, as observed in *Z. chilensis*, is common in all skates (Oddone *et al.*, 2007). The symmetry of paired structures extended to other part of the reproductive system, which is also consistent with previous studies on skates that have shown no difference between oocyte number and oviducal-gland width (Mabragaña *et al.* 2002; Ebert 2005; Ebert *et al.* 2008). While male maturity occurred at *c.* 88 cm  $L_T$ , however, the relationship between  $L_C$  and  $L_T$  during the maturation phase suggested that there was an unusually high degree of plasticity in the size at maturity compared to other skates (Ebert, 2005).

Despite relatively large geographical differences between sampling locations, the results from the present study provide similar estimates of sexual maturity to those made previously in the south-western Pacific Ocean (Licandeo *et al.*, 2006) and the south-western Atlantic Ocean (Oddone *et al.*, 2005; Paesch & Oddone, 2008), suggesting that size at maturity is a conservative trait in this species as a compensatory dynamic over latitudinal gradients in the entire fishery and occurrences zones (Frisk, 2010).

Large batoids appear to be longer-lived, slower growing and have lower reproductive output among the elasmobranchs, which makes them highly susceptible to overexploitation (Dulvy *et al.*, 2000). Besides, fisheries may change abundance and distribution of skates as most of these fisheries are biased towards larger individuals (Jennings *et al.*, 1999; Frisk, 2010). Indeed, there is a negative correlation between skate body size and population trend (Walker & Hislop, 1998; Dulvy *et al.*, 2000), and *Z. chilensis* is no exception. According to Licandeo *et al.* (2006), the main targets of the *Z. chilensis* fishery in Chile are immature fish. The present results indicate

that 106 cm  $L_T$  females (c. 14 years-old) and 86 cm  $L_T$  males (c. 11 years-old) represent 85% of total catch and, as small *Z. chilensis* (<35 cm  $L_T$ ) are discarded, there is evidence of a fishery highly biased towards mid-sized *Z. chilensis* that may compromise the stock integrity.

Reproductive seasonality could not be determined given the scarcity of gravid females and the limited number of months sampled by this fishery. The monthly mean maximum ovarian-follicle diameter and  $I_H$  did not, however, differ significantly across the 4 month study period which is consistent with the suggestion that deep-water skate species may not exhibit a defined reproductive or egg-laying season (Braccini & Chiaramonte, 2002; Mabrugaña *et al.*, 2002; Ruocco *et al.*, 2006; Ebert *et al.*, 2008). It should be noted though that the data in the current study would also be consistent with a defined reproductive season that coincided with the sampling period, and further studies of this species across all months of the year are necessary to resolve the issue. Fishing records of *Z. chilensis* in the southern Falkland Islands demonstrated that an intense fishing operation culminated in a drastic stock collapse (Agnew *et al.*, 2000). The present results indicate that 89% of the females captured were below size at maturity, which may pose a serious threat to their population.

The size structure of the *Z. chilensis* catch in the Valdivia fishing zone (39.4° S to 40.5° S) differs considerably when compared to the reported catch from fishing grounds to the south: around Chiloé Island (41.5° S to 43.5° S), Moraleda Channel (43.8° S to 45.9° S) and Castro-Magallanes Channel (51.0° S to 54.0° S) (Quiroz *et al.*, 2009). In the case of females, mature individuals comprised only 8–10%

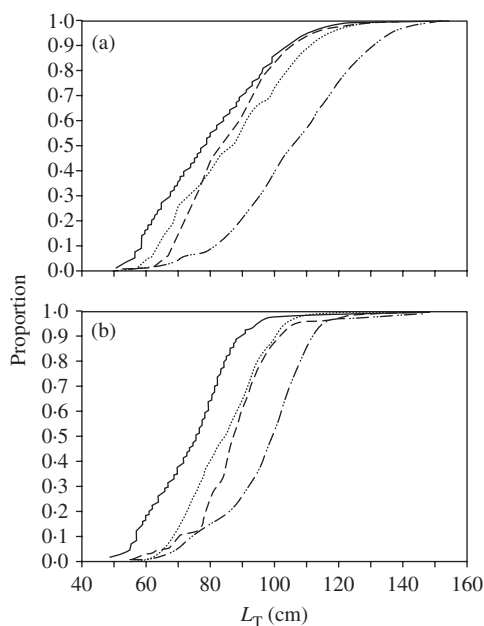


FIG. 7. Accumulated size frequencies of *Zearaja chilensis* (a) females and (b) males by fishing grounds (modified from Quiroz *et al.*, 2009): Valdivia 39.4° S to 40.5° S (—), Chiloé Island 41.5° S to 43.5° S (.....), Moraleda Channel 43.8° S to 45.9° S (---) and Castro-Magallanes Channel 51.0° S to 54.0° S (-.-).

of the catch in the northern fishing grounds (Valdivia, Chiloé Island and Moraleda Channel), but closer to 50% in the most southerly fishing grounds [Fig. 7(a)]. This pattern is repeated for males, with mature individuals comprising *c.* 75% of the catch in the Castro-Magallanes Channel zone compared with *c.* 14% in the Valdivia zone [Fig. 7(b)]. Evidence of an increasing median  $L_T$  ( $L_T$  of 50% of the catch) with respect to latitude can be observed in both sexes even though the same fishing gear is used in all zones. The reason for these differences in catch size structure may be the result of fishing effort moving south as the southernmost fishing grounds have been developed relatively recently compared to the Valdivia zone (Quiroz *et al.*, 2011). If the southern fishery catch composition represents a relatively natural situation, then the catch size structure in the northern fisheries suggests that they are at particular risk of collapse if the tonnage landed is maintained, as mature *Z. chilensis* numbers appear to have been overfished. Growth rates and recruitment need to be evaluated in each fishery zone for a better understanding of the population ecology and dynamics of *Z. chilensis* in southern Chile. If the intrinsic vulnerability and long life spans of *Z. chilensis* are considered, the implications for survival and the signs of an imminent fishery collapse need to be reviewed by management authorities before local extirpation occurs, such as have been documented for other species of skates by Dulvy & Forrest (2010).

Authors wish to thank all of the ELASMOLAB crew involved in ‘Programa de Conservación de Tiburones (PCT)’ for their valuable help in field trips sampling and biological dissections. We are very grateful to all the fishermen involved, especially at ‘Caleta Amargos’ and A. Belliazzi for his valuable help in the field work. Additional thanks to J. Stead for her invaluable comments on an early draft, as well as two anonymous referees for their useful comments on earlier versions of this manuscript. This contribution was supported by Dirección de Investigación of Universidad Austral de Chile (DID-UACH). C.B. was supported by CONICYT–Becas Chile grant.

## References

- Agnew, D. J., Nolan, C. P., Beddington, J. R. & Baranowski, R. (2000). Approaches to the assessment and management of multispecies skate and ray fisheries using the Falkland Islands fishery as an example. *Canadian Journal of Fisheries and Aquatic Sciences* **57**, 429–440.
- Bahamonde, F., Ojeda, G., Leiva, B., Muñoz, L., Rojas, M., Donoso, M., Céspedes, R. & Gili, R. (1996). Pesca exploratoria de raya volantín en la zona sur-austral. *Instituto de Fomento Pesquero Informe técnico No. 94–11*. Valparaíso: IFOP.
- Braccini, J. M. & Chiaramonte, G. E. (2002). Reproductive biology of *Psammobatis extenta*. *Journal of Fish Biology* **61**, 272–288. doi: 10.1111/j.1095-8649.2002.tb01752.x
- Brander, K. (1981). Disappearance of common Skate *Raja batis* from Irish Sea. *Nature* **290**, 48–49.
- Brickle, P., Laptikhovskiy, V., Pompert, J. & Bishop, A. (2003). Ontogenetic changes in the feeding habits and dietary overlap between three abundant rajid species on the Falkland Islands’ shelf. *Journal of the Marine Biological Association of the United Kingdom* **83**, 1119–1125.
- Capapé, C. & Quignard, J. P. (1974). Contribution à la biologie des Rajidae des côtes tunisiennes. 1. *Raja miraletus*, Linné, 1758: répartition géographique et bathymétrique, sexualité, reproduction, fécondité. *Archives de Institut Pasteur Tunis* **51**, 39–60.
- Chen, C. T., Liu K. M. & Chang, Y. C. (1997). Reproductive biology of the bigeye thresher shark, *Alopias superciliosus* (Lowe, 1839) (Chondrichthyes: Alopiidae), in the north-western Pacific. *Ichthyological Research* **44**, 227–235.

- Cortés, E. (2000). Life-history patterns and correlations in sharks. *Reviews in Fisheries Science* **8**, 299–344. doi: 10.1080/10408340308951115
- Dodd, J. M., Dodd, M. H. I. & Duggan, R. T. (1983). Control of reproduction in elasmobranch fishes. In *Control Process in Fish Physiology* (Rankin, J. C., Pitcher, T. J. & Duggan, R. T., eds), pp. 221–285. New York, NY: John Wiley & Sons.
- Dulvy, N. K. & Forrest, R. E. (2010). Life histories, population dynamics, and extinction risks in Chondrichthyans. In *Sharks and Their Relatives II: Biodiversity, Adaptive Physiology and Conservation* (Carrier, J. C., Musick, J. A. & Heithaus, M. R., eds), pp. 639–680. Boca Raton, FL: CRC Press.
- Dulvy, N. K. & Reynolds, J. D. (2002). Predicting extinction vulnerability in skates. *Conservation Biology* **16**, 440–450.
- Dulvy, N. K., Metcalfe, J. D., Glanville, J., Pawson, M. G. & Reynolds, J. D. (2000). Fishery stability, local extinctions and shifts in community structure in skates. *Conservation Biology* **14**, 283–293.
- Dulvy, N. K., Sadovy, I. & Reynolds, D. (2003). Extinctions vulnerability in marine populations. *Fish and Fisheries* **4**, 25–64.
- Ellis, J. R. & Shackley, S. H. (1997). The reproductive biology of *Scyliorhinus canicula* in the Bristol Channel, U. K. *Journal of Fish Biology* **51**, 361–372.
- Ebert, D. A. (2005). Reproductive biology of skates, *Bathyraja* (Ishiyama), along the eastern Bering Sea continental slope. *Journal of Fish Biology* **66**, 618–649. doi:10.1111/j.0022-1112.2005.00628.x
- Ebert, D. A., Compagno, L. J. V. & Cowley, P. D. (2008). Aspects of the reproductive biology of skates (Chondrichthyes: Rajiformes: Rajoidei) from southern Africa. *ICES Journal of Marine Science* **65**, 81–102. doi: 10.1093/icesjms/fsm169
- Frisk, M. G. (2010). Life History Strategies of Batoids. In *Sharks and Their Relatives II: Biodiversity, Adaptive Physiology and Conservation* (Carrier, J. C., Musick, J. A. & Heithaus, M. R., eds), pp. 283–318. Boca Raton, FL: CRC Press.
- Frisk, M. G., Miller, T. J. & Forgarty, M. J., (2001). Estimation and analysis of biological parameters in elasmobranch fishes: a comparative life history study. *Canadian Journal of Fisheries and Aquatic Sciences* **58**, 969–981.
- Fuentealba, M., Leible, M. & Morillas, J. (1990). Histología gonádica de *Raja (Dipturus) flavirostris* Philippi 1892 (Pisces: Chondrichthyes). *Estudios Oceanológicos* **9**, 57–62.
- García, M. L. (1984). Sobre la biología de *Discopyge tschudii* (Chondrichthyes, Narcinidae). *Physis (Buenos Aires)* **103**, 101–112.
- Girard, M. & Du Buit, M. H. (1999). Reproductive biology of two deep-water sharks from the British Isles, *Centroscymnus coelolepis* and *Centrophorus squamosus* (Chondrichthyes: Squalidae). *Journal of the Marine Biological Association of the United Kingdom* **79**, 923–931.
- Hamlett, W. C. & Koob, T. J. (1999). Female reproductive system. In *Sharks, Skates and Rays: The Biology of Elasmobranch Fishes* (Hamlett, W. C., ed.), pp. 398–443. Baltimore, MD: Johns Hopkins University Press.
- Hammer, Ø., Harper, D. A. T. & Ryan, P. D. (2001). PAST: Paleontological Statistics Software Package for Education and Data Analysis. *Palaeontologia Electronica* **4**, 1–9.
- Holden, M. J. (1977). Elasmobranchs. In *Fish Population Dynamics* (Gulland, J. A., ed.), pp. 187–216. London: John Wiley Press.
- Hubbs, C. N. & Ishiyama, R. (1968). Methods for the taxonomic study and description of skates (Rajidae). *Copeia* **1968**, 483–491.
- Iglésias, S., Toulhoat, L. & Sellos, D. Y. (2009). Taxonomic confusion and market mislabeling of threatened skates: important consequences for their conservation status. *Aquatic Conservation: Marine and Freshwater Ecosystems* **20**, 319–333. doi: 10.1002/aqc.1083
- Jennings, S., Greenstreet, S. P. R. & Reynolds, J. D. (1999). Structural change in an exploited fish community: a consequence of differential fishing effects on species with contrasting life histories. *Journal of Animal Ecology* **68**, 617–627.
- Kyne, P. M., Courtney, A. J. & Bennett, M. B. (2008). Aspects of the reproduction and diet of the Australian endemic skate *Dipturus polyommata* (Ogilby) (Elasmobranchii: Rajidae), by-catch of a commercial prawn trawl fishery. *Journal of Fish Biology* **72**, 61–77. doi: 10.1111/j.1095-8649.2007.01655.x

- Lamilla, J., Pequeño, G. & Figueroa, H. (1984). Aspectos biológicos de *Psammobatis lima*, Poeyppig, 1835, en el litoral de Valdivia, Chile (Elasmobranchii, Rajidae). *Revista de la Comisión Permanente del Pacífico Sur* **14**, 183–209.
- Last P. R., White, W. T., Pogonoski, J. & Gledhill, D. C. (2008). New Australian skates (Batoidea: Rajoidea): background and methodology. In *Descriptions of New Australian Skates (Batoidea: Rajoidea)* (Last, P. R., White, W. T., Pogonoski, J. & Gledhill, D. C., eds), pp. 1–8. Hobart: CSIRO Marine and Atmospheric Research.
- Licandeo, R. R., Lamilla, J. G., Rubilar, P. G. & Vega, R. M. (2006). Age, growth, and sexual maturity of the yellownose skate *Dipturus chilensis* in the south-eastern Pacific. *Journal of Fish Biology* **68**, 488–506. doi: 10.1111/j.0022-1112.2006.00936.x
- Mabragaña, E., Lucifora, L. O. & Massa, A. M. (2002). The reproductive ecology and abundance of *Sympterygia bonapartii* endemic to the south-west Atlantic. *Journal of Fish Biology* **60**, 951–967. doi: 10.1006/jfbi.2002.190
- Martin, L. K. & Cailliet, G. M. (1988). Aspects of the reproduction of the Bat Ray, *Myliobatis californica*, in Central California. *Copeia* **1988**, 754–762.
- Massa, A. M. & Hozbor, N. M. (2003). Peces cartilagosos de la plataforma argentina: explotación, situación y necesidades para un manejo pesquero adecuado. *Revista del Frente Marítimo* **19**, 199–206.
- Menni, R. & López, H. (1984). Distributional patterns of Argentine marine fishes. *Physis (Buenos Aires)* **42**, 71–85.
- Mollet, H. F., Cliff, G., Pratt, H. L. Jr. & Stevens, J. D. (2000). Reproductive biology of the female shortfin mako, *Isurus oxyrinchus* Rafinesque, 1810, with comments on the embryonic development of lamnoids. *Fishery Bulletin* **98**, 299–318.
- Musick, J. A. & Ellis, J. K. (2005). Reproductive evolution of Chondrichthyans. In *Reproductive Biology and Phylogeny of Chondrichthyes: Sharks, Batoids, and Chimaeras* (Hamlett, W. C., ed.), pp. 45–79. Plymouth: Science Publishers.
- Oddone, M. C. & Velasco, G. (2006). Relationship between liver weight, body size and reproductive activity in *Atlantoraja cyclophora* (Elasmobranchii: Rajidae: Arhynchobatinae) in oceanic waters off Rio Grande do Sul, Brazil. *Neotropical Biology and Conservation* **1**, 12–16.
- Oddone, M. C., Paesch, L. & Norbis, W. (2005). Size at first sexual maturity of two species of rajoid skates, genera *Atlantoraja* and *Dipturus* (Pisces, Elasmobranchii, Rajidae), from the south-western Atlantic Ocean. *Journal of Applied Ichthyology* **21**, 70–72. doi: 10.1111/j.1439-0426.2004.00597.x
- Oddone, M. C., Amorim, A. F., Mancini, P. L., Norbis, W. & Velasco, G. (2007). The reproductive biology of *Rioraja agassizi* (Müller and Henle, 1841) (Chondrichthyes: Rajidae) in southeastern Brazil, SE Atlantic Ocean. *Scientia Marina* **71**, 593–604.
- Paesch, L. & Oddone, M. C. (2008). Change in size-at-maturity of the yellownose skate *Dipturus chilensis* (Guichenot, 1848) (Elasmobranchii: Rajidae) in the SW Atlantic. *Neotropical Ichthyology* **6**, 223–230. doi: 10.1590/S1679-62252008000200009
- Pequeño, G., Navarro, R. & Oporto, J. (1988). *Discopyge tschudii* Heckel 1845: Aporte a su taxonomía con hincapié en su dimorfismo sexual (Chondrichthyes, Narcinidae). *Estudios Oceanológicos* **7**, 41–50.
- Quiroz, J. C., Wiff, R. & Céspedes, R. (2009). Reproduction and population aspects of the yellownose skate, *Dipturus chilensis* (Pisces, Elasmobranchii: Rajidae), from southern Chile. *Journal of Applied Ichthyology* **25**, 72–77. doi: 10.1111/j.1439-0426.2007.00914.x
- Quiroz, J. C., Wiff, R., Cubillos, L. A. & Barrientos, M. A. (2011). Vulnerability to exploitation of the yellownose skate (*Dipturus chilensis*) off southern Chile. *Fisheries Research* **109**, 225–233. doi: 10.1016/j.fishres.2011.01.006
- Restrepo, V. R. & Watson, R. A. (1991). An approach to modelling crustacean egg-bearing fractions as function of size and season. *Canadian Journal of Fisheries and Aquatic Sciences* **48**, 1431–1436.
- Roberts, C. M. & Hawkins, J. P. (1999). Extinction risk in the sea. *Trends in Ecology and Evolution* **14**, 241–246. doi:10.1016/S0169-5347(98)01584-5
- Ruocco, N. L., Lucifora, L. O., Diaz de Astarloa, J. M. & Wohler, O. (2006). Reproductive biology and distribution of the white-dotted skate, *Bathyraja albomaculata*, in the

- southwest Atlantic. *ICES Journal of Marine Science* **63**, 105–116. doi: 10.1016/j.icesjms.2005.08.007
- SERNAP (2007). *Anuario Estadístico de Pesca. Servicio Nacional de Pesca*. Santiago: Ministerio de Economía, Fomento y Reconstrucción.
- SERNAP (2009). *Anuario Estadístico de Pesca. Servicio Nacional de Pesca*. Santiago: Ministerio de Economía, Fomento y Reconstrucción.
- Smith, J. W. & Merriner, J. M. (1986). Observations on the reproductive biology of the Cownose ray, *Rhynoptera bonasus*, in Chesapeake Bay. *Fishery Bulletin* **84**, 871–877.
- Sokal, R. R. & Rohlf, F. J. (1987). *Introduction to Biostatistics*, 2nd edn. New York, NY: W. H. Freeman Press.
- Sosebee, K. A. (2005). Maturity of skates in northeast United States waters. *Journal of Northwest Atlantic Fisheries Science* **35**, 141–153. doi:10.2960/J.v35.m49
- Stevens, J. D., Bonfil, R., Dulvy, N. K. & Walker, P. A. (2000). The effects of fishing on shark, rays, and chimaeras (Chondrichthyans), and the implications for marine ecosystems. *ICES Journal of Marine Sciences* **57**, 476–494. doi: 10.1006/jmsc.2000.0724
- Walker, P. A. & Hislop, J. R. G. (1998). Sensitive skates or resilient rays? Spatial and temporal shifts in ray species composition in the central and north-western North Sea between 1930 and the present day. *ICES Journal of Marine Science* **55**, 392–402. doi: 10.1006/jmsc.1997.0325
- Wetherbee, B. M. (1996). Distribution and reproduction of the southern lantern shark from New Zealand. *Journal of Fish Biology* **49**, 1186–1196. doi: 10.1111/j.1095-8649.1996.tb01788.x

### Electronic References

- Gálvez, M., Sepúlveda, A., Díaz, C., Miranda, L., Rebolledo, H. & Cuevas, C. (1998). Biomasa estacional de merluza común por área barrida por la flota industrial pesquera en la zona centro-sur. *Instituto de Investigación Pesquera VIII Región Informe técnico No. 96–33*, Concepción: INPESCA. Available at [http://www.fip.cl/prog\\_x\\_year/1996/9633.htm/](http://www.fip.cl/prog_x_year/1996/9633.htm/) (accessed 1 May 2011).
- Lamilla, J., Acuña, E., Araya, M., Oliva, M., Kong, I., Villaroel, J. C., Hernández, S., Concha, F., Vögler, R., Bustamante, C. & Mutche, E. (2005). Lineamientos básicos para desarrollar el Plan de Acción Nacional de Tiburones. *Universidad Austral de Chile Informe técnico No. 2004–18*, Valdivia. Available at <http://www.fip.cl/proyectos/2004/2004-18.htm/> (accessed 1 May 2011).