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Fisheries Biology of the Undulate Ray, *Raja undulata*, in the Algarve (Southern Portugal)

(Elasmobranch Fisheries – Poster)

by

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Abstract

The population dynamics of the undulate ray, *Raja undulata*, one of the most important elasmobranch fishes captured along the Portuguese south coast (Algarve), was studied. Cedar wood oil immersion and alizarin red S techniques were used to enhance vertebral growth bands and estimate age. The parameters of the Von Bertalanffy growth function were estimated and no differences between males and females were found. The estimated parameters for all data were: L_{inf} = 110.22, K = 0.11 and t_0 = -1.58. Evidence of an annual deposition pattern of a pair of bands (one opaque and one hyaline) was found by marginal increment analyses. The total mortality rate for age classes fully recruited to a trammel net fishery was estimated to be 0.469. Natural mortality rate varied between 0.200 and 0.219 and fishing mortality rate varied between 0.250 and 0.269, depending on the method used to estimate natural mortality. The parameters estimated in this study will be useful for evaluating the state of the stock and assessing risk.

Introduction

Due to their characteristic slow growth rates (Martin and Cailliet, 1988), low fecundity with delayed reproductive effort, geared towards the production of small numbers of progeny (Kusher *et al*., 1992) after a long gestation period (Smale and Goosen, 1999) elasmobranch fishes are highly susceptible to overexploitation.

In Portugal, particularly in the Algarve, catches of rays have been decreasing considerably in recent years. This reduction in the catches has been followed by an increase in commercial value. More specifically, in the last 10 years the catches of rays have decreased more than 46% at a national level and 42% in the Algarve (Fig. 1), while their commercial value has increased 75% at a national level and 71% in the Algarve (DGPA, 2000). In a trammel net fishery study that occurred in the Algarve during the year 2000, elasmobranch fishes accounted for 3.6% of the total catches in numbers, with rays representing 76.0% of these elasmobranch fishes. A total of 516 Kg of *Raja undulata* were caught, accounting for 8% of the total catch in weight. (Erzini *et al*., 2001).

The knowledge of population dynamics parameters such as the age structure of the population, growth and mortality rates is essential for the assessment and evaluation of the state of the stocks and the determination of current, optimum and maximum exploitation rates. With the assessment and evaluation of the undulate ray population, *Raja undulata*, in Algarve waters as the final objective, population dynamics parameters such as growth and mortality rates were estimated for fish caught mainly in a trammel net fishery.

Material and Methods

Specimens for biological sampling were collected between October 1999 and February 2001 from a commercial fishing vessels operating with trammel nets along the Algarve (Fig. 2). A total of 238 individuals were caught and measured on board for total length (TL, cm) and a selection of 97 taken to the laboratory for age determination. This sub sample for age estimation was completed in terms of length frequencies with 14 specimens caught with beach seines and 76 acquired in the local fish markets, having made sure that they came fromthe same fishing area.

Vertebrae were cleaned according to the methodology proposed by Cailliet *et al*. (1983). Preliminary tests were conducted and the most efficient band enhancing techniques proved to be the cedar wood oil immersion (Cailliet *et al*., 1983) and the alizarin red S dye (LaMarca, 1966). Each vertebra was observed by one reader on three separate occasions, temporarily spaced by a minimum of 30 days. A valid age was only considered if the same reading was attributed at least twice. Age length keys were built and t-student tests used to compare mean lengths-at-age between sexes.

Age validation was accomplished by marginal increment analysis. A linear relationship between the vertebral radius along the growth bands deposition plane (VR) and the individual length (in this case TL) was established. The vertebrae edge of a minimum of 10 animals per month was analyzed and classified as opaque or hyaline (Tanaka and Mizue, 1979)

The von Bertalanffy growth function was fitted to the length-at-age data, with growth parameters estimated by the non-linear least squares method (NLIN procedure in SAS (1988)). Individual ages were corrected taking into account the birth date, assumed to be 1^{st} January, and the date of capture. This methodology allowed the variability, associated with having a large sampling period, to be minimized. Male and female growth parameters were compared using the maximum likelihood test.

The age composition of the total trammel net catch (n=238) was estimated by applying the age length key to the catch length distribution. Following Clark (1983), restricted least-squares estimates were obtained by minimizing the following criterion:

$$\sum_i (\hat{p}_i - \tilde{p}_i)^2$$

where $\hat{p}$ = Xp, $\tilde{p}$ is the length distribution of the catch, X a matrix whose columns represent the relative length distributions of the age classes and p is a vector of the estimated age structure in proportions. Non-linear optimisation (PROC NLP procedure in the SAS (1988) system) was used to estimate the age elements of p (Hartman, no date).

The estimated age structure of the catch was used to estimate the instantaneous total mortality rate (Z) by the catch curve method (Sparre *et al*., 1989). Natural mortality rate (M) was estimated using the empirical models developed by Pauly (1980) using 175 stocks of fish and Djabali *et al*. (1994) for Mediterranean species. Longevity was calculated by the Alagaraja (1984) equation. The instantaneous fishing mortality rate (F) was estimated as the difference between Z and M.

Results

The majority of the specimens selected for age determination (n=187) were successfully aged, since agreement was not achieved in only 5 individuals (2.7%). The sub-sample consisted of 14 age classes (ages 0 to 13). The best represented age classes were between ages 3 and 8 (76.4%). Some overlapping of the lengths-at-age distributions was apparent, especially for older age classes. It was possible to observe that growth was more accelerated in the first years of life, and this was reflected in the higher growth increments of the younger age classes. These length increments decreased progressively for older age classes (Table 1).

A comparison of the mean lengths-at-age of males and females showed significant differences only for age classes 1 and 8 (*t-test*: $P < 0.05$), and no differences for the other age classes (*t-test*: $P > 0.05$)

A significant linear regression between VR and TL was established (*Anova*: $P<0.01$):

$$TL = 15.127\ VR + 13.154 \quad (r^2 = 0.95,\ n = 107,\ \text{range: } 22.4 \text{ to } 88.2\text{cm TL})$$

Vertebral edge was analyzed in 139 specimens and it was possible to observe that a pair of bands (one opaque and one hyaline band) was deposited annually. The opaque band was deposited mostly during the summer months (April to October) while the hyaline band during the winter (December to March) (Fig. 3).

The estimated von Bertalanffy parameters were:

All data: $L_{inf} = 110.22$, $K = 0.11$ and $t_0 = -1.58$ ($r^2 = 0.99$, range: 19.4 to 88.2cm TL)
Males: $L_{inf} = 112.26$, $K = 0.10$ and $t_0 = -1.23$ ($r^2 = 0.99$ range: 23.0 to 83.2cm TL)
Females: $L_{inf} = 108.81$, $K = 0.11$ and $t_0 = -1.55$ ($r^2 = 0.99$ range: 19.4 to 88.2cm TL)

No significant differences between parameters estimated for males and females were found (*Max likelihood test*: $P > 0.05$).

The regression line fitted to the catch curve (Fig. 4) estimated a total mortality rate of 0.469 year^{-1}. Table 2 presents a summary of the mortality rates and longevity estimates obtained.

Discussion

The most adequate techniques for age determination in *R. undulata* are the cedar wood oil immersion and the coloration with alizarin red S. The cedar wood oil immersion has the additional advantage to be very fast to apply, which makes it suitable to be used on large samples. Both these techniques have been previously used with success in age determination of elasmobranchs. The alizarin red S dye was used by LaMarca (1966) on the sand tiger shark (*Carcharias taurus*), by Moulton *et al*. (1992) on the gummy shark (*Mustelus antarcticus*) and the tope shark (*Galeorhinus galeus*) and by Troynikov and Walker (1999) also on *M. antarcticus*. Regarding the *Raja* genus, it has been used by DuBuit (1972) on the blue skate (*R. batis*) and on the cuckoo ray (*R. naevus*). The cedar wood oil immersion has been previously described by Cailliet *et al*. (1983) and used with success by Martin and Cailliet (1988) on the bat ray (*Myliobatis californica*). Walker *et al*. (1995) performed an extensive comparative analysis between the alizarin red S technique and a new, more elaborate and expensive method, micro radiography. Due to the very slight improvements that the micro radiography technique presented, this author concluded that it was better to perform analyses on large samples with the more easily applicable alizarin red S technique.

The smaller length classes were poorly represented in the sample, despite all efforts to catch juvenile fish. Furthermore, it is probable that the captured age 0 specimens represent the upper length limit of this age class. This may have occurred either because smaller fish are not yet recruited to the fisheries, or because juvenile fish occur in different areas than the ones sampled, possibly nearer to the coast in more shallow and sheltered areas. In fact, although rays and skates are mostly sedentary fishes (Holden, 1994), there is some evidence that juveniles might migrate to nursery areas nearer to the coast (Pawson and Nichols, 1994). This fact was in part confirmed due to most of the smaller specimens being caught by beach seines inside the Ria Formosa coastal lagoon.

The process of age validation is a critical subject in age and growth studies. The determination of the periodicity of the deposition of growth bands is essential in any age and growth study, and we can only model growth once age estimation has been validated. In this study, by the analysis of the band forming on the edge of the vertebrae, we concluded that a pair of bands (one opaque and one hyaline band) is formed each year, with the opaque band deposited mostly during the summer months and the hyaline band during the winter months. This pattern has been described for other elasmobranch species, such as the leopard shark (*Triakis semifasciata*) (Smith, 1984; Kusher *et al*., 1992) and the starspotted smooth hound (*Mustelus manazo*) (Tanaka and Mizue, 1979). Regarding the *Raja* genus, this pattern has been described for the thornback ray (*R. clavata*) the small eyed ray (*R. microocellata*) and the spotted ray (*R. montagui*) by Ryland and Ajayi (1984), for the little skate (*R. erinacea*) by Waring (1984) and for the big skate (*R. binoculata*) and the longnose skate (*R. rhina*) by Zeiner and Wolf (1993).

As is usually the case for most elasmobranch fishes (and most of the *Raja* species as well), the estimated values of K are low, revealing the slow growth rate characteristic of these fishes. The values of t_0 differing considerably from 0, may be due to a poor representativeness of the younger age classes, namely ages 0 and 1.

Waring (1984) calculated the mortality for *Raja erinacea* of the northeast coast of the United States and obtained estimates of Z from 0.54 to 1.76 between 1968 and 1978. Those values are greater than the value of 0.469 estimated in this study. Furthermore, in the present study, the first fully recruited age was 7 years old, while *R.* erinacea fully recruited at 5 years of age. Some studies have been carried out for *R. erinacea* and *R. ocellata* by the Northeast Fisheries Science Center (NEFSC, 2001) and values of F in 1999 were estimated to be 0.34 and 0.39 respectively. Again these values are higher than the ones calculated for *R. undulata* in this study, of 0.25 or 0.27, depending on the value of M assumed.

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TABLE 1. Age-length distributions of *Raja undulata* in the Algarve. TL = total length, n = number of specimens, Av = Average total length, StDev = standard deviation and Incr = increment. All measurements are in cm.

TL (cm)	Age group (year)														n
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	
18	1														1
20															0
22	3														3
24	1														1
26		1													1
28		1													1
30		1													1
32		1													1
34															0
36															0
38			3												3
40			1	3											4
42			3	2											5
44				6											6
46			1	7	3										11
48				3	4										7
50				3	9										12
52				1	7	5									13
54				2	4	3	1								10
56					1	2	2								5
58					1	4	4								9
60						3	5								8
62					1	3	9	1							14
64							2	2							4
66						1	2	5							8
68							4	2	1						7
70							1	1	4						6
72							1	3	2						6
74								1	1	2	2				6
76								2	3	1	2				8
78									2	2	3				7
80										2	2				4
82											3	3	1		7
84													2		2
86															0
88														1	1
n	5	4	8	27	30	21	31	17	13	7	12	3	3	1	182
Av	22.5	29.8	41.9	46.9	52.2	57.9	63.1	69.4	74.2	77.8	79.5	82.5	84.4	88.2	
StDev	1.89	1.87	2.36	3.89	3.45	4.14	4.35	4.31	3.54	2.81	2.91	0.61	1.26		
Incr		7.35	12.08	5.04	5.23	5.76	5.17	6.29	4.78	3.62	1.67	3.03	1.87	3.83	

TABLE 2. Mortality rates, with the respective upper and lower 95 % confidence intervals (CI95%). Natural mortality rate was calculated with the Pauly and the Djabali et al models and the total mortality rate by the catch curve method. It is also included the longevity calculated after the Alagaraja model.

	Natural mortality ($year^{-1}$)			Fishing Mortality ($year^{-1}$)			Total Mortality	Longevity
	Estimate	CI95%(-)	CI95%(+)	Estimate	CI95%(-)	CI95%(+)	($year^{-1}$)	(year)
Pauly (1980)	0.219	0.215	0.223	0.250	0.246	0.254	0.469	21.004
Djabali *et al.* (1994)	0.200	0.196	0.204	0.269	0.265	0.273	0.469	23.062

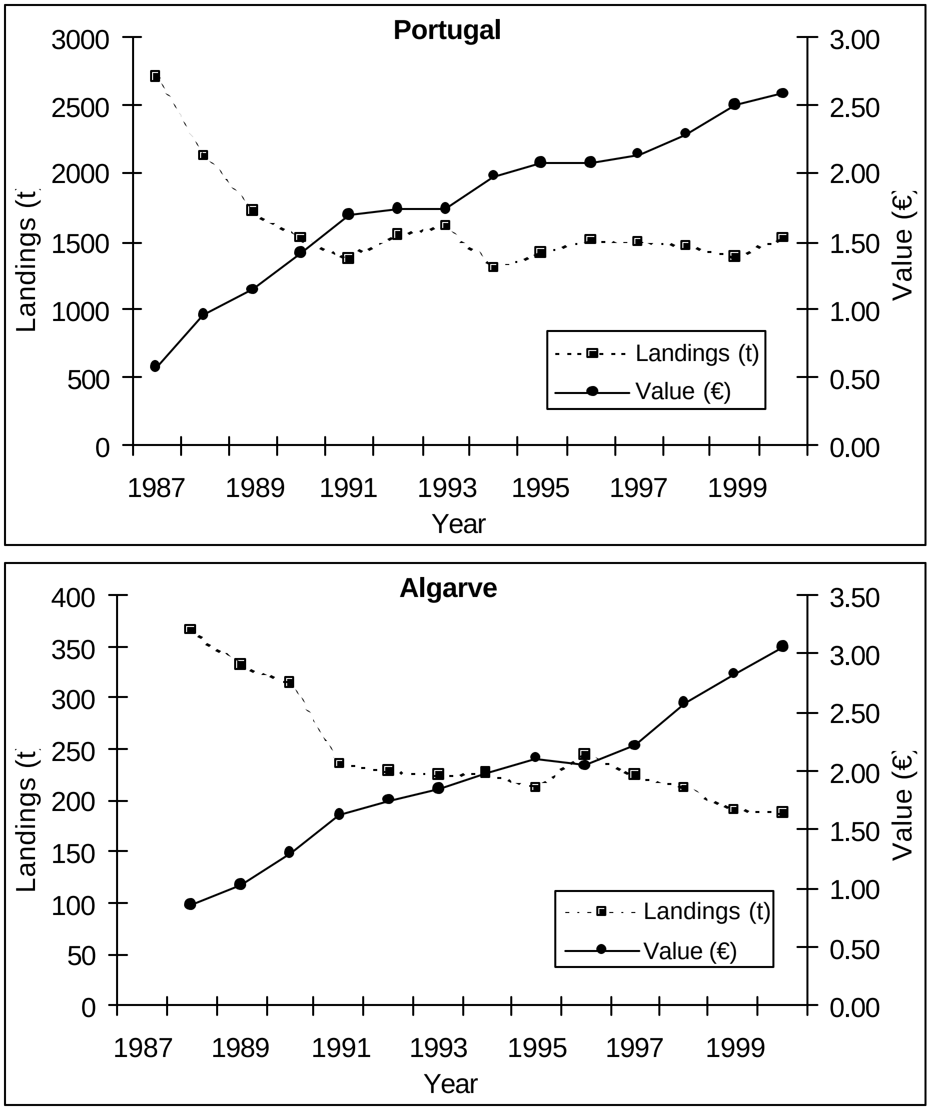

Fig. 1. Landings and commercial value of rays in the last years, both in Portuguese waters and in the Algarve (DGPA, 2000).

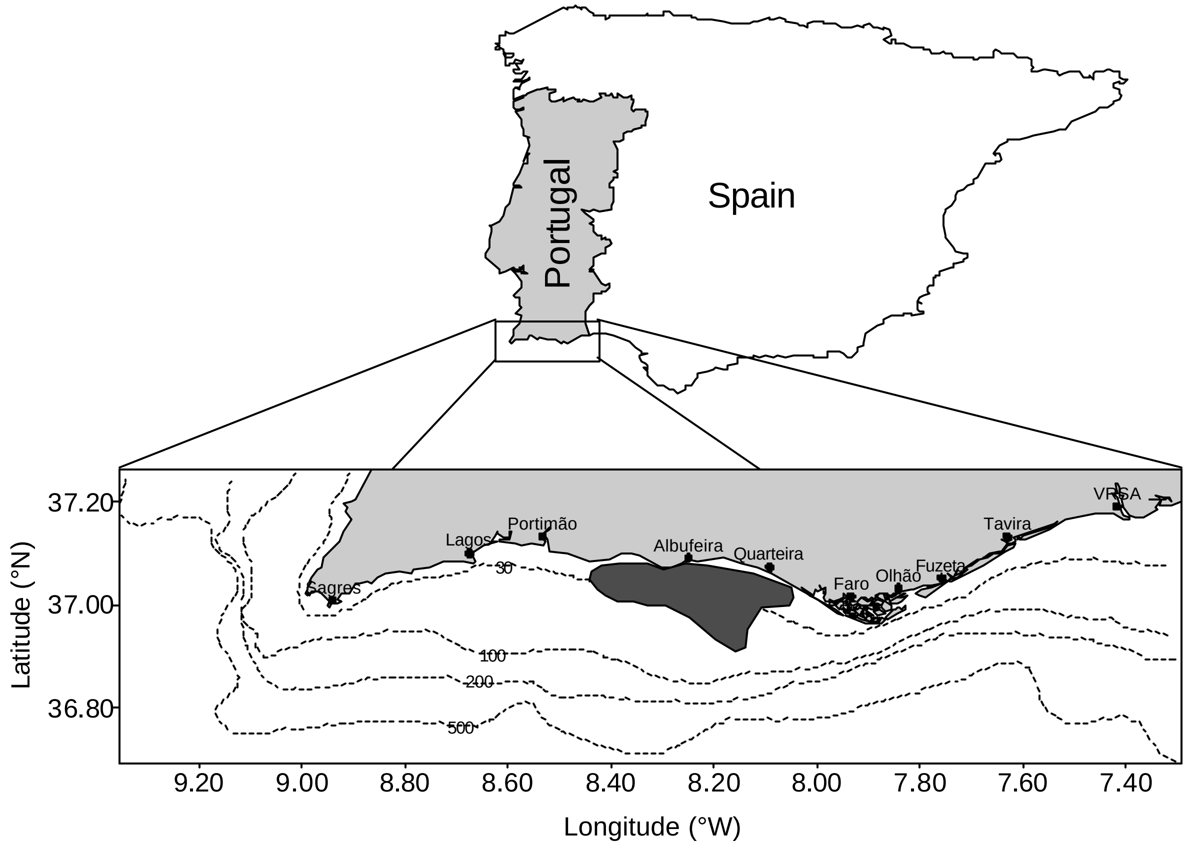

Fig. 2. Map of the Algarve coast with the location of the fishing trials with the trammel nets.

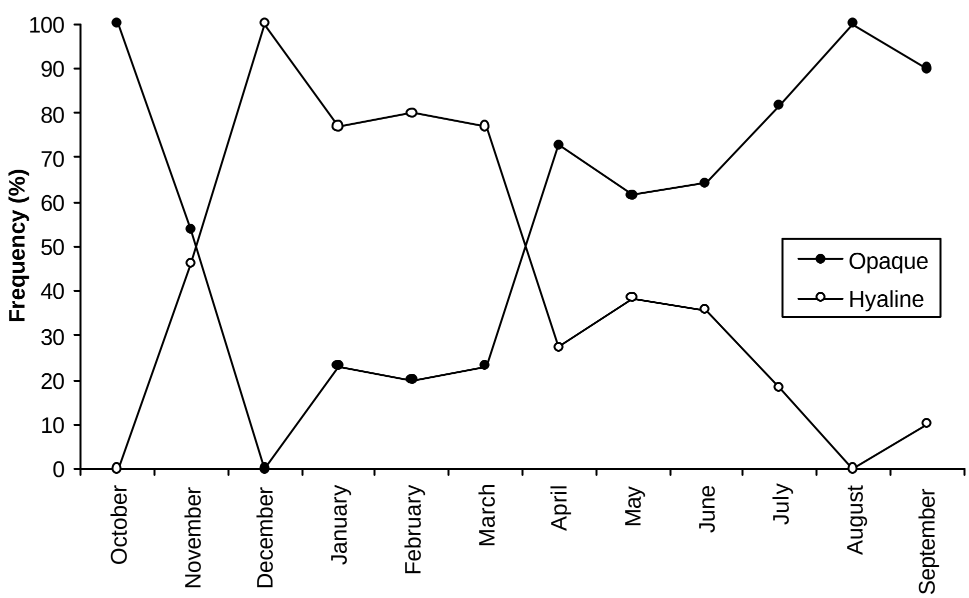

Fig. 3. Relative frequency of vertebrae of *Raja undulata* with opaque and hyaline edges, along a one year period.

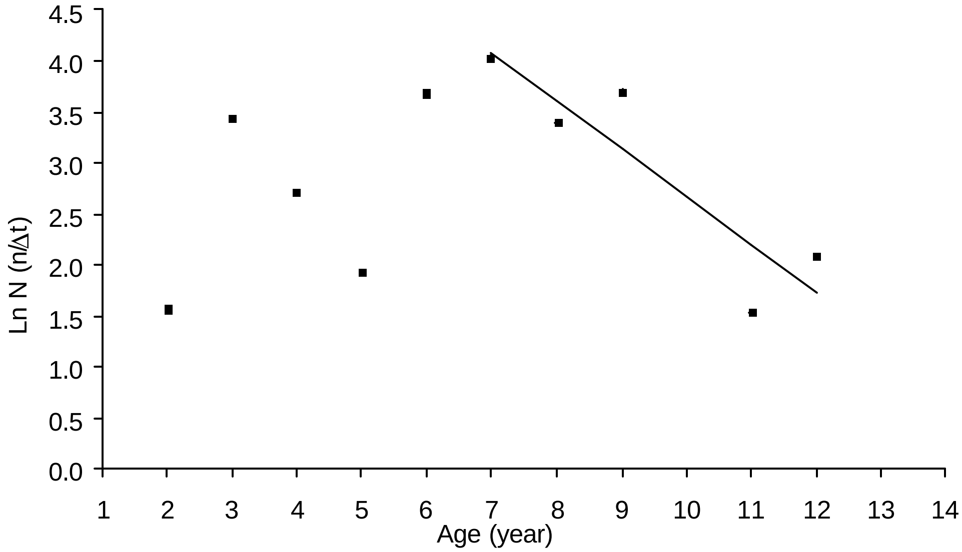

Fig. 4. Age structured catch curve for the estimation of total mortality (Z) for *Raja undulata*, caught with trammel nets along the Algarve.