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RELEASE EXPERIMENTS WITH *OCTOPUS VULGARIS* CUVIER, 1797 IN GALICIA, NW SPAIN. FIRST RESULTS ON RECAPTURE RATE, DISTRIBUTION AND GROWTH

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OCTOPUS VULGARIS
TAGGING
T-BAR ANCHOR TAGS
RELEASE
RECAPTURE RATE
DISTRIBUTION
GROWTH

ABSTRACT. – This paper describes the release experiments carried out with 465 octopus (*Octopus vulgaris* Cuvier, 1797) with an average weight ranging from 703 to 986 g in three different areas in the Ría of Vigo, Galicia, NW Spain. Thirty-seven individuals were recaptured by fishermen, representing a total recapture rate of 7.9 %. Among these, 80.5 % remained within 5 km of the release point, showing a sedentary behavior. The specific growth rate (SGR) in weight was 0.00902 ± 0.00468; there was not a significant difference between males and females. The exponential growth curve is the best fitting theoretical model. Life expectancy in Ría de Vigo waters was estimated at 18 months for males, and 16 months for females. Throughout the recapture process, males were predominant over females, giving a sex ratio of 1.83:1. Data reported in this paper on recapture rate, sedentary behavior and instantaneous growth rate can be used as reference for future stocking programs in Galicia.

INTRODUCTION

Nagasawa *et al*. (1993) provides an excellent compilation of the experiments on marking cephalopods, which include different species of cuttlefish, squid and octopus, in Japanese waters to study their distributive and migratory patterns. However, very few papers deal with *Octopus* species tagging. Hot branding was widely used with *O. vulgaris* caught in the Seto Inland Sea for fishery biological purposes by Inoue *et al*. (1953) and Itami (1964). Katsutami (1968) used colored vinyl tubing sewed to the musculature of the arms and mantle of *O. vulgaris* caught in the same area. *O. vulgaris* injected with trypan blue and/or neutral red were released in southern Tokyo Bay by Tsuchiya *et al*. (1978) to study seasonal migration of this species on basis of recoveries. Domain *et al*. (2000) using Petersen discs studied the growth of *O. vulgaris* following a tag-recapture study in Senegalese waters, similar to the one that Robinson and Hartwick (1986) had carried out with *O. dofleini*.

On previous researches carried out at the Spanish Institute of Oceanography (IEO) in Vigo, Fuentes *et al*. (2000, 2006) analyzed the most adequate type of tag for adults and newly-hatched paralarvae of *O. vulgaris* (Cuvier, 1797), respectively. After having analyzed a wide range of tag types, they concluded that *T-bar anchor tag* and Petersen discs were the most appropriate for subadults tagging. In this work *T-bar anchor tag* was considered to be the most suitable given its higher speed of placement, and less injury produced, when compared with Petersen discs.

Commercial octopus catches have decreased in the last few years in Galicia from 3,885 t in 1999 to 1,987 t in 2009 (Galician Government, 2010). As a result of this catch decrease, the Galician Government has established a recovery plan for *O. vulgaris* suspending temporarily the extractive activities during three months, and establishing a minimum legal capture weight of 1 kg. It is probable that other control measures, such as restocking, will be adopted in the future.

In fact, the Galician authorities have already considered restocking as a means to approach the problem of fisheries reduction in other marine species, such as turbot or lobster. Since 2003, approximately 10,000 turbots have being annually released in the Galician rías, carrying out an exhaustive control of the recaptures afterwards (Mariño *et al*. 2009). Octopus is not among those selected species, since its full life cycle has only been completed at experimental level (Iglesias *et al*. 2004). However, octopus restocking has already been considered in Japanese enhancement programmes (JASFA, Japan Sea-Farming Association; Yashima Station).

The main objective of this research was to carry out a preliminary tagging and release experiment with 465 subadults of *O. vulgaris*, to establish the primary foundations needed for future larger-scale stocking programmes, and also give an insight into the growth of the species in the wild, and observe the migratory patterns of the released individuals in the Galician rías.

MATERIALS AND METHODS

Approximately 500 octopus subadults were captured with the traditional traps employed by fishermen operating in the Ría de Vigo. They were transported to the IEO facilities in 200 L tanks at a maximum density of 60 kg m^{-3}. Octopuses were transferred afterwards to 10,000 L open-circuit tanks, and fed on unfrozen common crab, *Carcinus maenas* Linnaeus, 1758, at a daily ration of 3-5 % of the stocked biomass.

Acclimatization lasted 3 to 4 days, afterwards each octopus was individually weighted with a Mettler balance (0.01 g accuracy) and tagged. Sex and observations such as the lack of arm fragments, presence of arm regenerations, and bruised head or mantle noted were also determined.

T-bar anchor tags (Hallprint® yellow 35 mm flexible T-shaped tags) were used to perform massive markings to 465 octopuses with a tagging gun at an estimated speed of 150 tags per hour. They were subsequently released and monitored in the natural environment.

Tags were placed perpendicularly to the dorsal side and close to the base of the third left arm, avoiding harming suckers (Fuentes *et al*. 2006). Each octopus was later introduced in a rectangular mesh bag, which allows an appropriate handling during transportation, since it prevents from escaping, and also reduces attacking each other.

They were transported in 200 L containers at a maximum density of 30 octopuses per tank, with oxygen-saturated seawater at 11-13 mg L^{-1}. Transportation took 5 to 7 minutes to an oceanographic vessel. During the trip to the release points, which lasted less than one hour, continuous water flow was used.

According to the geographical location and depth, three release points were chosen in the Ría of Vigo (Fig. 1). Point 1 was located at the North East of Cíes Islands (42º13.330 N, 8º55.505 W) 45.5 m depth, was the most oceanic point. The second point, surrounding San Simón Island (42º18.150 N, 8º37.950 W), was the innermost point of the inlet, with depth less than 5 m. A third point was an intermediate zone between these two, located North of Estelas Islands (42º08.745 N, 8º53.202 W) with depths ranging from 21 to 38 m. The most important fishing grounds for this species correspond to the first and the last releasing areas (Cíes and Estelas Islands), while in San Simón captures are rather scarce, given its shallow waters and low salinity.

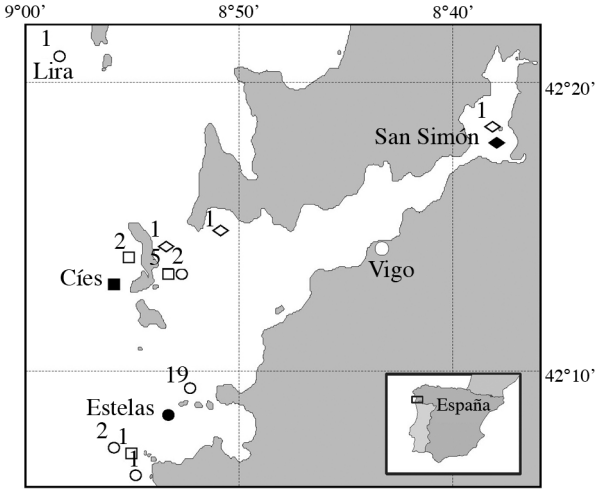

Fig.1. – Location of the *Octopus vulgaris* releasing points (black dots) and recaptures (white dots) in the Ría de Vigo, Galicia, NW Spain: Estelas (circles), Cíes (squares) and San Simón (diamonds).

These areas were chosen in order to verify whether migrations of released individuals occurred in response to changes in food availability, salinity-temperature variations or habitat requirements according to their life cycle (i.e., mating, spawning or egg hatching).

An overview of the conditions of the 9 releases performed from May to August 2001 is presented in Table I. A total of 465 individuals were released, 270 in Estelas area, 109 in the outer face of Cíes Islands and the last 86 in San Simón Bay. Mean weights of released individuals ranged between 703.3 ± 104.1 g and 986.7 ± 269.4 g and the global male:female ratio was 1:1.

Prior to the release, a major information campaign was launched among fishermen associations located in the Ría de Vigo. Posters were distributed showing the type of the tag, its

Table I. – Summary of the tagging experiment of 465 octopus released in the Ría de Vigo, Galicia, NW Spain.

Date of tagging	Date of release	Name	Water temperature (º C)	Individuals released	No. of Males	No. of Females	Ratio M:F	Mean weight ± SD (g)
				Individuals released				
30/05	31/05	Estelas	16.9	50	36	14	2.6:1	857.7 ± 321.9
13/06	14/06	Estelas	15.8	50	21	29	0.7:1	777.7 ± 137.2
20/06	20/06	Estelas	17.5	53	16	34	0.5:1	775.6 ± 154.0
28/06	28/06	Estelas	15.9	69	27	42	0.6:1	785.9 ± 134.0
05/07	09/07	Estelas	16.3	48	18	30	0.6:1	703.0 ± 104.1
11/07	12/07	Cíes	15.2	59	28	31	0.9:1	751.1 ± 118.5
26/07	26/07	S.Simón	18.5	48	28	20	1.4:1	867.3 ± 139.1
02/08	03/08	Cíes	15.8	50	26	24	1.1:1	852.6 ± 127.5
09/08	09/08	S.Simón	19.4	38	21	17	1.2:1	986.7 ± 269.4

Table II. – Summary of the 37 recaptures obtained in the octopus tagging experiment in Galicia.

Release point	Capture area	Absolute migration (km)	No. of individuals	Tag recapture time (days)
Estelas	Estelas	0-1	19	13, 5, 5, 5, 15, 15, 15, 4, 31, 76, 57, 57, 80, 115, 121, 119, 126, 154, 195
	Cíes	9-10	2	19, 118
	Baredo-Baiona	3-4	2	49, 80
	5 miles from Silleiro	12-13	1	140
	Lira	80-85	1	140
Cíes	Cíes	0-2	5	56, 40, 82, 87, 94
	External Cíes	3-4	2	45, 83
	Baredo-Baiona	10-11	1	156
San Simón	Cabalo	2-3	1	2
	Liméns-Barra	18-20	1	189
	Cíes	24-25	1	88

dimensions and instructions were also provided on how to proceed when a marked individual was captured.

Daily growth rate (g day^{-1}) was estimated according to $Wt_2 – Wt_1 / t_2 – t_1$. Where Wt_1 and Wt_2 are the wet weights (g) at times of release and recapture and $(t_2 – t_1)$ corresponds to the time in days elapsed from the release.

Modelling of the data and the calculation of the growth equations in Galician waters were carried out using the method developed by Kaufmann (1981) from tag-recapture experiments. With the data reported by fishermen, of wet weight (g) and sex of recapture individuals and time elapsed from the release, the specific growth rate (SGR) in weight was estimated by the following equation:

$$SGR = (\ln Wt_2 – \ln Wt_1)/(t_2 – t_1)$$

Only positive SGR values were used for data analysis, and recaptures of less than 10 days after release were discarded to allow a minimal time interval necessary for a significant change in weight (Domain *et al*. 2000, Robinson & Hartwick 1986).

Growth rates were compared for males and females analyzing the SGR means and variance by sex (t-test of means).

Representing SGR *versus* mean weight values, the exponential growth equation was selected as the best fit of the observed data (Kaufmann 1981):

$$Wt = \exp(SGR(t + t_0))$$

Where Wt is the wet weight at recaptured (g), t the time (days) and SGR the specific growth rate estimated from recaptures; t_0 was estimated considering a wet weight of 500 g for a 6-month old individual (Iglesias *et al*. 2004); t_1 was estimated from the equation, as Wt_1 is known; and $t_2 = t_1 + \Delta t$; then theoretical Wt_2 was estimated and compared to the observed values following Robinson & Hartwick (1986).

Taking into consideration the maximum weight of the commercial Galician catches (12 kg for males and 8 kg for females) the theoretical longevity of *O. vulgaris* from the Galician rías was finally estimated from this equation.

Even though it is impossible to know the exact track followed by each one of the released individuals, absolute migration of recaptured specimens was estimated according to the straight line vector travelled by the releases. Although this method underestimates the total distance, it has already been employed by other authors and allows comparing distances among recaptures. The distance covered according to the time employed was used to calculate the speed of movements.

RESULTS

The tag-recapture study in the Ría de Vigo yields a total recapture success of 7.9 %. The number of individuals obtained in each area, the range of migration distance (km) and the period of time elapsed since the release, are shown in Table II.

Analyzing recaptures according to the area where the individuals had been released, the following results were observed (Fig. 1):

Estelas Islands area. 26 out of 270 octopus were recaptured, i.e., 9.6 %. The great majority (19 individuals) were captured near the release point (Estelas Islands); two near Cíes Islands and another two more westwards, in Baredo (Baiona). Only two specimens travelled more than 20 km away; one was caught within 5 nautical miles of Silleiro Cape and the other off Carnota coast (Lira, Coruña), covering a linear distance of approximately 85 km in 140 days.

Cíes Islands. In this location, 109 individuals were released; 8 were recaptured (7.3 %) within a 5 km radius of the release point, 5 in the area surrounding Cíes Islands (Punta Príncipe and Punta Agoeira), two more outside Cíes and the last one near Baredo, Baiona.

San Simón Bay. 89 individuals were released in this location, 3 out of which were recaptured, which represented 3.4 %. One of these specimens migrated only 3 km towards the inner part of the Ría and was recaptured in Punta do Cabalo, Vilaboa. The other two migrated more

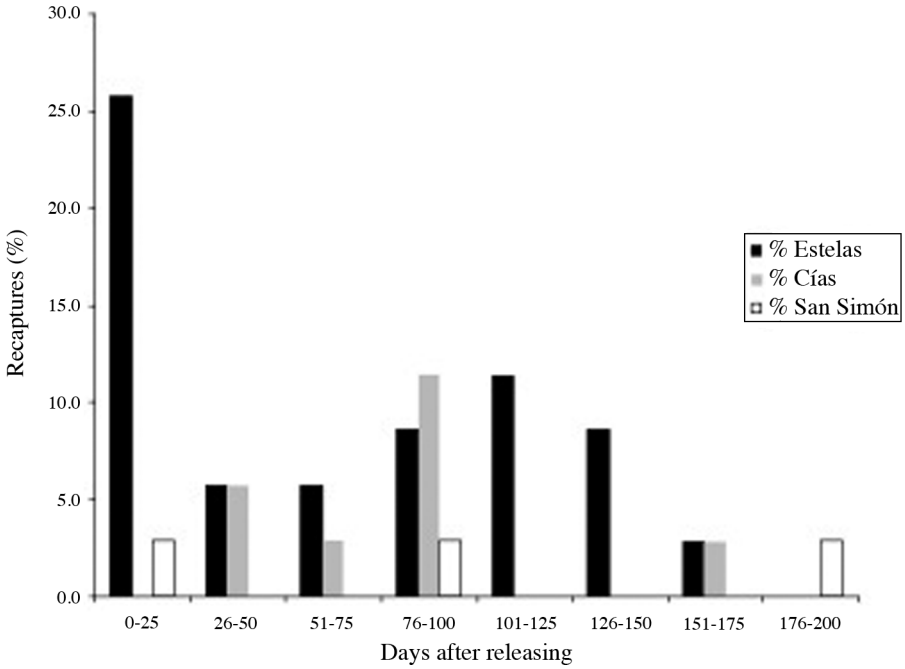

Fig. 2. – Time course of recapture data for *Octopus vulgaris* tagged in Ría de Vigo.

than 25 km towards the outer part of the Ría, one northwards the Ría, in Liméns beach and the other near Punta Príncipe, in Cíes Islands.

The data of distance covered and time elapsed for each recapture is showed in Table II.

80.5 % of recaptured individuals remained resident in a radius of 5 km from the release point, 13.9 % within 5-20 km and only two were recaptured more than 20 km away, at 25 and 85 km, respectively.

The time elapsed between the release and the recapture varies from 2 to 195 days (Fig. 2), observing two ranging modes: one from 0 to 25 days, and another from 75 to 100 days. During the first period, 90 % of the recaptures corresponds to individuals released in Estelas Islands and 10 % to San Simón Bay; and from 75 to 100 days, 50 % of the recaptured individual comes from Cíes Islands; 37.5 % from Estelas and 12.5 % from San Simón Islands.

The highest daily growth rates (g day^{-1}) was 32.9 g, although the most frequent values ranged from 10 to 15 g day^{-1}.

The instantaneous growth rate SGR was 0.00902 ± 0.00468 for all the recaptured specimens, 0.00892 ± 0.00438 for males and 0.00931 ± 0.00555 for females.

After proving that the observed differences were not statistically significant ($P > 0.05$) between SGR values of males and females the exponential growth equation for all of the individuals with no distinction for sex was estimated:

$W_t = \exp(0.00902(t + 507.36))$

Where t_0 was estimated considering a wet weight of 500 g for a 6-month old individual (Iglesias *et al*. 2004).

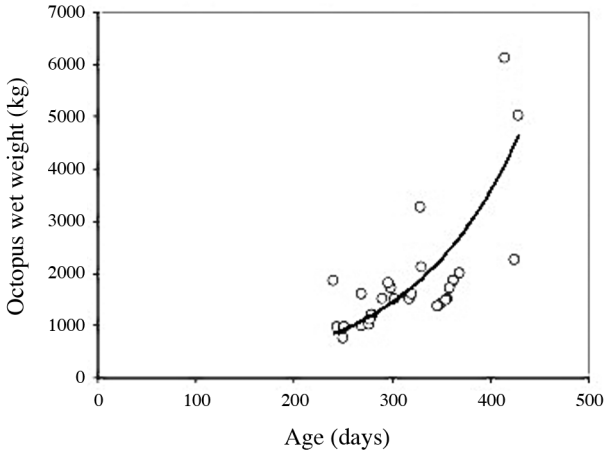

Fig. 3. – Theoretical exponential growth curve of *Octopus vulgaris* in the sea. An "observed value" (white dot) is the weight (g) and age (days) at recapture time.

The theoretical curve of this equation is represented in Fig. 3, where the distribution of the observed values is also shown.

Considering that the maximum weight recorded in the commercial Galician catches of *O. vulgaris* and applying the previous growth equation, the theoretical longevity of *O. vulgaris* in the area was estimated as 18 months for males and 16 for females.

It is interesting to note that the great majority of recaptured specimens were males (22 over 37), which represents a sex ratio of 1.83:1 over the total catch. 100 % of individuals identified by sex recapture in Cíes and San Simón areas were males, and 57 % in Estelas Islands.

DISCUSSION

The major findings of this study: 7.9 % of recapture rate, sedentary behavior within a 5 km radius from the release point, maximum speed of movement of 0.6 km day^{-1} and specific growth rate of 0.00902 in the wild, would be discussed in this section.

Recaptures rate

The global recapture rate of this study, 7.9 %, is in the range of similar experiments with cephalopods cited in the literature. For instance, Inoue *et al*. (1953), studying the fisheries biology of *O. vulgaris*, released 195 hot burn marked octopuses recapturing 21 individuals, which represented a recapture rate of 10.8 %. Itami (1964) released 1559 specimens, using the same mark and recaptured 14 (0.9 %). Katsutami (1968) released 1,001 octopuses with vynil tubes attached to their arms and their inner mantle edge and recaptured 13 individuals (1.3 %). Higher figures are shown by Tsuchiya *et al*. (1987), who marked 1,743 specimens in Tokyo Bay with trypan blue and neutral red, obtaining 486 recaptures, i.e., 27.9 %. More recently, Domain *et al*. (2000) and Caveriviere *et al*. (2001) tagged and released more than 4,000 *O. vulgaris* in Senegalese waters with Petersen discs, obtaining 24 % of recapture rates.

As a conclusion on this topic, the recapture rate of about 8 % can be considered as a reference for a future restocking programme at a larger scale in Galicia. However, next studies with smaller animals should be carried out to reduce cost of raising octopus to the sizes of the present work.

Distribution related to migratory patterns

In terms of distribution, the majority (80.5 %) of octopus shows the typical sedentary behavior patterns of cephalopod, remaining within a radius of 5 km from the releasing point. Exceptionally, one octopus covered a linear distance of 85 km in 140 days; some studies have shown octopus capable of undergoing significant migrations like Itami (1964) who detected that some of the 1,500 released specimens covered a distance of 48 km over a 2-month period.

Tagged individuals released in Cíes and Estelas Islands, where natural population habitually exists, remained resident within the release area, whilst individuals released in the inner part of the Ría de Vigo generally tend to migrate or travel outwards the ría. This migration pattern might have been led by the innate ability of individuals to search for more appropriate conditions (in terms of salinity, temperature or spawning grounds) to develop the critical phases of their life cycle. Such is the case of San Simón releasing area, characterized by its low salinity and shallow waters, not very suitable for *O. vulgaris*. The same migratory trend towards the external area of the rias has also been observed by Iglesias & Rodríguez-Ojea (1994) when turbot *Scophthalmus maximus* Linnaeus, 1758 was released in the same area. The specimen that exceptionally reached Carnota waters (85 km linear distance) might have been propelled by the northward current or water mass flowing parallel to the Galician coast. This Middle North Atlantic Water (MNAW) flows between 100 and 400 m deep in northward direction along the Galician shelf (Frouin *et al*. 1990, Huthnance *et al*. 2002).

Time elapsed since the release

The fact that the first days after release individuals are still concentrated in a short area could explain that a mode of capture occurred between 0 and 25 days after the release. But also some individuals were recaptured 126, 140, 154, 156, and 189 or even 195 days after releasing, which demonstrates the considerable mark persistence and its validity for short life cycle species like octopus.

Speed of movement

The average speed corresponding to the longest distance (85 km in 140 days) was 0.607 km per day, which is in the same order of magnitude as the termohaline circulation (circulation of deep water masses) with values of 1 cm s^{-1} (i.e., 0.864 km day^{-1}). This supports the hypothesis that MNAW northward direction along the Galician platform could have been responsible for the high speed and for the final location observed in this individual. However the specimen that migrated from San Simón to Cíes showed a daily average speed of 0.284 km. Evidently, octopuses do not have the same swimming ability as the teuthoids or sepioids mentioned above. According to the observations performed by Altman (1967) and Kayes (1974) in the natural environment, *O. vulgaris* usually remains for a long period of time inside its cave or shelter, swimming short distances during the day, and travelling longer distances in the nightime. During spawning, short movements towards the coast have also been observed by Mangold-Wirz (1963).

Growth

Growth values in octopus in the natural environment obtained from this research were between 10 and 15 g per day^{-1}, remaining below the values obtained in previous experiments carried out under culture conditions, ranging from 20.5 to 33.2 g per day^{-1} in tanks (Iglesias *et al*. 1997), and 16.7 g per day^{-1} in floating cages (Rey-Méndez 1998).

The specific growth rate obtained in this experience (0.00902 ± 0.00468) lies within the margins of the values registered by other authors in previous experiments. Thus, Domain *et al*. (2000) gave a SGR of 0.0096 (N = 71) and

0.0130 (N = 564) for *O. vulgaris* in Senegal coast. Smale & Buchan (1981) report values from 0.0064 to 0.0208 at higher temperature. Cagnetta & Sublimi (1999) report values of 0.0107 when fed on fish monodiet; 0.0172 if on crab monodiet, and 0.0177 with tattler fish. Rodríguez & Carrasco (1999) obtained 0.0130 after 5 months at 11-18º C feeding the octopuses with crustaceans, fish and mussels. Iglesias *et al*. (2000) obtain 0.0077 and 0.0095 with specimens of an average weight of 873 and 883 g at a temperature between 13 and 16º C; and finally, Oltra *et al*. (2004) 0.0138 and 0.0169 with specimens of 532 and 783 g, respectively. The variation between SGR results might be due to initial body weight, food provided (in laboratory studies) and temperature.

SGR rate of males and females were not significantly different in our data. Pereiro & Bravo de La Laguna (1981) found that males growth is faster than females after 1.5 year, however Domain *et al*. (2000) and Smale & Buchan (1981) said than females growth is faster than males on the African coast.

Longevity estimations of this paper (18 months for males and 16 months for females) fit with previous data of Domain *et al*. (2000) who estimated from the exponential equation a period of 18-20 months for males of 6-8 kg and 14-17 months for females of 5 kg on Senegalese coast. Smale & Buchan (1981) give a lower longevity of 12-15 months for males and 9-12 for females, for *O. vulgaris* from South Africa coast. These results from tag-recapture experiments differ with those obtained for the wild population by indirect methods; i.e., Pereiro & Bravo de La Laguna (1981) & Guerra (1979) applying the asymptotic von Bertalanffy model found larger individuals of 24 months or even more.

Mangold-Wirz (1963) expressed doubts about the application of indirect methods to study growth of octopus and, in consequence, we propose that more research on growth of the wild population of *O. vulgaris* is needed.

Sex ratio. Biological meaning

The fact that most octopuses recaptured were male, even though the sex ratio at releasing was 1:1, could be explained by the seasonal period of the release, which was carried out between May 30th and August 9th 2001; and recaptures took place between June 2001 and January 2002. The long spawning season of this species in Galicia (approximately March to September; Mangold-Wirg 1963 & Guerra 1975) and the female post-laying behavior can explain the low proportion of females in the recaptures; females might have occupied sheltered areas quickly after release to lay their eggs, reducing the accessibility to fishing. Another cause of the lack of females in the recaptures could be explained by the massive mortality of females when individuals are bigger than 15-19 cm (1-1.5 years) cited by Cort & Pérez-Gándaras (1973) in the wild population of the Saharian bank-coast.

Most ecological studies based on tag-recapture experiments with cephalopods have only focused on migration and distribution patterns. Nagasawa *et al*. (1993) offer some other ecological aspects of the squid *Todarodes pacificus*, such as migration, migration speed, identification of population, age and growth. In combination with estimations of fishing effort data obtained from recapture rates, they also analyze the possible application of such knowledge to stock management purposes.

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