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Mark–recapture investigation on *Octopus vulgaris* specimens in an area of the central western Mediterranean Sea

MARCO MEREU, BLONDINE AGUS, RITA CANNAS, ALESSANDRO CAU, ELISABETTA COLUCCIA AND DANILA CUCCU

Dipartimento di Scienze della Vita e dell'Ambiente, Università di Cagliari, Via T. Fiorelli, 1 - 09126 Cagliari, Italy

T-bar anchor tags and Petersen discs were used during a preliminary mark–recapture experiment in the wild on 268 *Octopus vulgaris*. Discs, despite causing some injuries, were characterized by a quicker healing (within 5 days) and a higher retention rate than T-bar tags (about 97% versus 22%, respectively), therefore they were considered the best technique for tagging the animals in the subsequent growth studies. From 2010 to 2013, a total of 1604 *O. vulgaris* (74.4% with a total weight <300 g) were tagged with discs and released in an area of the central western Sardinian Sea (western Mediterranean Sea). Ninety-one specimens were recaptured after 4–63 days of freedom, 59 of which (31 males and 28 females) showed positive growth increments after a minimum time of 8 days at liberty. In general, a high individual variability (0.96–9.09 g day^1) and higher mean daily growth rates in females (3.07–3.65 g day^1) than in males (2.08–2.98 g day^1) were recorded, but this difference was not statistically significant. Using tag–recapture data, the first exponential growth curves for both sexes of *Octopus vulgaris* of small–medium size from the Mediterranean Sea were obtained, and compared with those available in the literature for the species.

Keywords: *Octopus vulgaris*, tagging, growth, growth curves, Mediterranean Sea

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INTRODUCTION

The common octopus (*Octopus vulgaris* Cuvier, 1797) is the most important octopus species caught in the world (Guerra, 1997).

In recent years a decline of this species has been estimated worldwide (FAO, 2006, 2013) highlighting the need to develop an eco-sustainable fishery management approach. In this view, age and growth studies of wild populations are essential for assessment and management purposes (Perales-Raya *et al.*, 2014). While indirect ageing methods are generally considered not applicable for cephalopods (Semmens *et al.*, 2004), different direct methods have been applied with *Octopus vulgaris*, based on the analysis of stylets (Barratt & Allcock, 2010; Hermosilla *et al.*, 2010), eye lens (Gonçalves, 1993) and beaks (e.g. Canali *et al.*, 2011; Cuccu *et al.*, 2013a; Perales-Raya *et al.*, 2014). In addition, many studies have been carried out in captivity (e.g. Mangold & Boletzky, 1973; Smale & Buchan, 1981; Villanueva, 1995) but only a few mark–recapture studies have been performed in the wild (Nagasawa *et al.*, 1993; Domain *et al.*, 2000; Mereu *et al.*, 2010). Mark–recapture studies on octopus are rare due to the low retention rate of traditional tags and for the difficulty in tagging juveniles and then following them for the entire life cycle (Semmens *et al.*, 2004).

Corresponding author:
D. Cuccu
Email: cuccu@unica.it

Numerous tests in tanks, conducted to identify the appropriate tag for *O. vulgaris*, have shown that only Petersen discs and T-bar anchor tags, inserted at the base of the third left arm, can ensure satisfactory results (Taki, 1941; Inoue *et al.*, 1953; Katayama & Morita, 1960; Domain *et al.*, 2000; Fuentes *et al.*, 2006).

Until now, growth parameters using mark–recapture methodology have been estimated only for octopus specimens from Senegalese waters (Domain *et al.*, 2000), whilst for the Mediterranean Sea, a unique mark–recapture preliminary experiment has been carried out in Sardinian waters (Mereu *et al.*, 2010). The main goals of the present paper were dual: to identify the most appropriate external tagging technique for octopus between Petersen discs and T-bars, and to estimate growth parameters for small- to medium-sized *Octopus vulgaris* in the Mediterranean Sea using, for the first time, mark–recapture data collected in the wild.

MATERIALS AND METHODS

A wide tag–recapture project focused on *Octopus vulgaris* was carried out in Sardinia from 2008 to 2013 in an area of the central western Sardinian Sea (western Mediterranean Sea) (Figure 1). It was funded by the local regional administration and realized with the strict collaboration of researchers and fishermen. All the investigated animals were caught during the commercial octopus-fisheries season by traps, performed in spring–summer by two vessels at depths from 20 to 50 m.

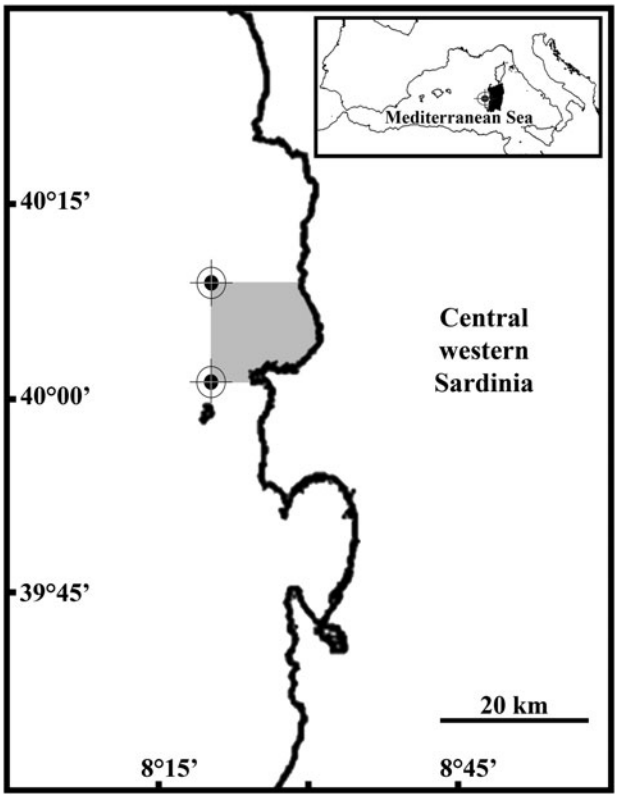

Fig. 1. Area of the mark–recapture investigation.

In order to identify the most suitable tag for *Octopus vulgaris* to be used in tag–recapture experiments, both Petersen discs and T-bar anchor tags were tested in a preliminary phase.

The Petersen discs (SCUBLA SNC; colour discs: yellow and white) consisted of two numbered discs (8 mm) joined by a nickel pin (76 mm), which can pierce any part of the body. Two other transparent discs of the same diameter reinforced both discs; the insertion of the tag was completely manual.

The T-bar anchor tags (Hallprint®; T-bar anchor tags – type TBA) were pieces of flexible T-shaped plastic. The short bar of the T (10 mm) was inserted into the animal's body and the longer bar (30 mm, white) bore an inscription that included the tag number, address and telephone number of the research institute. This tag was inserted with a gun produced by the same company.

Tagging and measurements were made on board the fishing vessels. Recaptures were obtained by the commercial fishery. In order to increase the success of the recaptures some posters describing the project were distributed and positioned in the recreational areas of the western Sardinian ports, and a reward was offered for each recapture returned.

In a preliminary phase from May to November 2008, 268 animals were tagged after having been anaesthetized according to Fuentes *et al.* (2006) by immersion for 5 min in cold seawater (4–5°C), with the addition of a few drops of ethyl alcohol.

Petersen discs and T-bars were both applied at the base of the third left arm, in agreement with Domain *et al.* (2000) and Fuentes *et al.* (2006). After the tagging, dorsal mantle length (ML, to the nearest mm), total weight (TW, to the nearest 1 g) and sex were recorded. Afterwards, the animals were maintained for about 1 h in a tank (with running seawater and an oxygenator) to monitor mortality and tag retention before they were released into the same fishing areas (Figure 1). For each recaptured specimen, ML, TW and the tag status (intact: tag in good condition with an identifiable code; damaged: tag broken, with code not identifiable; lost: absence of tag) were recorded; injuries produced by the tag and the healing process were also examined and annotated.

Handling and holding of animals took into account the ethical and welfare considerations reported by Moltschaniwskyj *et al.* (2007).

From 2010 to 2013, a total of 1604 *Octopus vulgaris* were tagged with Petersen discs on the third left arm following the same procedure used in the preliminary phase of the experiment, also for anesthetization, measurements and checking on recaptured specimens.

The recapture rates (RR) were calculated as the percentage of the number of recaptured specimens with respect to the total number of tagged animals.

The daily growth rates (DGR), expressed in g day^{-1}, were calculated as:

$$DGR = (TW_{T2} - TW_{T1})/DF$$

where TW_{T1} and TW_{T2} were the weights at the tagging and recapture times, respectively, and DF (days of freedom) was the interval in days between the two weighings.

The method developed by Kaufmann (1981) was used to analyse and adjust the models for growth curves from the capture–recapture data, as already used in other studies for the same species (Domain *et al.*, 2000) and for *Octopus dofleini* (Robinson & Hartwick, 1986). In order to determine the parameters of the growth curves, and to choose between different types of curves, instantaneous relative growth rates *G* were estimated by the equation:

$$G = (\ln TW_{T2} - \ln TW_{T1})/DF$$

The graphic representation of *G* values distribution compared with the corresponding mean weight values for the considered interval DF (i.e. the geometric mean of the weight TW_{T1} and TW_{T2}), enable the rapid determination of whether there is a relationship between the size and the growth rate. If no significant relationship exists, the growth equation is exponential and the mean of *G* is calculated and used as the only parameter needed for growth adjustment. Otherwise, the nature of the relationship is further explored to determine another type of growth curve (Domain *et al.*, 2000).

Only recaptures with positive *G* after at least 8 DF were used to calculate growth parameters, considering this is the time of healing of the wound caused by the tag insertion observed during the preliminary experiment, and this is the shortest time period in which we have observed changes in weight. For both sexes, *G*s obtained in the different years were compared with the ANOVA analysis; values of the different years were combined to create the growth curves. For each sex and for the entire sample, the relative age (days) at T_0 time, corresponding to the smallest specimen of 30 g of weight, was estimated using the growth curves equations obtained. In order to plot the growth curves, the relative age (days) of the recaptures (TW_{T2}) were computed through the application of the same equations mentioned above.

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The ANCOVA and residual mean square error (RMSE) analyses were applied to compare the growth curves obtained in this study with those proposed by Domain *et al.* (2000) from Senegalese waters, here indicated as B1 (1997) and B2 (1998), respectively. The comparisons were also performed standardizing B1 and B2 at the weight at the relative age zero (WT_0A) observed in this study.

RESULTS

Tag–recapture experiment in the wild

Before the release in the sea, no mortality was recorded on 148 males (145–660 g of TW) and 120 females (80–570 g of TW) tagged with both Petersen discs and T-bars (Figure 2A) in the preliminary phase. Overall, 22 males and 10 females were recaptured after 5–49 days at freedom (DF) (Table 1).

Petersen discs, except for one specimen in which the tag was lost, were all in an excellent condition. On the contrary, most of the T-bar tags were lost or damaged, and they did not allow identification of the specimen code (Figure 2B).

Unlike the Petersen discs, T-bar tags did not cause wounds on the animals. However, in all recaptures the injuries caused at the time of tagging by Petersen discs were already healed, even in the seven specimens recaptured after only 5 DF (Figure 2C, D). On the basis of these results, Petersen discs were chosen as suitable markers for *Octopus vulgaris* tagging–recapture experiments in the wild. From 2010 to 2013, a total of 853 *Octopus vulgaris* males (30–660 g of TW) and 751 females (30–700 g of TW) were tagged and released at sea (Table 2; Figure 1).

In particular, 72.2% of males and 76.8% of females were characterized by TW less than 300 g (i.e. the minimum landing size imposed by the local Sardinian legislation, regional decree no 22 of 17 July 2002).

Overall, 59 males and 32 females were recaptured after a minimum of 4 to a maximum of 63 DF. In all specimens, the tags were undamaged with an identifiable code, and the wounds caused by the nickel pin had healed.

Fig. 2. *Octopus vulgaris*: specimen tagged with both Petersen discs and T-bar (A), recaptured specimen with T-bar tag damaged (B), area of skin under the Petersen disc immediately after tagging (C) and at time of recapture (D).

Table 1. *Octopus vulgaris*: details on the recaptures from the preliminary tagging experiment.

Petersen disc status	T-bar status	Males: Number of specimens	Males: Days of freedom	Females: Number of specimens	Females: Days of freedom
Intact	Intact	3	8–34 [22 ± 13]	4	5–49 [23 ± 19]
Intact	Damaged	6	5–34 [11 ± 11]	0	–
Intact	Lost	13	12–49 [28 ± 11]	5	20–49 [33 ± 15]
Lost	Damaged	0	–	1	28

Overall, the recapture rate (RR) was 5.67%, with higher RR values in males (2.67–4.86) than in females (0.21–3.67) in all surveyed years except for 2013 (Table 2).

Fifty-nine recaptures (31 males and 28 females), re-caught after 8–63 DF (mean ± standard deviation: 29 ± 14), displayed positive increments in weight with higher daily growth rates (DGR) and instantaneous relative growth rates (G) in females.

In particular in females after 8–63 DF, DGR and G mean values varied from 3.07 to 3.65 g day^{-1} and from 0.00888 to 0.01098, respectively; in males after 11–62 DF, DGR varied from 2.08 to 2.98 g day^{-1} and G from 0.00655 to 0.00956 (Table 3).

Gs were independent of the total weights in both sexes ($P > 0.05$), and no significant differences among growth rates in the different years were recorded for either males (ANOVA: $F = 1{,}18$ and $P = 0.3352$) or females (ANOVA: $F = 0{,}40$ and $P = 0.7549$). Consequently, for each sex, all Gs from the different surveys were combined to obtain the following relative exponential growth curves (Figure 3):

$$TW_{males} = \exp[0.0079\,(T + 430.53132)]$$

$$TW_{females} = \exp[0.0105\,(T + 323.92359)]$$

For both sexes, the weight at the relative age zero was 30 g (weight of the smallest specimens of the sample). Even if the mean of Gs was bigger in females than males, no significant differences (ANOVA: $F = 3{,}74$ and $P = 0.0581$) were recorded between the two sexes; an exponential growth curve that includes both sexes was also calculated (Figure 3):

$$TW_{both\ sexes} = \exp[0.0091\,(T + 323.92359)]$$

Comparison of the growth curves obtained with mark–recapture studies in the wild

Table 4 summarizes the results of the comparisons of the growth curves obtained for *Octopus vulgaris* with mark–recapture studies in the wild. The ANCOVA and RMSE analyses indicate that the curves obtained in the present paper are closer to the B1 (1997) curves from Domain *et al.* (2000), in particular for females (Table 4). After standardization at the weight of 30 g (our relative age zero), the ANCOVA analysis did not show differences for the female curves, and the RMSE value was equal to zero; similar results were obtained for the male curves (Table 4).

DISCUSSION

Mark–recapture studies in the wild represent useful tools to estimate growth, age and lifespan, and to increase information on the ecology and ethology of the species; unfortunately, until now only a few studies have been completed on cephalopod species (e.g. Ezzedine-Najai, 1997; Lipinski *et al.*, 1998; Sauer *et al.*, 2000).

In particular, for the common octopus the vast majority of the literature is focused on the identification of suitable tagging methods. Taki (1941), Inoue *et al.* (1953), Katayama & Morita (1960), Itami (1964) and Takeda *et al.* (1981) tested tags made of pieces of sewn material, metal plaques, removal of suckers, heat burning, wires and colorant. Among these experiments, only trypan blue and burning produced acceptable results, but according to Itami (1964) the first method did not allow the identification of the specimens, while the second caused a high rate mortality, in particular in small specimens. Tsuchiya *et al.* (1986) examined the effectiveness of a wide range of external tags (anchor tag, dart tag, Petersen discs, fingerling tag, metal ring, nylon thread) and dyes (methylene blue, neutral red, erythrosine and saffranine T); the colorants were especially successful and had little influence on the marked animals, allowing a high recapture rate (27.9%).

Table 2. *Octopus vulgaris*: number of specimens tagged; sizes and recapture rates in the different surveys.

		2010 (April–August)	2011 (June–November)	2012 (March–August)	2013 (April–September)
Males	N	221	258	210	164
	TW	30–660 (283.2 ± 131.9)	30–480 (205.8 ± 86.3)	30–460 (228.0 ± 106.8)	50–570 (259.1 ± 109)
	RR	4.86%	2.79%	4.16%	2.67%
Females	N	232	208	175	136
	TW	30–570 (230.4 ± 126.0)	30–410 (200.9 ± 91.9)	30–480 (209.0 ± 109.8)	40–700 (241.6 ± 116.7)
	RR	2.43%	0.21%	2.34%	3.67%
Total	N	453	466	385	300
	TW	30–660 (255.6 ± 131.7)	30–480 (202.8 ± 89)	30–480 (218.0 ± 109.1)	40–700 (251.2 ± 112.7)
	RR	7.28%	3.00%	6.50%	6.34%

N, number of specimens tagged; TW, total weight; RR, recapture rate; value ± standard deviation in parentheses.

Table 3. *Octopus vulgaris*: recapture rates, days at freedom, daily growth rates and specific growth rate of males and females with positive increments registered in the different surveys from 2010 to 2013.

		2010	2011	2012	2013
Males (N = 31)	RR (%)	1.99	1.93	1.56	2.33
	DF (days)	11–47 (28 ± 12)	14–45 (24 ± 13)	15–47 (27 ± 12)	22–62 (37 ± 12)
	DGR (g day^{-1})	1.62–5.42 (2.98 ± 1.30)	1.00–4.76 (2.08 ± 1.22)	1.32–4.67 (2.97 ± 1.39)	1.23–4.50 (2.89 ± 1.20)
	G	0.00335–0.01270 (0.00655 ± 0.00311)	0.00292–0.01331 (0.00667 ± 0.00349)	0.00471–0.01398 (0.00904 ± 0.00341)	0.00317–0.02166 (0.00956 ± 0.00575)
Females (N = 28)	RR (%)	1.99	0.21	2.08	3.33
	DF (days)	11–49 (24 ± 11)	21	8–63 (30 ± 19)	15–60 (32 ± 18)
	DGR (g day^{-1})	0.96–9.09 (3.65 ± 2.81)	5.00	2.04–7.75 (3.65 ± 1.85)	1.17–5.00 (3.07 ± 1.21)
	G	0.00294–0.01754 (0.00888 ± 0.00521)	0.02000	0.00596–0.01986 (0.01098 ± 0.00488)	0.00392–0.03325 (0.01103 ± 0.00922)

RR, recapture rates; DF, days of freedom; DGR, daily growth rates; G, specific growth rate; mean value ± standard deviation in parentheses.

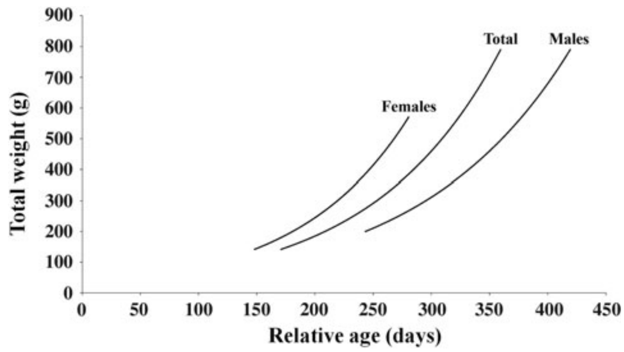

Fig. 3. *Octopus vulgaris*: exponential growth curves for males, females and both sexes (Total) obtained with the tag–recapture data.

Table 4. *Octopus vulgaris*: comparison of the growth curves obtained in this study (A) with those reported in the literature (B1 and B2) from other mark–recapture studies, for both sexes; WT_oA and WT_oB, weights at the relative age zero recorded respectively in this study and in Domain *et al.* (2000).

	Present results	Domain *et al.* (2000)		ANCOVA		RMSE
	A	B1	B2	*F*	*P*	
Males	[WT_oA]	[WT_oB]		410.8	<0.01	469.46
	[WT_oA]		[WT_oB]	281.0	<0.01	1507.91
	[WT_oA]	[WT_oA]		122.7	<0.01	115.53
	[WT_oA]		[WT_oA]	224.3	<0.01	740.05
Females	[WT_oA]	[WT_oB]		451.3	<0.01	259.32
	[WT_oA]		[WT_oB]	319.9	<0.01	1624.66
	[WT_oA]	[WT_oA]		0.0	=1.00	0.00
	[WT_oA]		[WT_oA]	266.3	<0.01	820.46

The weights at the relative age zero used in the curves are shown in brackets; RMSE, residual mean square error.

As regards external marks, it is known that octopuses can make movements with their arms to remove their own tags or those of others (Tsuchiya *et al.*, 1986; Domain *et al.*, 2000; Fuentes *et al.*, 2006). This behaviour could negatively influence the recapture rates, and consequently the success of the experiment. Despite this, until now, the use of external marks is the only method compatible with wild experiments carried out in fishing grounds within fishery management programmes. In this case, taking into account that mortality due to the tags doesn't seem to exist (Fuentes *et al.*, 2006), the choice is limited only to the kind of tag to use, being easily recognizable by fishermen, and in which part of the body to insert it to minimize its loss.

Studies in tanks on the use of external tags identified Petersen discs and T-bars, inserted at the base of the third left arm, as the most persistent systems (Domain *et al.*, 2000; Fuentes *et al.*, 2006).

On the basis of the above studies and our preliminary investigation, Petersen discs have been identified as the most suitable external tag to use in the mark–recapture experiments in Sardinian waters. Despite the laborious manual process to apply the tag and the injuries produced by it, its retention rate (about 97%) was much higher than that of T-bars (about 22%) and the healing process was fast, within a minimum of 5 days.

Within our experiment, made on specimens 74.4% of which weighed less of 300 g, the maximum persistence time

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obtained by the discs (63 days) was shorter than that recorded in captivity for tagged specimens of 500–1000 g of weight (3 months; Fuentes *et al.*, 2006). This difference can be explained by the fact that, at sea, the tag could be lost or removed more easily, and also because its persistence could be inferior in small animals, affecting the recapture rates (RR in our 4-year investigation was 3–7.28%). Another factor that could have lowered the recapture rates could be that the mark–recapture experiments were carried out within the reproductive period of the species. It is known that during the reproductive season, mature females move inside dens, generally inaccessible to fishing gears, to spawn their eggs. This could explain the low percentage of females recaptured in general and, especially in 2011, when the tagging experiment started later than the other years and in coincidence with the peak of deposition.

Despite the limitations met, the mark–recapture experiment on *Octopus vulgaris* has allowed obtaining of the first growth results in the Mediterranean Sea, at least for small to medium specimens in the wild.

Previously, apart from the analogous experiment done in Senegalese waters (Domain *et al.*, 2000), numerous other studies on *O. vulgaris* growth have been conducted in captivity on specimens both in the Atlantic (e.g. Smale & Buchan, 1981; Chapela *et al.*, 2006) and the Mediterranean (e.g. Nixon, 1966; Mangold & Boletzky, 1973; Prato *et al.*, 2010). Most of these studies reported a variable growth as a consequence of variation in temperature; for example Mangold & Boletzky (1973) obtained different growth rates at 10°C (1.2–3.9 g day^{-1}), 15°C (1.6–5.9 g day^{-1}) and 20°C (6.2–23.6 g day^{-1}) and Chapela *et al.* (2006) registered 8–18 and 19–26 g day^{-1} respectively in winter (13.4–14.2°C) and in summer (16.2–16.5°C). Moreover Nixon (1966) and Smale & Buchan (1981) recorded growth rates of 1.9–7.7 g day^{-1} (14–27°C) and 2.58–29.67 g day^{-1} (17–28°C), respectively. Prato *et al.* (2010) highlighted how different foods could affect growth rates; they obtained mean growth rates varying from 7.57 ± 2.40 to 20.10 ± 1.17 g day^{-1} when testing five different diets. Aguado Giménez & García García (2002) observed that both diet and temperature affect *O. vulgaris* growth rates, showing that the optimum temperature for growth was 17.5 and 20°C for food intake while maximum food efficiency was achieved at a lower temperature (16.5°C).

Overall, considering the different methodologies used, it is very difficult to compare the mean growth rates of the present study (2.08–3.65 g day^{-1}) with those available in the literature. As observed in previous studies, a high individual variability (0.96–9.09 g day^{-1}) has been observed in Sardinian waters. Moreover, in accordance with the literature data (Smale & Buchan, 1981; Domain *et al.*, 2000), our results show higher growth rates in females than in males, even if the difference between the two sexes is not statistically significant.

Besides temperature and food availability, other factors such as gender, maturation, senescence and natural or tag injury can influence the growth process in *O. vulgaris* leading to null/negative growth rates and this could explain why ~35% of our recaptures had negative or zero *G*s regardless of the days at freedom.

For these reasons, in this study, only specimens with positive *G* were considered to calculate the growth parameters of *O. vulgaris*. Moreover, an interval of 8 days of freedom was considered as the minimum time necessary to minimize the possible stress due to the tagging process and for change in weight to be recordable.

The octopus growth curves reported in this paper are different from those obtained by the indirect method i.e. modal progression analysis on size frequency (e.g. Guerra, 1979; Hatanaka, 1979) and by direct aquarium studies (e.g. Smale & Buchan, 1981; Prato *et al.*, 2010). Semmens *et al.* (2004) indicated that the first method is not suitable for cephalopods and the second one does not replicate the natural environment. As a mark–recapture experiment in the field the present study is comparable with the previous one done by the same methodology (Domain *et al.*, 2000).

In particular the comparison showed that curves reported by Domain *et al.* (2000) from the fieldwork in 1997 (called B1 in this paper) were closer to ours, in particular for females, differing only for the weight at the relative age zero, that was 50 g instead of our 30 g.

Although our sample was composed mainly of small specimens, we cannot exclude the presence of mature and spawning males; indeed in Sardinian waters these conditions could be reached by males at a minimum size of 195 and 203 g, respectively (Cuccu *et al.*, 2013b). In this case, their presence in the recapture sample could have affected the male growth rate, considering that mature males expend a lot of energy searching for females to mate with (Hanlon & Messenger, 1996; Semmens *et al.*, 2004; Cuccu *et al.*, 2013a, b), and that senescence is generally accompanied by a significant loss of weight (e.g. Tait, 1986; Cuccu *et al.*, 2013b).

Conversely, it is hardly plausible that female growth rates in the recaptures could have been influenced by the reproductive behaviour because the females reach sexual maturity at greater sizes and during spawning they become inaccessible to fishing.

These results suggest that, at least for males, it could be more appropriate to establish for each specimen the sexual maturity stage at the time of recapture, in order to exclude spawning and spent specimens from the growth curves calculation.

Overall, the investigation on *Octopus vulgaris* described in this paper, aside from confirming the objective difficulties that are encountered in the mark–recapture experiments, has increased the knowledge on tagging studies in the wild.

Albeit preliminary and with all the limitations that emerged within this study, these growth results on small–medium octopuses are the first for the Mediterranean Sea, and represent valid and basic information for future management fishing plans.

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REFERENCES

Aguado Giménez F. and García García B. (2002) Growth and food intake in *Octopus vulgaris* Cuvier (1797): influence of body weight, temperature, sex and diet. *Aquaculture International* 20, 472–487.

Barratt I.M. and Allcock A.L. (2010) Ageing octopods from stylets: development of a technique for permanent preparations. *ICES Journal of Marine Science* 67, 1452–1457.

Canali E., Ponte G., Belcari P., Rocha F. and Fiorito G. (2011) Evaluating age in *Octopus vulgaris*: estimation, validation and seasonal differences. *Marine Ecology Progress Series* 441, 141–149.

Chapela A., González A.F., Dawe E.G., Rocha F.J. and Guerra A. (2006) Growth of common octopus (*Octopus vulgaris*) in cages suspended from rafts. *Scientia Marina* 70, 121–129.

Cuccu D., Mereu M., Cau Al., Pesci P. and Cau A. (2013a) Reproductive development *versus* estimated age and size in a wild Mediterranean population of *Octopus vulgaris* (Cephalopoda: Octopodidae). *Journal of the Marine Biological Association of the United Kingdom* 93, 843–849.

Cuccu D., Mereu M., Porcu C., Follesa M.C., Cau Al. and Cau A. (2013b) Development of sexual organs and fecundity in *Octopus vulgaris* Cuvier, 1797 from the Sardinian waters (Mediterranean Sea). *Mediterranean Marine Science* 14, 270–277.

Domain F., Jouffré D. and Caverivière A. (2000) Growth of *Octopus vulgaris* from tagging in Senegalese waters. *Journal of the Marine Biological Association of the United Kingdom* 80, 699–705.

Ezzedine-Najai S. (1997) Tagging of the cuttlefish, *Sepia officinalis* L. (Cephalopoda: Decapoda), in the Gulf of Tunis. *Scientia Marina* 61, 59–65.

Food and Agriculture Organization (2006) *Cephalopods commodity update*. Rome: FAO.

Food and Agriculture Organization (2013) *Global production statistics 1950–2011. United Nations Food and Agriculture Organization.* Rome: FAO. http://firms.fao.org/gfcm/topic/17105/en (accessed 18 April 2014).

Fuentes L., Otero J.J., Moxica C., Sánchez F.J. and Iglesias J. (2006) Application of different external tagging methods to *Octopus vulgaris* Cuvier, 1797, with special reference to T-bar anchor tags and Petersen disks. *Boletin del Instituto Español de Oceanografia* 22, 3–11.

Gonçalves J.M. (1993) Octopus vulgaris *Cuvier, 1797 (polvo-comum): sinopse da biologia e exploração*. PhD thesis, Universidade dos Açores, Horta, Portugal.

Guerra A. (1979) Fitting a von Bertalanffy expression to *Octopus vulgaris* growth. *Investigacíon Pesquera* 43, 319–327.

Guerra A. (1997) *Octopus vulgaris*: review of the world fishery. In Lang M.A. and Hochberg F.G. (eds) *Proceeding of the Workshop on The Fishery and Market Potential of* Octopus *in California*. Washington: Smithsonian Institution, pp. 91–97.

Hanlon R.T. and Messenger J.B. (1996) *Cephalopod behaviour*. Cambridge: Cambridge University Press.

Hatanaka H. (1979) Studies on the fisheries biology of common octopus off the northwest coast of Africa. *Bulletin Far Seas Fishery Research Laboratory, Shimizu* 17, 13–124.

Hermosilla C.A., Rocha F., Fiorito G., González A.F. and Guerra A. (2010) Age validation in common octopus *Octopus vulgaris* using stylet increment analysis. *ICES Journal of Marine Science* 67, 1458–1463.

Inoue K., Hamaguchi A. and Li A. (1953) Preliminary mark and release experiment of common octopus. *Hyogo Prefectural Fisheries Experimental Station (HPFES), HPFES Annual report 1952*, 123 pp [In Japanese].

Itami K. (1964) Marks for common octopus and results of marking experiments. *Suisanzoshoku* 12, 119–125 [In Japanese].

Katayama K. and Morita S. (1960) Preliminary survey of common octopus. *Okayama Prefectural Fisheries Experimental Station (OPFES), OPFES Annual report*, 32 pp [In Japanese].

Kaufmann K.W. (1981) Fitting and using growth curves. *Oecologica* 49, 293–299.

Lipinski M.R., Hampton I., Sauer W.H.H. and Augustyn C.J. (1998) Daily net emigration from a spawning concentration of chokka squid (*Loligo vulgaris reynaudii* d'Orbigny, 1845) in Kromme Bay, South Africa. *ICES Journal of Marine Science* 55, 258–270.

Mangold K. and Boletzky S. (1973) New data on the reproductive biology and growth of *Octopus vulgaris*. *Marine Biology* 19, 7–12.

Mereu M., Masala P., Maccioni A., Stacca D., Cau Al. and Cuccu D. (2010) Tagging *Octopus vulgaris* (Octopoda: Octopodidae) in an area of central western Sardinian waters. *Biologia Marina Mediterranea* 17, 306–307.

Moltschaniwskyj N.A., Hall K., Lipinski M.R., Marian J.E.A.R., Nishiguchi M., Sakai M., Shulman D.J., Sinclair B., Sinn D.L., Staudinger M., Van Gelderen R., Villanueva R. and Warnke K. (2007) Ethical and welfare considerations when using cephalopods as experimental animals. *Review Fish Biology Fisheries* 17, 455–476.

Nagasawa K., Takayanagi S. and Takami T. (1993) Cephalopod tagging and marking in Japan: a review. In Okutani T., O'Dor R.K. and Kubodera T. (eds) *Recent advances in fisheries biology*. Tokyo: Tokai University Press, pp. 313–329.

Nixon M. (1966) Changes in body weight and intake of food by *Octopus vulgaris*. *Journal of Zoology, London* 150, 1–9.

Perales-Raya C., Jurado-Ruzafa A., Bartolomé A., Duque V., Nazaret Carrasco M. and Fraile-Nuez E. (2014) Age of spent *Octopus vulgaris* and stress mark analysis using beaks of wild individuals. *Hydrobiologia* 725, 105–114.

Prato E., Portacci G. and Biandolino F. (2010) Effect of diet on growth performance, feed efficiency and nutritional composition of *Octopus vulgaris*. *Aquaculture* 309, 203–211.

Robinson S.M.C. and Hartwick E.B. (1986) Analysis of growth based on tag recapture of the giant pacific *Octopus dofleini martini*. *Journal of the Zoological Society of London* 209, 559–572.

Sauer W.H.H., Lipinski M.R. and Augustyn C.J. (2000) Tag recapture studies of the chokka squid *Loligo vulgaris reynaudii* d'Orbigny, 1845 on inshore spawning grounds on the south-east coast of South Africa. *Fisheries Research* 45, 283–289.

Semmens J.M., Pecl G.T., Villanueva R., Jouffre D., Sobrino I., Wood J.W. and Rigby P.R. (2004) Understanding octopus growth: patterns, variability and physiology. *Marine Freshwater Research* 55, 367–377.

Smale M.J. and Buchan P.R. (1981) Biology of *Octopus vulgaris* off the east coast of South Africa. *Marine Biology* 65, 1–12.

Tait R.W. (1986) *Aspects physiologiques de la sénescence post-reproductive chez* Octopus vulgaris. PhD thesis, Université Paris VI, Paris, France.

Takeda R., Karata S., Nakamoto K., Nakano T., Sakai T., Itami K., Sano Y., Nose S., Mitsuo N., Yahashi T., Nakamura K., Sakai N., Hamano N., Doi T. and Kawakami T. (1981) Survey of large-scale propagation area in 1980 (Meitan area: common octopus). *Hyogo Prefectural Fisheries Experimental Station (HPFES), HPFES Annual report 1980*, pp. 359–369 [In Japanese].

Taki I. (1941) On keeping octopods in an aquarium for physiological experiments, with remarks on some operative techniques. *Venus* 10, 140–156.

Tsuchiya H., Ikeda F. and Shimizu T. (1986) The study on octopus (*Octopus vulgaris* Cuvier) resource in Tokyo Bay–III. Experiment of marking methods for octopus. *Bulletin Kanagawa Prefectural Fisheries Experimental Station* 7, 45–53 [In Japanese].

and

Villanueva R. (1995) Experimental rearing and growth of planktonic *Octopus vulgaris* from hatching to settlement. *Canadian Journal of Fisheries and Aquatic Sciences* 52, 2639–2650.

Correspondence should be addressed to:
D. Cuccu
Dipartimento di Scienze della Vita e dell'Ambiente,
Università di Cagliari, Via T. Fiorelli,
1 - 09126 Cagliari, Italy
email: cuccu@unica.it