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On the relationship between beaks and body size in *Sepia officinalis* from the Southern Tyrrhenian Sea (Central Mediterranean)

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Abstract: This paper provides information on the relationships between beak growth and body size in *Sepia officinalis* (Linnaeus, 1758) from the southern Tyrrhenian Sea (Central Mediterranean). Beaks of 146 specimens of *Sepia officinalis* (77 females, 69 males) were examined. To find possible differences between the mandibles of females and males, a t test was performed on morphometric data and a multivariate analysis carried out afterwards. Results indicated that the relationships between dorsal mantle length (ML) and beak measurements were allometric. The crest of both the upper and lower beaks grows faster than other parts of the beak in males and females. Changes in the beak morphometry depend only on body size and are not correlated with sex and maturity stage.

Résumé : *Sur la relation entre les mandibules et la taille du corps chez* Sepia officinalis *dans la partie sud de la Mer Tyrrhénienne (Méditerranée centrale)*. Ce travail apporte des informations sur la relation entre la croissance des mandibules et la taille chez *Sepia officinalis*, fondées sur des échantillons capturés au chalut dans le Sud de la Mer Tyrrhénienne. Un total de 146 individus (77 femelles, 69 mâles) a été collecté et les mandibules ont été étudiées. Afin de déterminer les possibles différences entre les mandibules de femelles et mâles, un test t a été effectué sur la biométrie des mandibules. Une analyse multivariable a été réalisée sur l'ensemble des données biométriques obtenues sur les femelles et sur les mâles. L'allométrie de croissance entre la longueur dorsale du manteau et les différentes mesures effectuées sur les mandibules a été calculée. Elle est minorante dans la majorité des cas. La croissance des mandibules n'est ni liée au sexe ni au stade de maturité.

Keywords: Beaks, Mantle length, *Sepia officinalis*, Cephalopoda, Mediterranean Sea

Introduction

Cephalopod mandibles, or beaks, gained continuously increasing attention in the last few decades (e.g. Mercer et al., 1980; Wolff, 1982; Clarke & Maddock, 1988; Ghofar, 1990; Hernández-García, 2003). Although recently questioned at the species level (Ogden et al., 1998), the use of beak morphology as a systematic character has been rather extensively and successfully applied for taxonomic purposes (Clarke, 1962a,b, 1980, 1986; Mangold & Fioroni, 1966; Smale et al., 1993 and many others) and squid beaks were included in the guidelines for taxonomic identification

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of species (Roper & Voss, 1983). They are useful tools also in cephalopod size estimates (Clarke, 1986), their developmental changes are important elements in investigating cephalopod ecology (Hernandez-García et al., 1998), beak microstructure could prove to be a useful tool in age determination (Raya & Hernandez-Gonzalez, 1998) and beaks found in the stomachs of cephalopods predators can be used to estimate size and biomass of the identified species (e.g., Clarke, 1987), which otherwise would be impossible in many cases. The species-specific relationships between the measurements of some parts of the beak and the size and total mass of cephalopod species have also been studied (e.g. Gröger et al., 2000), and increasing effort is being spent to improve the existing knowledge on beak morphology and ontogenetic development.

In spite of all this accumulated research, very little information is available on the beak and body size relationship on *Sepia officinalis* Linné, 1758 one of the most investigated cephalopod species, both in the Atlantic Ocean (e.g., Boletzky, 1983) and in the Mediterranean Sea (e.g., Relini et al., 1999).

This paper provides information on the morphometric changes that occur with growth of the beaks of the common cuttlefish *Sepia officinalis* from the Southern Tyrrhenian Sea (Central Mediterranean Sea). In particular, the influence of sex and stage of maturity on beak shape was studied.

Materials and Methods

A total number of 103 specimens of *Sepia officinalis* came from experimental trawl surveys (GRUND and MEDITS projects, Relini, 1998; Bertrand et al., 2002) carried out in the southern part of the Tyrrhenian Sea (central Mediterranean Sea), and 73 were collected from commercial landings from the same area. The following measures were taken on all specimens: dorsal mantle length (DML in mm), total weight (g), sex and macroscopic sexual maturity according to Mangold-Wirz (1963); the weight of the reproductive system organs (*i.e.*, ovary, nidamental glands, oviducal glands, oviducts, testis and Needham's complex) was also recorded.

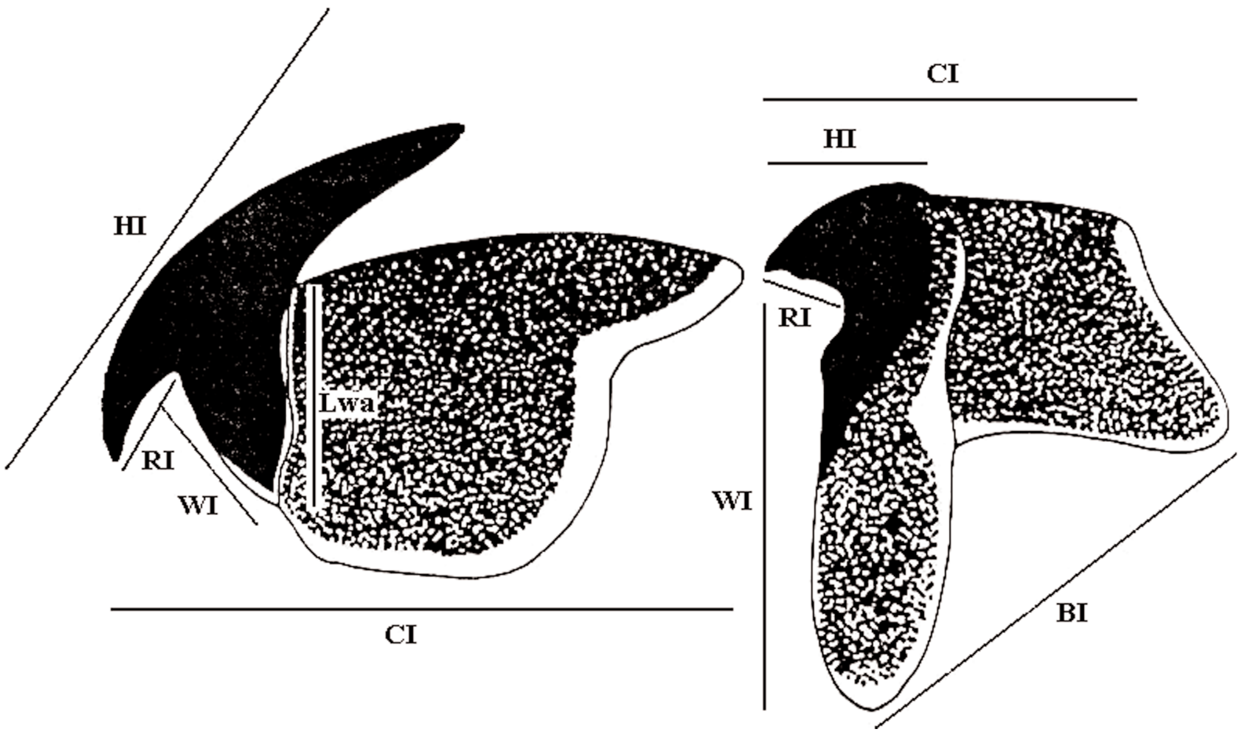

Figure 1. *Sepia officinalis*. Beaks (from Mangold & Fioroni, 1966). Terminology of the different part of lower and upper beak. Rostral length (Rl), hood length (Hl), crest length (Cl), wing length (Wl), the amplitude of the lateral wall (LWa) in the upper beak, and length of the baseline (Bl) in the lower beak.

Figure 1. *Sepia officinalis*. Mandibules (d'après Mangold & Fioroni, 1966). Dénomination des différentes parties des mandibules inférieures et supérieures. Longueur du rostre (Rl), longueur du capuchon (Hl), longueur de la crête (Cl), longueur de l'aile (Wl), hauteur du mur latéral (Lwa) de la mandibule supérieure, et longueur de la base (Bl) de la mandibule inférieure.

A total of 146 beaks (77 females, 69 males) were examined and the mandibles, collected on defrosted cuttlefishes, were preserved in 70% ethanol. The following measures were taken on both the upper (UB) and lower (LB) beaks as illustrated in Fig. 1 (nomenclature according to Clarke, 1986): rostral length (Rl), hood length (Hl), crest length (Cl), wing length (Wl), the distance between jaw angles (JAd); and the amplitude of the lateral wall (LWa) in the upper beak, and the length of the baseline (Bl) in the lower beak. All measurements were taken to the nearest 0.01 mm with digital calipers.

The classic power model ($Y = a.DML^b$) was adopted to relate each beak measurement to the corresponding individual size (DML); in order to stabilize variance, coefficients were estimated after natural logarithmic (Ln) transformation: $Ln(Y) = Ln(a) + b.Ln(DML)$.

The Student's t-test was used to evaluate the departure from the isometric condition (H_0: b = 1).

In order to test the influence of sex and maturity condition on beak morphology, a Principal Component Analysis (PCA) was carried out on the correlation matrix R of the standardized morphometric variables. To remove the size effect, each variable was standardized to the corresponding individual dorsal mantle length. The above mentioned analyses were computed with the PRIMER statistical package (Plymouth Routines In Multivariate Ecological Research) developed at the Plymouth Marine Laboratory, United Kingdom (Clarke & Warwick, 1994).

Results

Females ranged between 70 and 179 mm and males between 52 and 140 mm ML. Size ranges of males and females, lower and upper beak measurement ranges (Cl, HI, RI, WI, BI, Lwa and Jad of Lower and Upper beaks), according to maturity stages, are reported in Table 1. Females were divided into four groups in according to the eggs size: group one (immature females) with eggs diameter no bigger than 2 mm; group II, females in maturation with eggs having a diameter comprised from 2.1 to 4.0 mm; group III, females in maturation with eggs diameter between 4.1 and 6.0 mm; group IV, mature females, with eggs diameter between 6.1 and 8.0 mm. In figure 2, the group "maturing females" was formed putting together groups II and III.

In immature females (group I) dorsal mantel length

Table 1. *Sepia officinalis*. Range of measurements on lower and upper beaks in relation with dorsal mantle length (DML), sex and maturity stage. Rl: rostral length, Hl: hood length, Cl: crest length, Wl: wing length, Jad: distance between the jaw angles, Lwa: amplitude of the lateral wall in the upper beak, Bl: length of the baseline in the lower beak.

Tableau 1. *Sepia officinalis*. Gamme des longueurs mesurées sur les mandibules inférieures et supérieures en fonction de la longueur dorsale du manteau (DML), du sexe et du stade de maturité. Rl : longueur du rostre, Hl : longueur du capuchon, Cl : longueur de la crête, Wl : longueur de l'aile, Jad : distance entre les angles des mandibules, Lwa : hauteur du mur latéral de la mandibule supérieure, Bl : longueur de la base de la mandibule inférieure.

					Lower Beak			
Females	**DML**	**N.**	**Cl**	**HI**	**RI**	**WI**	**BI**	**Jad**
I	70-130	20	7.8-12.38	3.09-5.88	1.13-3.09	7.45-10.79	8.14-14.89	3.55-6.21
II	105-160	12	10.39-15.66	4.53-7.94	1.62-4.12	9.02-14.46	13.06-18.19	4.56-7.81
III	100-155	18	9.43-15.43	4.13-7.47	1.57-4.13	7.96-14.09	11.3-15.71	3.89-7.38
IV	100-179	27	11.43-18.54	5.19-9.01	1.96-5.01	9.38-16.41	13.3-23.03	5.14-8.42
					Lower Beak			
Males	**DML**	**N.**	**Cl**	**HI**	**RI**	**WI**	**BI**	**Jad**
I	52-100	12	5.53-9.17	2.04-4.27	1.11-2.05	5.11-9.91	5.74-11.23	2.51-4.22
II	73- 140	16	8.33-13.67	3.74-6.34	1.49-2.57	8.35-14.02	9.54-15.48	4.14-5.79
III	104-140	41	9.45-14.97	3.64-7.63	1.28-3.84	8.26-14.56	11.07-17.01	3.93-6.79
					Upper beak			
Females	**DML**	**N.**	**Cl**	**HI**	**RI**	**WI**	**Lwa**	**Jad**
I	70-130	20	13.61-21.38	10.04-16.16	2.42-4.47	4.03-7.69	4.96-10.07	1.89-3.72
II	105-160	12	18.1-25.4	13.47-18.98	3.13-4.99	4.82-7.52	7.78-12.02	2.46-4.92
III	100-155	18	17.08-24.83	13.41-19.19	3.02-4.7	4.89-8.87	8.08-10.76	2.5-3.91
IV	100-179	27	19.68-30.79	14.12-23.23	3.8-6.04	5.55-10.32	9.42-13.82	3.11-4.96
					Upper beak			
Males	**DML**	**N.**	**Cl**	**HI**	**RI**	**WI**	**Lwa**	**Jad**
I	52-100	12	9.56-15.42	7.5-12.15	1.77-3.18	3.15-5.9	4.68-6.83	1.48-2.44
II	73- 140	16	14.38-23.12	11.06-17.49	2.91-4.41	4.88-8.22	6.73-10.77	2.1-3.96
III	104-140	41	16.6-24.67	11.48-20.23	2.18-4.62	4.84-9.02	6.83-12.02	2.24-4.22

Table 2. *Sepia officinalis*. Regression equations between the dorsal mantle length and beak characteristics. DML: dorsal mantle length, Rl: rostral length, Hl: hood length, Cl: crest length, Wl: wing length, Jad: distance between the jaw angles, Lwa: amplitude of the lateral wall in the upper beak, Bl: length of the baseline in the lower beak, n: number of specimens, R^2: determination coefficient, r: correlation coefficient, s: probability on estimation of b (for a theoretical value of b = 1), ES(b): standard error of b.

Tableau 2. *Sepia officinalis*. Equation des régressions entre la longueur dorsale du manteau et les dimensions des mandibules. DML : longueur dorsale du manteau ; Rl : longueur du rostre, Hl : longueur du capuchon, Cl : longueur de la crête, Wl : longueur de l'aile, Jad : distance entre les angles des mandibules, Lwa : hauteur du mur latéral de la mandibule supérieure, Bl : longueur de la base de la mandibule inférieure, n: nombre d'individus, R^2: coefficient de détermination, r: coefficient de corrélation linéaire, s: probabilité calculée sur l'estimation de b (pour b théorique = 1), ES(b): erreur standard sur b.

Sepia officinalis

Females

Regression equations	n	DML range	R^2	r	s	Standard error (b)
ln DML =2,392 + 0,963 ln Cl LB	77	76 -179	0.909	0.953	ns	0.035
ln DML = 3.435 + 0.791ln Hl LB	77	76 -179	0.823	0.907	0.001	0.042
ln DML = 4.445 + 0.416 ln Rl LB	77	76 -179	0.521	0.722	0.001	0.046
ln DML = 2.799 + 0.847 ln Wl LB	77	76 -179	0.682	0.826	0.05	0.067
ln DML = 2.424+ 0.904 ln Bl LB	77	76 -179	0.786	0.886	ns	0.055
ln DML = 3.553+ 0.743 ln Jad LB	77	76 -179	0.678	0.823	0.001	0.059
ln DML = 1.545 + 1.072 ln Cl UB	77	76 -179	0.935	0.967	0.05	0.033
ln DML = 1.906 + 1.051 ln Hl UB	77	76 -179	0.878	0.937	ns	0.045
ln DML = 3.880+ 0.677 ln Rl UB	77	76 -179	0.616	0.785	0.001	0.062
ln DML = 3.506+ 0.703 ln Wl UB	77	76 -179	0.709	0.842	0.001	0.048
ln DML = 3.013+ 0.805 ln Lwa UB	77	76 -179	0.763	0.873	0.001	0.052
ln DML = 4.116+ 0.584 ln Jad UB	77	76 -179	0.538	0.734	0.001	0.063

Males

Regression equations	n	DML range	R^2	r	s	Standard error (b)
ln DML =2.328 + 1.001 ln Cl LB	69	52 -150	0.92	0.959	ns	0.036
ln DML = 3.405 + 0.829 ln Hl LB	69	52 -150	0.859	0.927	0.001	0.041
ln DML = 4.245+ 0.635 ln Rl LB	69	52 -150	0.533	0.73	0.001	0.073
ln DML = 2.548 + 0.947 ln Wl LB	69	52 -150	0.696	0.834	ns	0.077
ln DML = 2.341 + 0.951 ln Bl LB	69	52 -150	0.809	0.899	ns	0.057
ln DML = 3.264 + 0.912 ln Jad LB	69	52 -150	0.737	0.859	ns	0.066
ln DML = 1.554 + 1.083 ln Cl UB	69	52 -150	0.935	0.967	0.05	0.035
ln DML = 1.966 + 1.049 ln Hl UB	69	52 -150	0.89	0.943	ns	0.045
ln DML = 3.754+ 0.778 ln Rl UB	69	52 -150	0.706	0.84	0.001	0.061
ln DML = 3.225 + 0.804 ln Wl UB	69	52 -150	0.72	0.849	0.005	0.061
ln DML = 2.858+ 0.867 ln Lwa UB	69	52 -150	0.756	0.87	0.05	0.06
ln DML = 3.835 + 0.817 ln Jad UB	69	52 -150	0.675	0.821	0.05	0.069

ranged between 70 and 130 mm; in group II it ranged between 105 and 160 mm, in group III between 100 and 155 mm and in group IV between 100 to 179 mm. Males were divided into three groups: immature, with ML ranging between 50 and 100 mm, maturing, with ML between 73 and 140 mm, and mature, with ML between 104 and 140 mm.

The relationships of each mandible measurement with ML in males and females are shown in table 2. The slopes (b) of the linear regressions indicated that most relationships were negatively allometric or isometric. The most striking result was the negative allometric (b < 1) growth of the rostrum of the lower beak. Values of the respective regression coefficients (RlUB, RlLB) were higher in males

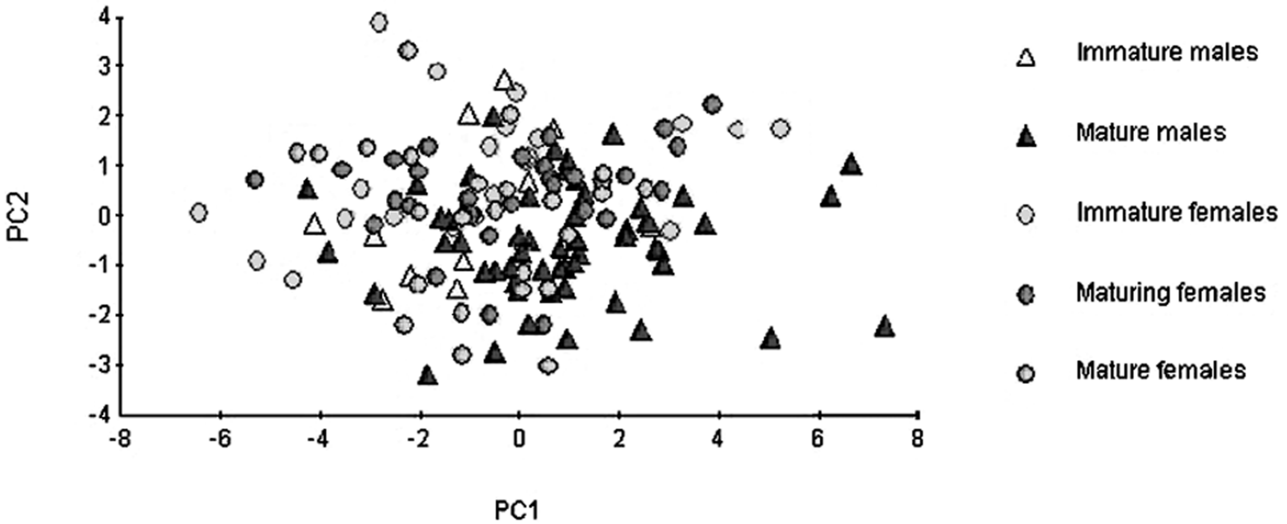

Figure 2. *Sepia officinalis*. Principal Component Analysis (PCA) on beaks measurements.
Figure 2. *Sepia officinalis*. Analyse en Composantes Principales (ACP) sur les mesures des mandibules.

($p < 0.05$) than females.

The crest of each beak grows faster than other parts of the beak both in males and females, followed by hood.

Table 3. *Sepia officinalis*. Results of Principal component analysis (PCA) for twelve variables. Coordinates (correlations) on the two principal components.

Tableau 3. *Sepia officinalis*. Résultats de l'Analyse en Composantes Principales (ACP) réalisée sur douze variables. Coordonnées (corrélations) sur les deux composantes principales.

PCA *Sepia officinalis*			
	Variable	PC1	PC2
a	Crest length Lower Beak	-0.305	0.187
b	Hood length lower Beak	-0.296	0.294
c	Rostral length lower beak	-0.267	-0.201
d	Wing length lower beak	-0.280	0.250
e	Legth of the baseline lower beak	-0.290	0.324
f	Distance between jaw angles lower beak	-0.293	-0.230
g	Crest length Upper Beak	-0.306	0.183
h	Hood length upper Beak	-0.299	0.333
i	Rostral length upper beak	-0.287	-0.110
l	Wing length upper beak	-0.265	-0.462
m	Amplitude of the lateral wall upper beak	-0.293	-0.220
n	Distance between jaw angles Upper beak	-0.278	-0.446

Results of the PCA are shown in Fig. 2 and Table 3. The first principal component explained 46% of the total morphometric variability, while the second principal component showed much less variability than the first one (14.5%). Neither component was significant; thus sex and maturity stage were not the trigger factors explaining changes in the morphology of beaks.

The most striking result was the positive allometric ($b > 1$) growth of the rostrum of the lower beak. Values of the respective regression coefficients (RlUB, RlLB) were higher in males ($p < 0.05$) than females.

Discussion

Changes in beak pigmentation with growth and maturation are known to occur in cephalopod species, e.g. *Todarodes sagittatus* (Lamarck, 1798) (Hernández-Garcia et al., 1998; *Todaropsis eblanae* (Ball, 1841), Hernández-García, 2003). In *Sepia officinalis* of the Southern Tyrrhenian Sea, a transformation in the beak coloration was observed, from the red-brown of the young specimens to the dark brown of the most advanced stages, as already reported by Mangold & Fioroni (1966).

In some Ommastrephidae, it has been shown that those parts of the beaks which support important muscular insertions (like the hood, the walls and the crest) grow faster than other parts (e.g., Sanchez, 1981; Castro & Hernandez-Garcia, 1995; Hernandez-Garcia et al.,1998). This is likely to be related to the role of these structures (Hernandez-Garcia et al., 1998) in the function of the beaks: their fast development allows a faster adaptation to the ingestion of larger prey fragments. This was observed also in our samples, where the crest of the upper beak grew faster, followed by the hood.

Similarly, the relatively slower growth of the rostrum, already observed for *Todarodes sagittatus* (Hernandez-Garcia et al., 1998), is probably due to the fact that this part has a slicing function, not a supporting one, and is consequently subject to erosion.

Allometric growth is a rather common phenomenon that describes changes observed in relative size and shape of different morphological characters during overall growth with age (Sweet, 1980). Analyses of ontogenetic characters, however, rarely consider the multidimensional aspects of growth (Strauss, 1987). The changes observed here in the morphometric relationships of the beaks during the present study were neither correlated with sex nor with the stage of maturity but depended only on body size (Tab. 3; Fig. 2). Consequently, these results support the importance of beak analyses to investigate ontogenetic development in cephalopod species.

References

Bertrand J., Gil de Sola L., Papacostantinou C., Relini G. & Souplet A. 2002. The general specifications of the Medits surveys. *Scientia Marina,* **66** (suppl. 2): 9-17.

Boletzky S.V. 1983. *Sepia officinalis*. In : *Cephalopod Life Cycles*, vol. I (P. Boyle ed), pp. 31-52. Academic Press, London.

Castro J.J. & Hernandez-Garcia V. 1995. Ontogenetic changes in mouth structures, foraging behaviour and habit use of *Scomber japonicus* and *Illex coindetii*. *Scientia Marina*, **59**: 347-355.

Clarke M.R. 1962a. Significance of Cephalopod Beaks. *Nature*, **193**: 560-561.

Clarke M.R. 1962b. The identification of cephalopod "beaks" and the relationship between beak size and total weight. *Bulletin of the British Museum* (Natural History), *Zoology*, **8**: 449-480.

Clarke M.R. 1980. Cephalopoda in the diet of sperm whales of the southern hemisphere and their bearing on sperm whale biology. *Discovery Reports*, **37**: 324 pp.

Clarke M.R. 1986. *A Handbook for the identification of Cephalopod Beaks*. Clarendon, Oxford, 273 pp.

Clarke M.R. 1987. Cephalopod biomass. Estimation from predation. In: *Cephalopod Life Cycles*. *Vol. II*. *Comparative Reviews* (P.R. Boyle ed), pp. 221-237. Academic Press, London.

Clarke M.R. & Maddock L., 1988. Beaks of living coleoid cephalopoda. *The Mollusca*, **12**: 123-131.

Clarke K.R. & Warwick R.M. 1994. Change in marine communities: an approach to statistical analysis and interpretation. *Natural Environmental Research Council*, U.K., 144 pp. Plymouth: Plymouth Marine Laboratory.

Ghofar A. 1990. Morphometry, beaks and the relationships between beak and body size of the purpleback flying squid Symplectotheuthis oualaniensis caught off the coast of Lombok. *Media ED*, **4**: 2-6.

Gröger J., Piatkowski U. & Heinemann H. 2000. Beak length analysis of the Southern Ocean squid *Psychroteuthis glacialis* (Cephalopoda: Psychroteuthidae) and its use for size and biomass estimation. *Polar biology*, **23**: 70-74.

Hernández-García V. 2003. Growth and pigmentation process of the beaks of *Todaropsis eblanae* (Cephalopoda : Ommastrephidae). In: *Coleoid cephalopods through* time (K. Warnke, H. Keupp, S.V. Boletzky eds). *Berliner Paläobiol. Abh*., **03**: 131-140.

Hernandez-Garcia V., Piatkowski U. & Clarke M.R. 1998. Development of the darkening of *Todarodes sagittatus* beaks and its relation to growth and reproduction. *South AfricanJournal of Marine Science,* **20**: 363-373.

Mangold K. & Fioroni P. 1966. Morphologie et biométrie des mandibules de quelques céphalopodes méditerranéens. *Vie et Milieu*, **22**:1139-1196.

Mangold-Wirz K. 1963. Biologie des Céphalopodes benthiques et nectoniques de la Mer Catalane. *Vie et Milieu,* **Suppl. 13**: 1-285.

Mercer M.C., Mistra R.K. & Hurley G.V. 1980. Sex determination of the ommastrephid squid *Illex illecerebrosus* using beak morphometrics. *Canadian Journal of Fisheries Aquatic Science*, **37**: 283-287.

Ogden R.S., Allcock A.L., Watts P.C. & Thorpe J.P. 1998. The role of beak shape in octopod taxonomy. In : *Cephalopod Biodiversity, Ecology and Evolution* (A.I.L. Payne, M.R Lipinski & M.A.C. Roeleveld ; Eds.). *South African Journal of Marine Science* **20**: 29-36.

Raya C.P. & Hernandez-Gonzales C.L. 1998. Growth lines within the beak microstructure of the octopus *Octopus vulgaris* Cuvier, 1797. In : *Cephalopod Biodiversity, Ecology and Evolution* (A.I.L. Payne, M.R Lipinski & M.A.C. Roeleveld ; Eds.). *South African Journal of Marine Science,* **20**: 135-142.

Relini G. 1998. I progressi della ricerca italiana sulla pesca a strascico. *Biologia Marina Mediterranea,* **5**: 3-21.

Relini G., Bertrand J. & Zamboni A (eds) 1999. Synthesis of the knowledge on bottom fishery resources in the Central Mediterranean (Italy and Corsica). *Biologia Marina Mediterranea*, **6**: 680-686.

Roper C.F.E. & Voss G.L. 1983. Guidelines for taxonomic descriptions of cephalopod species. *Memoirs of the National Museum Victoria*, **44**: 48-63.

Sánchez P. 1981. Características bioecológicas de *Illex coindetii* (Vérany, 1837) en el Mar Catalán. Ph.D. thesis, Universidad de Barcelona: 219 p.

Smale M.J., Clarke M.R., Klages N.T.W. & Roeleveld M.A. 1993. Octopod beak identification. Resolution at a regional level (Cephalopoda, Octopoda, southern Africa). *South African Journal of Marine Science,* **13**: 269-293.

Strauss R.E. 1987. On Allometry and Relative Growth in Evolutionary Studies. *Systematic Zoology*, **36**: 72-75.

Sweet S.S. 1980. Allometric inference in morphology. *American Zoologist*, **20**: 643-652.

Wolff G.A. 1982. A beak key for eight eastern tropical Pacific cephalopod species with relationships between their beak dimension and size. *Fishery Bullettin*, **80**: 357-370.