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Contributions to knowledge on the maturation and fertility of the common octopus *Octopus vulgaris* Cuvier, 1797 on the Portuguese coast

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ABSTRACT

The aim of the present study was to study the reproduction of the common octopus *Octopus vulgaris* Cuvier, 1797 at three locations on the mainland Portuguese coast. The results showed a higher occurrence of mature females in May-July and November at both Cascais and Santa Luzia, and in February and November at Viana do Castelo. Mature males were found year round. The fertility of females from Santa Luzia was higher (average of 230 000 oocytes), which could be due to this location's more favourable environmental conditions. At Cascais, the average was 140 000 oocytes, and at Viana do Castelo, 120 000. Our results could be useful in drawing up more suitable management measures for octopus Portuguese stocks.

Keywords: Common octopus, reproduction, fertility, environmental conditions, stock management.

RESUMEN

Contribución al conocimiento de la madurez sexual y la fecundidad del pulpo común* Octopus vulgaris *Cuvier, 1797 en la costa portuguesa

El objetivo es el estudio de la reproducción del pulpo común Octopus vulgaris *Cuvier 1797 en tres localidades de la costa continental portuguesa. Los resultados demostraron un mayor registro de hembras maduras en mayo-julio y noviembre en Cascais y Santa Luzia, y en febrero y noviembre en Viana do Castelo. Hay machos maduros durante todo el año. La fecundidad de las hembras es mayor en Santa Luzia (con un promedio de 230 000 oocitos), lo que estaría asociado a las condiciones ambientales más favorables de esta localidad. En Cascais y Viana do Castelo el promedio fue de 140 000 y 120 000 oocitos, respectivamente. Estos datos podrán ser útiles para la propuesta de medidas más adecuadas para la gestión de las poblaciones de esta especie en las costas portuguesas.*

Palabras clave: *Pulpo común, reproducción, fertilidad, condiciones ambientales, gestión de poblaciones.*

INTRODUCTION

Cephalopod fisheries are among the few with some potential for expansion on a worldwide basis (Caddy and Rodhouse, 1998), and there is evidence that the fishing effort has changed ecological conditions, favouring cephalopods over other species (Balguerías and Quintero, 1998; Faure, 2002). In particular, the common octopus *Octopus vulgaris* Cuvier, 1797 is currently one of the main species in

Portuguese fisheries. In 1999 it was the second species in economic value and the fourth in landed weight (Sousa Reis *et al.*, 2001). A considerable increase in exploitation has occurred since the 1970s, when the Algarve-based fleet was responsible for more than 50 % of the total value and landings in Portugal. This percentage had dropped to 36 % by 1999 (*op. cit.*), due to increased exploitation in other places on Portugal's west coast, using clay pots and other traps, and also to a higher yield of trawling since 1989 (Cunha and Moreno, 1994).

The present study was part of the project POCTI/CTA/1707/95, CORRAM (Cefalópodes Octopodídeos: Relação do Recurso com o Ambiente Marinho), aimed at providing new data on the biology of *O. vulgaris* in Portuguese waters. Research to update present knowledge on the reproductive biology of this species should be given priority status, because the increasing exploitation of the common octopus, together with its high economic value and importance as a natural marine resource, mean that more adequate management measures for Portuguese stocks are required.

O. vulgaris has a short life cycle, perhaps only one year, as indicated by recent tagging experiments in natural environments (Domain, Jouffre and Caverivière, 2000; Caverivière, 2002), which have found lower ages than those estimated by indirect methods (Mangold, 1983). However, a reliable method for age determination is lacking, despite some progress using the upper beak microstructure (Raya and Hernández-Gonzalez, 1998; Hernández-López, Castro-Hernández and Hernández-García, 2001).

Common octopus reproduction is classified as simultaneous terminal reproduction (Rocha *et al.*, 2001), with a high number of eggs laid and small planktonic paralarvae with a high, but very variable, mortality rate which depends on environmental conditions, having consequences for subsequent levels of recruitment (Cavarevière, 2002; Faure, 2002). In the juvenile and adult stages, temperature and prey availability play a very important role due to their influence on growth and maturation. At higher temperatures, the *O. vulgaris* grows faster due to an increase in food ingestion (Mangold and Boletzky, 1973), since temperature does not seem to affect the rate of food conversion, which is about 50 % (Mangold, 1997). However, for a given temperature, there is a wide variability in individual growth, as has been shown in the laboratory (Mangold and Boletzky, 1973) and by tagging experiments in natural environment (Domain, Jouffre and Caverivière, 2000; Jouffre, Caverivière and Domain, 2002). Growth is very important in *O. vulgaris*, because larger females have higher reproductive potential (Mangold, 1987), and also due to the relationship between somatic growth and maturation, since rapidly growing individuals will attain sexual maturity earlier (Mangold, 1983).

The present study aimed to contribute to knowledge on the *O. vulgaris* life cycle along the Portuguese continental coast; namely, its maturation, seasonality and fertility, related to the different environmental conditions of the three locations.

MATERIALS AND METHODS

Sampling was performed between January 1999 and August 2000 by the commercial fleet at three locations on the Portuguese coast (figure 1), Viana do Castelo (north), Cascais (centre) and Santa Luzia/Tavira (south). About 20 individuals were captured monthly at each location, for a total of 1 237 individuals, 574 males and 663 females. Biometrical parameters (weight and mantle length) and sex were determined locally, and the reproductive organs were frozen for later laboratory analysis.

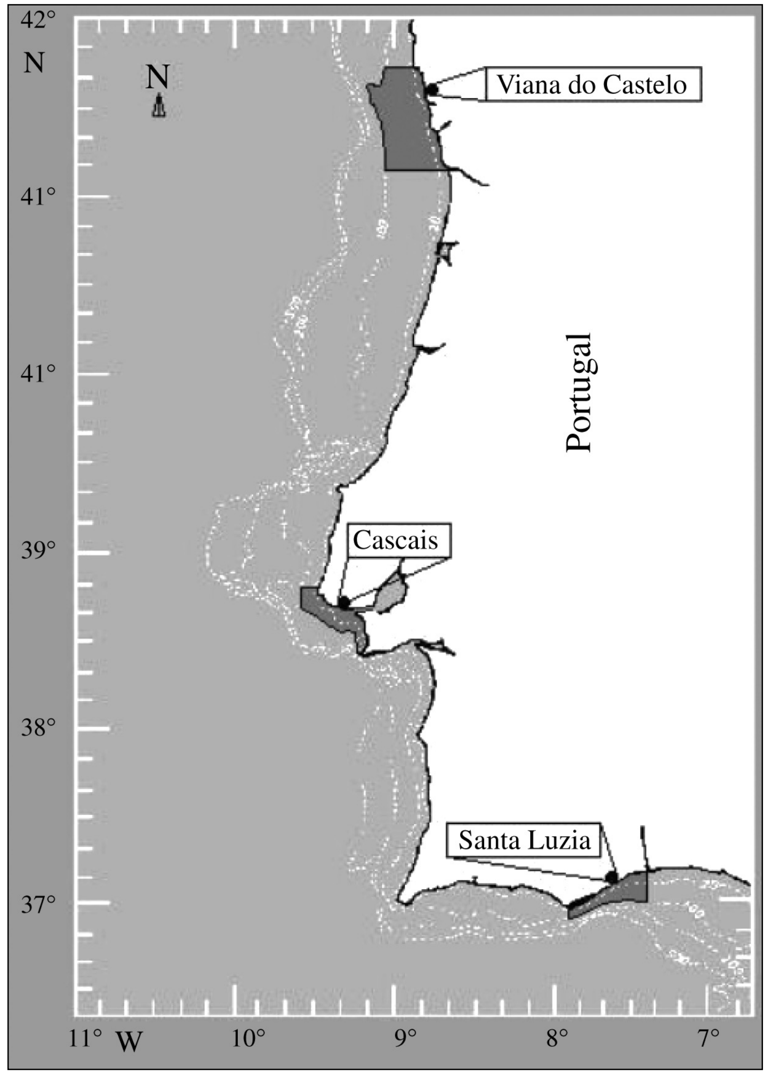
Fishing regulations prohibit the capture of individuals weighing less than 750 g; consequently, the sampling range was reduced, with individuals weighing less than this minimum representing only 10 % of the total individuals captured.

Data on the three locations' temperature was provided by Portugal's Institute of Meteorology. Information concerning prey availability was taken from Marques and Sousa Reis (2000).

In the laboratory, the female reproductive organs were weighed and measured for later calculation of the reproductive indices (Gonad-Somatic Index, Hayashi Index and Oviducal Gland Index). The number of spermatophores and their length (without flagella) were also determined from mature males in order to study male fertility.

The maturation stages were determined using visual characters, according to Gonçalves (1993), and the Project CORRAM Protocol: relative size, colour and appearance of reproductive organs. The most important details considered to determine the maturity stage were the relative size and as-

Figure 1. Fishing grounds and sampling sites



pect of the oviducal glands and ovary, for females, and the presence of spermatophores and Needham's sac aspect, for males. The size at maturity in females was determined using maturation curves.

To evaluate female fertility at the three locations, the number of oocytes was estimated in 87 ovaries. The tissue around the oocyte mass was removed from each ovary, and the oocyte mass was weighed. The total number of oocytes was obtained by counting three sub-samples, averaged and multiplied by total weight of the oocyte mass. The sub-samples were preserved using Gilson's solution, taking advantage of its capacity to harden the oocytes and, at the same time, chemically separate them from the surrounding tissue (Lowerre-Barbieri and Barbieri, 1993), making the counting an easier procedure.

RESULTS

Santa Luzia had the highest means for seawater surface temperature, between about 1 ºC (in winter months) and 3 ºC (summer months) higher than Cascais (figure 2). In Cascais, the temperature was slightly higher (about 0.5 ºC to 1 ºC) than in Viana do Castelo. Santa Luzia also had the highest prey availability (and more abundance of bivalves), followed by Viana do Castelo and, finally, Cascais. However, in the latter case, there could have been an important underestimate, because a different sampling method was used (Marques and Sousa Reis, 2000).

In both sexes, there are significant differences for weight and mantle length (table I). There are also significant differences for the multiple comparison between the three locations, except for the

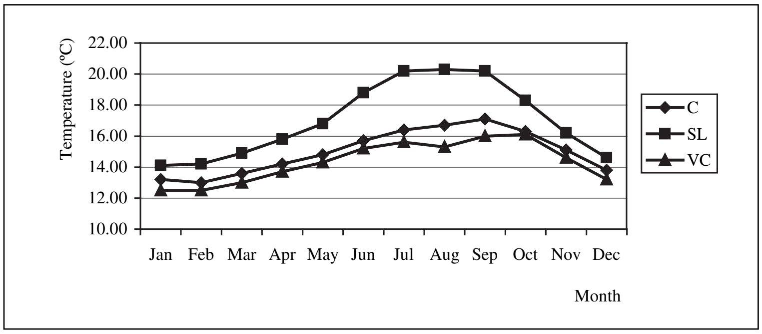


Figure 2. Mean monthly seawater surface temperature at the three locations (data from Portugal's Institute of Meteorology). (C): Cascais; (VC): Viana do Castelo; (SL): Santa Luzia/Tavira

male mantle length between Cascais and Viana do Castelo.

Females were more abundant, with sex ratios of 1.28:1, 1.17:1 and 1.04:1 in Cascais, Santa Luzia/Tavira and Viana do Castelo, respectively. However, the χ^2 test showed no significant deviation from the 1:1 proportion, whether monthly ($0.169 < p < 0.692$) or seasonally ($0.086 < p < 0.305$).

Mature females were observed almost year round, with a higher predominance in the February-August period. September-October and December-January were those months when the occurrence of mature females was lower or nil. A secondary peak in November was common for the three locations. In Viana do Castelo, the major peak was in February, followed by a lower one in May. In Cascais, the main maturation period occurred between June and August, reaching a maximum in July. Despite some fluctuations, the period of major occurrence of mature females in Santa Luzia/Tavira was between March and August, reaching the maximum observed in May (figure 3).

Table I. Major findings reported in the present paper, and statistical tests. Mean ± standard deviation, sample size in parentheses. The observed values at the three locations were compared with a Kruskal-Wallis test (KW) or with a one-way anova test (F). (ns): non-significant, $p > 0.05$; (*): $p < 0.05$; (**): $p < 0.01$; (***): $p < 0.001$), followed by a Dunn test (for KW) or a Tukey-Kramer test (for F) (superscript with identical letters indicates non-significant difference, $p > 0.05$). (F): females; (M): males; (W): weight; (ML): mantle length. (Sp.N): number of spermatophores; (Sp.L): length of spermatophores. (ON): estimated number of oocytes

	Cascais	S. Luzia	V. Castelo	Test
		Biometrics		
F W (g)	1 490.08 ± 686.77 (226)^{a}	1 877.04 ± 918.17 (233)^{b}	1 190.17 ± 501.86 (204)^{c}	KW = 90.109 ***
M W (g)	1 347.54 ± 626.25 (177)^{a}	1 752.37 ± 1021.0 (199)^{b}	1 163.44 ± 424.77 (196)^{c}	KW = 45.150 ***
F ML (mm)	167.66 ± 30.16 (226)^{a}	176.64 ± 28.85 (233)^{b}	157.08 ± 21.52 (204)^{c}	KW = 55.014 ***
M ML (mm)	156.44 ± 23.05 (177)^{a}	169.5 ± 30.73 (199)^{b}	152.62 ± 17.76 (198)^{a}	KW = 37.339 ***
		Male fertility		
Sp.N	117.0 ± 63.96 (116)	109.52 ± 73.52 (123)	108.41 ± 60.72 (135)	KW = 3.082 ^{ns}
Sp.L (mm)	23.3 ± 4.01 (111)^{ab}	24.43 ± 4.6 (121)^{a}	22.81 ± 3.68 (130)^{b}	F = 5.093 **
		Female fertility		
ON	141 113 ± 60 180 (35)^{a}	231 321 ± 80 317 (21)^{b}	119 787 ± 63 242 (31)^{a}	F = 18.905 ***
		Female size at maturity		
M_{25} (g)	1 250	1 800	1 100	-
M_{50} (g)	1 750	2 400	1 350	-

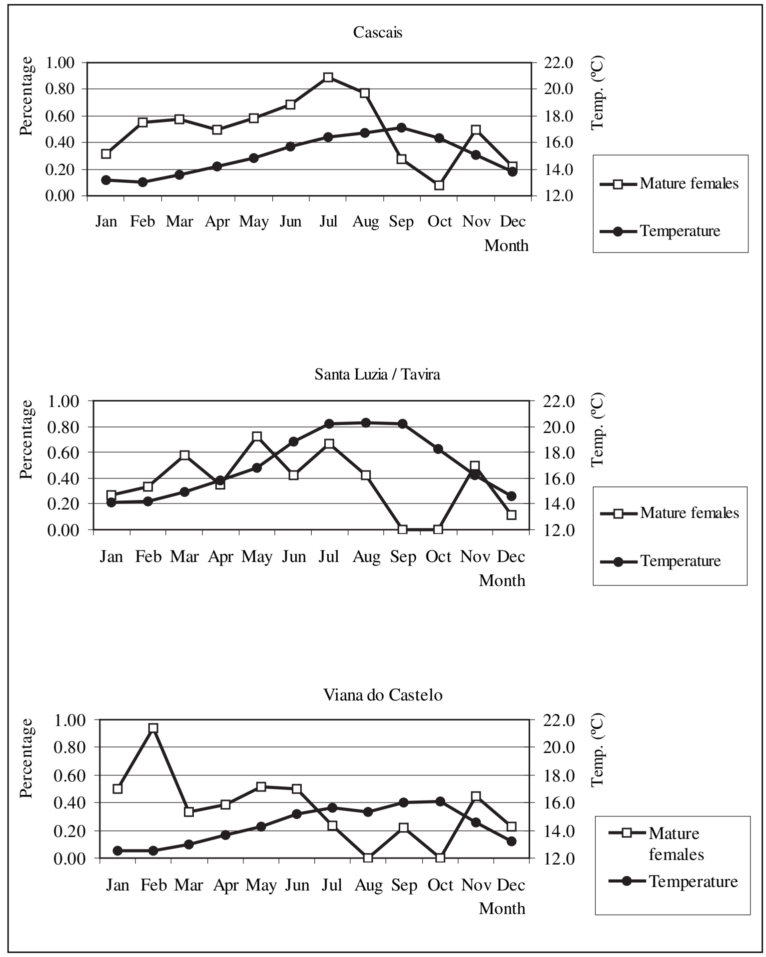


Figure 3. Occurrence of mature females and mean seawater surface temperature at the three sampling locations. (Temp.): temperature

The maturation indices showed a similar variation (taking into account that the Hayashi Index is an inverse index). Maturation size values are shown in table I (M_{25} and M_{50} are the sizes at which 25 % and 50 %, respectively, of the females were mature).

Regarding female fertility (table I), Santa Luzia/Tavira was the location with the highest mean fertility, of about 230 000 oocytes per female, followed by Cascais with about 140 009 oocytes, and finally Viana do Castelo with 120 0000 oocytes; these differences were significant. Nevertheless, there were significant differences between Santa Luzia and the other two locations, but not between Cascais and Viana do Castelo. Figure 4 shows the correlation between female weight and fertility ($r^2 = 0.65$).

Mature males were observed all year at the three locations, consisting of about 80 % of the total observed males. The values observed for mature male fertility (number of spermatophores and spermatophore length) are summarised in table I. There were no significant differences regarding the number of spermatophores. However, significant differences were found concerning spermatophore length, although not between Cascais and Santa Luzia or Cascais and Viana do Castelo –only between Santa Luzia and Viana do Castelo. The correlation between male weight and spermatophore size was relatively small ($r^2 = 0.52$).

DISCUSSION

As expected, octopi from Santa Luzia/Tavira were larger than the ones from the other two locations. The locale's higher temperature increases food consumption and growth rate, and since there is also higher prey availability, the octopi reach a higher weight. In Santa Luzia, the diet is also richer in bivalves, which could also explain (together with higher seawater temperatures) a higher growth rate for *O. vulgaris* in this area (Sousa Reis, 1985); this phenomenon was also observed in Senegal (Caverivière, 2002).

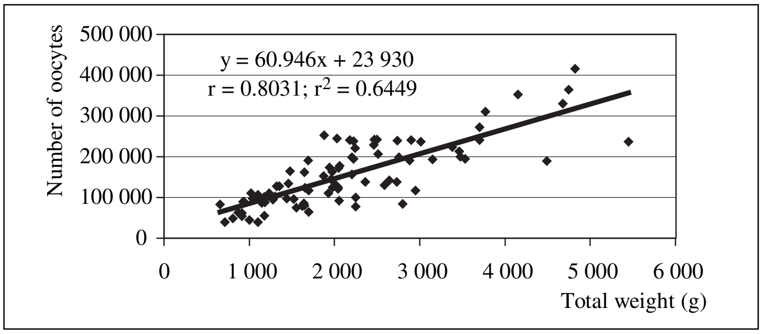


Figure 4. Number of eggs vs. weight, n = 87

Usually, the sex ratio is assumed to be 1:1 (Wells, 1978), although normally this is not really the case in fisheries, and some field reports, as pointed out by Mangold-Wirz (1963), and Hernández-García, Hernández-López and Castro-Hernández (2002). Different sampling strategies and sexual behaviour may be the cause for this, more than differences in the natural environment (Wells, 1978; Gonçalves, 1993). Other extensive field studies (Gonçalves, 1993; Quetglas *et al.*, 1998; Caverivière, 2002, the latter regarding small and average-sized individuals in Senegalese waters) have shown no significant differences between the sexes, and therefore, the observations made here are in keeping with the literature.

The occurrence of mature females rises with temperature, and this can be explained by the fact that the rate of metabolic processes accelerates with increasing temperatures. However, in some hotter months, the occurrence of mature females was low. After the temperature dropped between September and October, a secondary peak was observed in November. This fact must be related to the *O. vulgaris* reproduction strategy: in the months with high temperatures, the higher growth rate will be reflected in a larger number of eggs to be laid in the following months, when the temperature starts to decrease and maturation occurs. It is noteworthy that a small maturity peak observed in September in Viana do Castelo followed a slight drop in temperature between July and August. Females that failed to mature in November, since their maturation was retarded by low temperatures in December and January, possibly originated the February peak in Viana do Castelo. Table II summarises the observed spawning seasons in selected study cases. As at other locations (especially the Mediterranean and northwest African coast), the reproductive season on the Portuguese coast is wide and irregular, although it has main periods.

In continental Portuguese waters, *O. vulgaris* spawning depends only on the availability of matu-

Table II. *Octopus vulgaris* spawning seasons reported in selected studies

Area	Spawning seasons	Source
Azores	May and September	Gonçalves, 1993
Mediterranean	March-October, mainly in June-July	Mangold-Wirz, 1963
		Mangold and Boletzky, 1973
		Guerra, 1975
	Irregular, between January and July	Sánchez and Obarti, 1993
	Maturing females from May to August	Quetglas *et al.*, 1998
Northeastern Atlantic coast	April-May and September-October	Guerra, 1975
Sahara Bank	Mainly in spring	Hernández-García *et al.*, 1996
(Canary Islands)		Fernández-Nuñes *et al.*, 1996
	Year-round, primary peak in April and secondary in October-November	Hernández-García, Hernández-López and Castro-Hernández, 2002
Senegal	Year-round, mainly in end of summer and secondary peak in winter	Caverivière, 2002
Subtropical Atlantic	Year-round	Wodinsky, 1972

Table III. *Octopus vulgaris* female fertility reported in selected studies

Location	Number of oocytes/eggs (× 1000)	Source
Tunisia	150	Heldt, 1948
Mediterranean	127.5-402	Mangold-Wirz, 1963
	130-260	Guerra, 1975
Azores, Portugal	2-500	Gonçalves, 1993
Saharan Bank	152-350	Hernández-García, Hernández-López and Castro-Hernández, 2002

re females, since we can observe mature males all year. This was also observed off Majorca (Quetglas *et al.*, 1998) and Senegal (Caverivière, 2002). In fact, common octopus males can mature at small sizes (Wells, 1978; Mangold, 1983), and for the present study, a 260 g (10.2 mm ML) male was considered mature, having 61 spermatophores in its Needham's sac. However, the minimum number of spermatophores needed for the beginning of male reproductive activity is unknown (Guerra, 1975), and therefore it is difficult to distinguish mature males from maturing ones. It should be noted that the high percentage of mature individuals' occurrence was due to the small amount of captured individuals weighing less than 750 g, due to fishing regulations.

There are no differences among the three locations in the number of spermatophores found in males, and this must be related to the long period of male sexual activity (Nixon, 1969; Wells, 1978), with the consequent variation of the number of spermatophores packed into the Needham's sac. However, there are differences concerning the length of the spermatophores, probably related to the size of the males. Larger males from Santa Luzia have longer spermatophores, although the correlation is relatively small.

Concerning female fertility, Mangold (1983) estimates a variation between 100 000 and 500 000 eggs. Table III sums up the obtained results for fertility in selected study cases. The results obtained in the present study fall within the normally accepted range for *O. vulgaris*. During sexual maturation, there is a reduction of protein synthesis in the muscles and an increase of free amino acids in blood which will be used to form the oocyte yolks (O'Dor and Wells, 1978). Rosa, Nunes and Sousa Reis (2001) recorded the protein content variation of Cascais, Santa Luzia and Viana do Castelo females, observing protein depletion during the months with a higher occurrence of mature females. Thus, the number of eggs laid depends on female weight (Mangold, 1987; Gonçalves, 1993), and since the Santa Luzia females were larger, higher fertility (as observed) was to be expected, followed by Cascais and, finally, Viana do Castelo (although with no significant differences between these two locations).

The management of *O. vulgaris* stocks is difficult, due to the common octopus's features and the diversity of fishing methods used. The high variability of individual growth and the extent of the breeding season (which is the case on the Portuguese coast) make it difficult to detect the possible existence of different cohorts (Jouffre, Caverivière and Domain, 2002). Due to the different characteristics of each fishing gear, proposals for management measures must take them into account. For instance, trawls exploit mostly small and immature individuals, while pots and traps exploit larger and more mature ones (Sánchez and Obarti, 1993; Tsangridis, Sánchez and Ioannidou, 2002).

The short life cycle of *O. vulgaris* may be the reason for the annual cyclic fluctuations observed in some fisheries (Quetglas *et al.*, 1998; Caverivière, 2002; Faure, 2002), and the high dependence on environmental factors certainly influences the wide fluctuation in total catches (reflecting fluctuations in the population) during consecutive years. Finally, economic and human factors must be considered to the same extent as biological elements, in the process of making rational decisions for the management of such a complex issue as cephalopod fisheries (Failler, 2002).

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