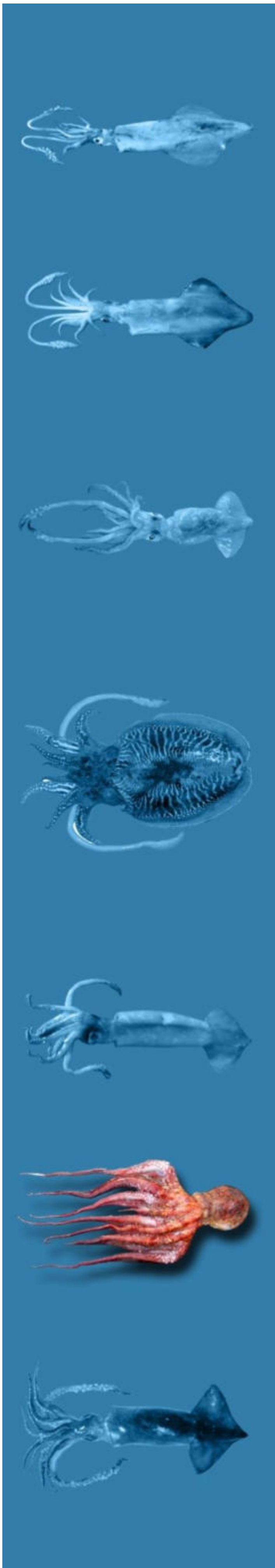
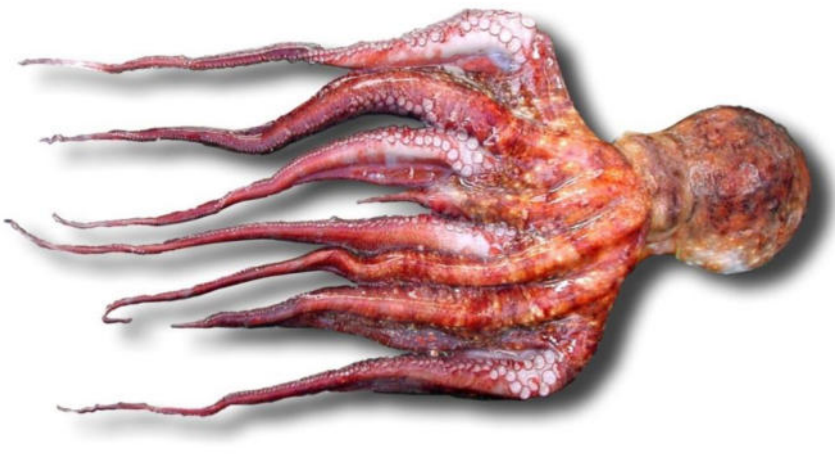
Cephalopod biology and fisheries in European waters: species accounts





Octopus vulgaris

Common octopus

3 *Octopus vulgaris* Cuvier, 1797

Pilar Sánchez, Roger Villanueva, Patrizia Jereb, Ángel Guerra, Angel F. González, Ignacio Sobrino, Eduardo Balguerias, João Pereira, Ana Moreno, A. Louise Allcock, Evgenia Lefkaditou, Graham J. Pierce, José Iglesias, and Uwe Piatkowski

Common names

Pieuvre, poulpe (France) ; Χταπόδι [chtapodi] (Greece) ; polpo (Italy) ; polvo (Portugal) ; pulpo común (Spain) ; common octopus (UK) (Figure 3.1).

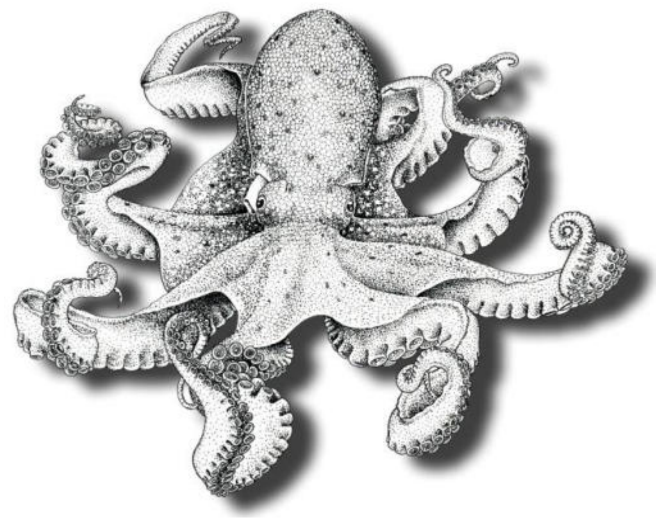


Figure 3.1. ***Octopus vulgaris*. Dorsal view. From Guerra (1992).**

Synonyms

(Following Norman and Hochberg, 2005).
Octopus albus Rafinesque, 1814: 29, *Octopus heteropus* Rafinesque, 1814: 28, *Octopus maculatus* Rafinesque, 1814: 29, *Octopus moschatus* Rafinesque, 1814: 28, *Octopus niger* Rafinesque, 1814: 28, *Octopus ruber* Rafinesque, 1814: 28, *Octopus brevitentaculatus* Blainville, 1826: 187, *Octopus tetradynamus* Rafinesque, 1814: 28, *Octopus pilosus* Risso, 1826: 4, *Octopus cassiopeia* Gray, 1849: 9, *Octopus bitentaculatus* Risso, 1854: 61, *Octopus rabassin* Risso, 1854: 67, *Octopus tritentaculatus* Risso, 1854: 63, *Octopus troscheli* Targioni-Tozzetti, 1869: 156, *Octopus octopodia* Tryon, 1879: 113, *Octopus coerulescentes* Arbanisch (Fra Piero), 1895: 267.

3.1 Geographic distribution

The common octopus, *Octopus vulgaris* Cuvier, 1797, is found in the Northeast Atlantic and the Mediterranean (Figure 3.2), and its presence is also reported in the western Atlantic (Caribbean Sea and northern South America), South Africa, India, and East Asia (Norman *et al.*, 2014; see **Remarks** section below). In the Northeast Atlantic, it extends from Dublin and Liverpool Bay (Massy, 1928), along the southern British coasts (Rees, 1950), occasionally as far as the southern North Sea (Grimpe, 1925; Adam, 1933; Jaeckel, 1958). Common along the French, Spanish, and Portuguese coasts (Magaz, 1934; Bouxin and Legendre, 1936; Sousa Reis, 1985), it is especially abundant on the Sahara Bank, off West Africa between 26 and 19°N (Bas, 1975; Bravo de Laguna, 1989), extending farther south and west to the Cape Verde Islands (Adam, 1962), and as far as the equator (Adam, 1983). Very abundant in the Azores region (e.g. Gonçalves, 1991), it is recorded from Madeira (Rees and Maul, 1956) and the Canary Islands (Hernández-García *et al.*, 1998a, 2002). It is widely distributed and abundant throughout the Mediterranean Sea (Mangold and Boletzky, 1987; Bello 2004; Salman, 2009**),** including the western and central Mediterranean (Mangold-Wirz, 1963a**;** Sánchez, 1986a; Belcari and Sartor, 1993; Jereb and Ragonese, 1994; Cuccu *et al.*, 2003a), the Adriatic Sea (Casali *et al.*, 1998; Krstulović Šifner *et al.*, 2005; Piccinetti *et al.*, 2012)**,** the Ionian Sea (Lefkaditou *et al.*, 2003a), and the Aegean Sea and the Levant Basin (D'Onghia *et al.*, 1992; Salman *et al.*, 1997, 1998; Lefkaditou *et al.*, 2003b; Duysak *et al.*, 2008). Old records of the species in the Sea of Marmara exist (e.g. Demir, 1952, in Ünsal *et al.*, 1999), but *Octopus vulgaris* has not been recorded by more recent research carried out in those waters (Katagan *et al.*, 1993; Ünsal *et al.*, 1999).

Figure 3.2. ***Octopus vulgaris.*** **Geographic distribution in the Northeast Atlantic and Mediterranean Sea.**

3.2 Taxonomy

3.2.1 Systematics

Coleoidea – Octopodiformes – Octopoda – Octopodidae – *Octopus.*

3.2.2 Type locality

Not stated in the original description of Cuvier (1797) but presumed to be western Mediterranean Sea.

3.2.3 Type repository

No type is believed to exist (see Lu *et al.*, 1995).

3.3 Diagnosis

3.3.1 Paralarvae

At hatching, paralarvae have an elongate, conical mantle. They are 2–3 mm long (total length). The arms are subequal in length, with three suckers on each arm and two chromatophores in one row on each arm. Hatchlings from the Northwest Pacific have 3–4 suckers per arm (Villanueva and Norman, 2008). See Hochberg *et al.* (1992) for a description of the full chromatophore pattern (but see also Figure 3.3 below).

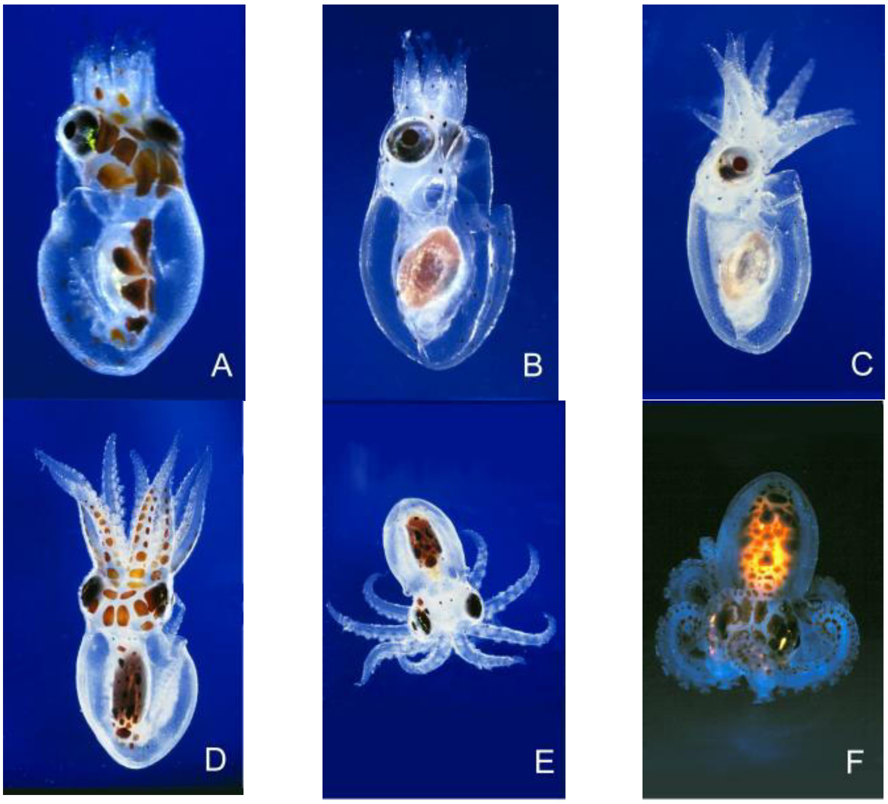


Figure 3.3. ***Octopus vulgaris*****. Individuals from hatching to settlement obtained from rearing experiments described in Villanueva (1995a). Images not to scale. Age (d) and mantle length (ML) of the individuals measured fresh are: (A) 0 d, 2.0 mm ML; (B) 20 d, 3.0 mm ML; (C) 30 d, 4.3 mm ML; (D) 42 d, 5.9 mm ML; (E) 50 d, 6.6 mm ML; and (F) 60 d, 8.5 mm ML. Octopuses from this experiment settled between 47 and 54 d. Individuals were photographed under anaesthesia (2% ethanol) potentially causing chromatophore contraction in some cases. Photos: Jean Lecomte, modified from Villanueva *et al*. (1995).**

3.3.2 Juveniles and adults

Adults reach 40 cm ML and 140 cm total length. They have a muscular sac-shaped mantle with a wide pallial aperture that extends beyond its lateral edges. The arms are robust at the base: the lateral arms are longest, and the dorsal ones shortest. The arms have two series (i.e. longitudinal rows) of suckers. Suckers 15–17 of arms 2 and 3 are enlarged in adults, especially in males. The third right arm of mature males is hectocotylized. The ligula is short and spoon-shaped. There are 7–11 lamellae on the outer side of the gill, including terminal lamellae. There are four papillae in the dorsal part of the mantle (one situated in the anterior part, another posterior, and two laterals). The species has reticulated skin, with four whitish spots: two between the eyes and two below the first dorsal papilla. The lower mandible (beak) is illustrated in Figure 3.4 (see also Nixon, 1969, and Clarke, 1986).

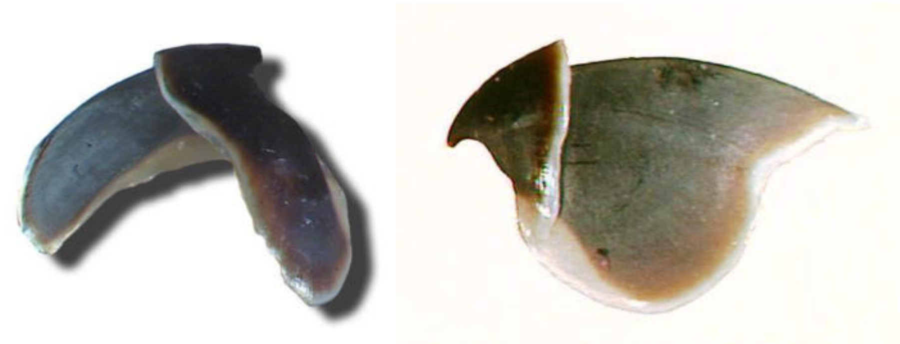


Figure 3.4. ***Octopus vulgaris*****. Lower beak (left) and upper beak (right), lateral views. Photo: Evgenia Lefkaditou.**

3.4 Remarks

Octopus vulgaris was traditionally believed to be a cosmopolitan species with a world-wide distribution (Roper *et al.*, 1984). Mangold and Hochberg (1991) and Mangold (1998) redefined its boundaries, suggesting that its distribution was restricted to the Mediterranean and the eastern Atlantic. Subsequent molecular work using the mitochondrial markers 16S rRNA and COIII showed, however, that the distribution of *O. vulgaris* in the Atlantic apparently extends to southern Brazil (Söller *et al.*, 2000) in the west, to Lanzarote and Senegal in the east, and as far south as Tristan de Cunha and False Bay, South Africa (Oosthuizen *et al.*, 2004; Warnke *et al.*, 2004; Teske *et al.*, 2007), and that it is also in the Indian Ocean (Guerra *et al.*, 2010a). Samples from Japan and Taiwan in the Pacific also appear to be conspecific with *O. vulgaris*. Nonetheless, those studies also showed that, throughout this distribution, there are octopuses that have been previously attributed to *O. vulgaris* that are, in fact, distinct species, e.g. *Octopus insularis* recently described from Brazil (Leite *et al.*, 2008). Substantial differences between the chromatophore patterns of paralarvae from the eastern and western Atlantic have been observed, which could provide evidence for the existence of distinct populations or even cryptic *O. vulgaris*-like species along the southern Brazilian coast (Vidal *et al.*, 2010). See Fioroni (1970), Packard (1974), and Messenger (2001), among others, for accounts of chromatophores in *O. vulgaris*.

According to Norman *et al.* (2014), the name *Octopus vulgaris* is currently applied to at least five morphologically similar, but unresolved, taxa with disjunct distributions across subtropical and temperate waters worldwide:

Octopus vulgaris sensu stricto	Mediterranean Sea, Central and Northeast Atlantic
Octopus "vulgaris" type I	Tropical western Central Atlantic
Octopus "vulgaris" type II	Subtropical Southwest Atlantic: Brazil
Octopus "vulgaris" type III	Temperate South Africa and southern Indian Ocean
Octopus "vulgaris" type IV	Subtropical/temperate East Asia

All are of high profile and have high fisheries value. All forms produce small eggs with planktonic hatchlings capable of wide dispersal across the open ocean, potentially supporting gene flow between the disjunct distributions of at least some forms. The species complex is in urgent need of revision and is highly likely to contain cryptic species (Norman *et al.*, 2014). Clearly, the true range of *O. vulgaris* has not yet been elucidated; however, its distribution throughout the Mediterranean and eastern Atlantic is undisputed.

3.5 Life history

The life history of the species is annual, with spawning year-round but with peaks in spring and autumn.

3.5.1 Egg and juvenile development

The early part of the life cycle of this species is reviewed by Mangold and Nixon (1996). The duration of the egg stage depends on incubation temperature, ranging from 20–30 d at 25°C to 100–120 d at 13°C (Mangold, 1983a). Under laboratory conditions, the duration of the planktonic phase seems to be inversely related to rearing temperature, ranging from 33 d at 25°C to nearly 2 months at 21°C. Recently, benthic juveniles of 8–10 mm ML have been found with 23–25 suckers per arm and weighing 100–125 mg fresh weight. Subadults reach 0.5–0.6 kg by 6 months after hatching in the laboratory (Itami *et al.*, 1963; Imamura, 1990; Villanueva, 1995a; Iglesias *et al.*, 2004; Okumura *et al.*, 2005; Carrasco *et al.*, 2006).

Moreno *et al.* (2009) found octopus paralarvae in plankton samples from Portuguese coastal waters (from 57 surveys during the period 1986–2004) mainly in the second half of the year, with peaks in July and November, probably related to two seasonal spawning peaks in Portuguese waters. Those authors also report a relationship between paralarva abundance and favourable upwelling conditions. In Galicia, seasonal upwelling is in late summer and early winter, and the (single) peak in hatchling abundance coincides with maximum zooplankton abundance (Otero *et al.*, 2007).

3.5.2 Growth and lifespan

The life cycle (embryonic and post-hatching life) has been completed under laboratory conditions, resulting in a lifespan of 356 and 339 d for a female and a male of 1.8 and 1.6 kg at death, respectively, reared with food in excess and in temperatures of 17–23°C (Iglesias *et al.*, 2004).

Sánchez and Obarti (1993) reported a maximum age of 15 months in the Mediterranean. Katsanevakis and Verriopoulos (2006) estimated a lifespan of 12–15 months in the eastern Mediterranean using a time-variant, stage-classified, matrix population model based on monthly density measurements of four size stages (1, <50g; 2, 50–200 g; 3, 200–500 g; and 4, >500 g) recorded during scuba diving. Perales Raya (2001) estimated the maximum age of *O. vulgaris* to be 12 months in Sahara Bank populations based on beak growth increment counts, and Hernández-López *et al.* (2001) estimated the maximum ages of males and females to be 12.3 and 13.3 months, respectively, in Canary Island populations. Smale and Buchan (1981) reported a maximum age of 12 months for females and 15 months for males under culture conditions off the east coast of South Africa, whereas Domain *et al.* (2000) reported lifespans of 14–17 months for females and 18–20 months for males in Senegalese waters. Daily increment deposition in *O. vulgaris* stylets has been validated in individuals maintained in aquaria and ranging in size from 248 to 1470 g (Hermosilla *et al.*, 2010).

Octopus vulgaris is characterized by rapid non-asymptotic growth (Alford and Jackson, 1993), with great individual variability in increases in length or weight. This variability has been found both in culture (Iglesias *et al.*, 2004) and in the wild (Domain *et al.*, 2000). Growth rate is influenced mainly by diet (Forsythe and van Heukelem, 1987; García García and Cerezo Valverde, 2006; Cerezo Valverde *et al.*, 2008) and temperature (Aguado Giménez and García García, 2002), although several authors have noted extreme variation in growth, even among individuals reared at the same temperature and fed the same food (Forsythe and van Heukelem, 1987; Villanueva, 1995a; Semmens *et al.*, 2004).

As in most if not all cephalopods, instantaneous relative growth rates (i.e. % increase in BW d^{-1}, or, sometimes % increase in ML d^{-1}) decrease in older animals, values ranging from 6.14 (%BW d^{-1}) in the smallest individuals to 0.94 in the largest (Forsythe and van Heukelem, 1987). Villanueva (1995a) measured daily growth rates of 2.49% ML d^{-1} and 8.19% BW d^{-1} during the first 2 months of life.

Growth rates, usually for large animals, have been measured in captivity by a number of authors. Mangold and Boletzky (1973) recorded growth rates at temperatures between 10 and 20°C. Although they noted great variation between individuals, daily growth rate was generally faster at higher temperatures. At 20°C, daily growth ranged from 1.68 to 4.14% of BW, although it reached 5% over short periods. This compares with 1.50–1.91% (2.74%) at 15°C and 0.78–1.01% (1.57%) at 10°C. Pham and Isidro (2009) obtained growth rates of 0.67–1.47% of BW d^{-1}. Estefanell *et al.* (2013) recorded growth rates of 1.6–1.8% of BW d^{-1} in captivity. Captive and wild growth rates were measured by Domain *et al.* (2000), the former based on tagging animals off Senegal, in waters of >20°C. Growth was slower in males than in females. The growth rate was ca. 1.36% of BW d^{-1} (both sexes combined) in captivity and between 0.85 (males in 1997) and 1.51% (females in 1998) in the wild, with slower growth at temperatures >25°C.

Length–weight relationships are summarized in Table 3.1.

Table 3.1. *Octopus vulgaris.* Length–weight relationships in different geographic areas for females (F), males (M), and sexes combined (All). Original equations are converted to W = aML^b, where W is body mass (g) and ML is dorsal mantle length (cm).

Region	*a*	*b*	Sex	Reference
Galicia	0.442	2.918	F	Guerra (1981)
	0.296	3.029	M	
	0.365	2.961	All	
	2.9	2.17	All	Otero *et al.* (2007)
Gulf of Cádiz	3.277	2.267	F	Silva *et al.* (2002)
	2.489	2.369	M	
	2.895	2.313	All	
South Africa	0.587	2.83	F	Smale and Buchan (1981)
	0.758	2.74	M	
	0.626	2.8	All	
Northwestern Mediterranean Sea	0.542	2.804	F	Guerra and Manriquez (1980)
	0.350	2.988	M	
	0.420	2.917	All	
Balearic Islands	0.413	2.916	F	Quetglas *et al.* (1998a)
	0.442	2.882	M	
	0.437	2.889	All	
Catalan Sea	1.654	2.576	F	Sánchez and Obarti (1993)
	3.306	2.323	M	
Gulf of Alicante	0.51	2.87	All	González *et al.* (2011)
Tunisia	0.371	2.8335	F	Jabeur *et al.* (2012)
	0.485	2.834	M	

	0.399	2.915	All	
Aegean Sea	0.138	2.60	All	Lefkaditou *et al.* (2007)
Northeastern Levant Sea	0.031	3.841	F	Duysak *et al.* (2008)
	0.1685	3.1219	M	
	0.1399	3.2001	All	

3.5.3 Maturation and reproduction

In Galicia, the sex ratio is ca. 1:1 most of the year, although females dominate samples collected in May (1:0.73) and September (1:0.58) (Otero *et al.*, 2007). Quetglas *et al.* (1998a) recorded the sex ratio in the Balearic Sea (Mediterranean) for each season and found no significant differences from 1:1. In the Gulf of Cádiz, the annual sex ratio was estimated as 1.06:1 (male:female) (Silva *et al.*, 2002). However, Smale and Buchan (1981) reported that, off South Africa, male numbers dominated during the months March–September and females during October–February (with the greatest departure from 1:1 in November when the sex ratio was ca. 3:1 in favour of females).

Females mature larger than males (Lourenço *et al.*, 2011a, b). In Galicia, weight at 50% maturity ($BWm_{50\%}$) was 1788 g for females and 903 g for males. The smallest mature females were 12 cm ML and 394 g BW, and the smallest mature males were 10 cm ML and 323 g BW (Otero *et al.*, 2007). In the Gulf of Cádiz, lengths (ML) and weights (BW) of the smallest mature specimens sampled by Silva *et al.* (2002) were 9.4 cm and 250 g in males, and 12 cm and 580 g in females.

Length at maturity ($MLm_{50\%}$) was 10.4 cm ML in males and 17.6 cm ML in females, and $BWm_{50\%}$ was estimated at 671 g in males and 2023 g in females. In the western Mediterranean, mantle length at first maturity is ca. 9.5 cm in males and 13.5 cm in females (Mangold-Wirz, 1963a). Cuccu *et al.* (2013) reported that the smallest mature specimens sampled in Sardinian waters (central western Mediterranean Sea) were 45 mm ML and 190 g BW in males, and 90 mm ML and 310 g BW in females. The $MLm_{50\%}$ was 70 mm for males and 120 mm for females, and $BWm_{50\%}$ was 320 g and 520 g for males and females, respectively. Males matured at 170–470 d, younger than females (210–390 d).

The spawning season extends throughout the year, with two peaks: one in spring and one in autumn in Northeast Atlantic populations. The main spawning season in the Mediterranean is June–July (Mangold, 1997). Rees and Lumby (1954) refer to spawning beginning in May in the English Channel, the precise timing varying with location and, possibly, temperature. In Galician waters, maturity and reproductive indices indicated spring to be the most important spawning season, although mature females are present during the months December–August, with a peak in May that is related to seasonal upwelling (Otero *et al.*, 2007). In northwestern Portugal, the species spawns during the period March–July, again coinciding with the northwest coast upwelling season, whereas on the south coast of Portugal, the species spawns mainly in summer between August and September, although there is sometimes a minor spawning peak in early spring along the south coast (Lourenço *et al.*, 2011a). In the Gulf of Cádiz, the breeding season extends from February to October, with spawning peaks in April–May and August (Silva *et al.*, 2002). In the Gulf of Alicante, the gonadosomatic index peaks between April and July for males and in July for females (González *et al.*, 2011).

The potential fecundity of mature females ranges from 70 000 to 634 445 oocytes (Mangold-Wirz, 1963a; Silva *et al.*, 2002; Otero *et al.*, 2007). Females attach small oval eggs of ca. 2.5 × 1 mm (Mangold-Wirz, 1963a) to hard substrata, mainly rocks, and care for the eggs until hatching.

The maximum number of spermatophores observed in the Needham's sac is 633 (Otero *et al.*, 2007), and the number and length of spermatophores tends to increase with size of male. In Galician waters (northwestern Spain), mean (± s.d.) potential fecundity was estimated at 221 447 ± 116 031 oocytes and mean oocyte length at 3.0 ± 0.8 mm. The mean number of fully developed spermatophores was 182 ± 88, with a mean length of 48.8 ± 10.6 mm (Otero *et al.*, 2007).

3.5.4 Natural mortality

The natural mortality of cephalopods during paralarva and settlement stages is high and is strongly related to environmental factors, which ultimately control the abundance of food for the paralarvae (zooplankton). The link between upwelling episodes and subsequent fishery catch rates for octopuses in Galicia is consistent with environmental factors having a major impact during the pelagic stage of the life cycle (Otero *et al.*, 2008). In the eastern Mediterranean, more than 50% of just-settled individuals die within three months, and the mortality rate falls thereafter up to ca. 6 months after settlement (Katsanevakis and Verriopoulos, 2006).

3.6 Biological distribution

3.6.1 Habitat

Octopus vulgaris is a merobenthic species inhabiting temperate, tropical, and subtropical waters. It is found from the coast out to the outer edge of the continental shelf (200 m) in temperatures of 6–33°C. Rees and Lumby (1954) note that the species tolerates temperatures as low as 6°C in the English Channel. It is a stenohaline species, tolerating salinity ranging from 29 (Delgado *et al.*, 2011) to 40 (Mangold, 1983a).

Local density of *O. vulgaris*, as has been documented for other species of octopuses, is affected by the availability of solid material (rocks, stones, shells, anthropogenic litter, etc) to be utilized for den construction (Katsanevakis and Verriopoulos, 2004).

3.6.2 Migrations

This species undertakes limited seasonal migrations. According to Rees and Lumby (1954), octopuses appear to move away from inshore waters in late summer and spend winter in deeper, offshore waters. No segregation between sexes has been observed (Mangold, 1983a).

3.7 Trophic ecology

3.7.1 Prey

The diet of *O. vulgaris* consists of crustaceans, fish, molluscs, and polychaetes (Table 3.2). No significant variation in diet has been reported for subadults and adults. Anraku *et al.* (2005) showed that prey selection under experimental conditions depended on chemical stimuli detected by chemoreceptors in the arms and lip (see Graziadei, 1971, for a description of the nervous system of the arms). Octopuses drill holes in the shells of shelled molluscs, allowing them to inject cephalotoxin, secreted by the posterior salivary glands, to paralyse the prey (e.g. Ghiretti, 1959, 1960; Cariello and Zanetti, 1977; Nixon, 1979; Nixon *et al.*, 1980).

Table 3.2. Prey composition of *Octopus vulgaris*, as known from studies in the Mediterranean Sea, Northeast Atlantic, and Sahara Bank (compiled from Nigmatullin and Ostapenko, 1976[1]; Guerra, 1978[2]; Ambrose and Nelson, 1983[3]; Nixon and Budelmann, 1984[4]; Sánchez and Obarti 1993[5]; Quetglas *et al.* 1998a[6]; Kallianiotis *et al.*, 2001[7]; Roura *et al.*, 2012[8]; Á. Guerra, pers. comm.[9])

Taxon	Species
Osteichthyes	indet.[6,8]
Blenniidae	*Blennius ocellaris* (butterfly blenny)[6], indet.[9]
Caproidae	*Capros aper* (boarfish)[6]
Carangidae	*Decapterus* spp.[1], *Trachurus* spp.[1]
Carapidae	*Carapus acus* (pearl fish)[6]
Centracanthi-dae	*Centracanthus cirrus* (curled picarel)[6]
Cepolidae	*Cepola macrophthalma* (as *C. rubescens*) (red bandfish)[2,7]
Clupeidae	*Sardinella* spp.[1], indet.[2]
Congridae	*Conger conger* (European conger)[7]
Gobidae	*Gobius niger* (black goby)[7], indet.[9]
Labriidae	indet.[9]
Lotidae	*Gaidropsarus vulgaris* (three-bearded rockling)[6]
Ophichthidae	*Ophichthus rufus* (Rufus snake-eel)[6], *Leptocephalus* spp.[1]
Ophidiidae	*Ophidion barbatum* (snake blenny)[7]
Serranidae	indet.[9]
Soleidae	indet.[1]
Sparidae	*Boops boops* (bogue)[1], *Dentex macrophthalmus* (large-eye dentex)[1], *Dentex gibbosus* (pink dentex)[1], *Dentex* spp.[1], *Pagellus acarne* (auxilliary seabream)[1], *Pagellus erythrinus* (common pandora)[1]
Trachinidae	*Trachinus* spp.[1]
Triglidae	indet.[1,9]
Uranoscopidae	*Uranoscopus* spp.[2]
Chondrichthyes	
Scyliorhinidae	*Scyliorhinus canicula* (lesser spotted dogfish)[7]
Crustacea	
Decapoda	indet.[6]
Dendrobranchi-ata-Penaeiodea	*Melicertus kerathurus*[2], *Solenocera membranacea*[2]
Pleocyemata-Anomura	*Anapagurus laevis*[2], *Anapagurus* spp.[2,5], *Galathea bolivari*[6], *G. intermedia*[6], *G. strigosa*[6], *Galathea* spp.[2,6], *Paguristes eremita*[6], *Pagurus prideaux*[6], Paguridea indet.[6], *Pisidia longicornis*[2], *Pisidia* spp.[5], indet.[8]
Pleocyemata-Brachyura	*Atelecyclus rotundatus*[6], *Atelecyclus* spp.[9], *Calappa granulata*[2], *Cancer pagurus*[9], *Carcinus maenas*[9], *C. aestuarii* (as *C. mediterraneus*)[2], *Dromia personata*[2], *Ebalia granulosa*[6], *E. tuberculosa*[6], *Ebalia* spp.[6], *Eriphia verrucosa*[9], *Ethusa mascarone*[2], *Eurynome spinosa*[6], *Goneplax rhomboides*[2,5,7], *Inachus dorsettensis*[6], *Inachus* spp.[2,9], *Liocarcinus corrugatus*[2,6], *L. depurator*[2,5,7], *L. pusillus*[6], *L. vernalis*[5], *Liocarcinus* spp.[2,6,9], *Macropodia* spp.[9], *Maja squinado*[9], *Medorippe lanata*[2], *Necora puber* (as *L. puber*)[9], *Pachygrapsus marmoratus*[9].
	Pachygrapsus spp.[2], Parthenopidae indet. [6], *Pilumnus spinifer*[6], *Pisa armata*[2], *P. nodipes*[2], *Polybius henslowii*[9], *Xantho pilipes*[6,8], indet.[5,6,8]
Pleocyemata-Caridea	*Aegaeon cataphracta* (as *Pontocaris cataphracta*)[2,5], *Alpheus* spp.[2,5], Alpheidae indet.[6], *Crangon crangon*[2], *Eualus cranchii* (as *Thoralus cranchii*)[6], *Palaemon serratus*[5], *Palaemon* spp.[2,9], *Pandalina brevirostris*[2], *Philocheras sculptus*[6], *Philocheras* spp.[2], *Processa* spp.[2], indet.[6,8]

Pleocyemata-Thalassinidea	indet.[8]
Stomatopoda	indet.[1]
Unipeltata-Squilloidea	*Squilla mantis*[2]
Euphausiacea	indet.[8]
Amphipoda	indet.[1,2]
Gammaridea	indet.[6]
Ostracoda	indet.[1]
Peracarida-Isopoda	indet.[1,6]
Cephalopoda	indet. [6]
Myopsida	*Alloteuthis africana*[1], *A. media*[6], *Loligo vulgaris*[1,2,6]
Octopoda	*Eledone moschata*[7], *Octopus vulgaris*[5,9], *Octopus* spp.[1,2]
Sepioidea	*Sepia* spp.[1,2,5,9], Sepiolidae indet.[6]
Gastropoda	indet.[5,7]
Cerithioidea	*Cerithium vulgatum*[3], *Turritella communis*[6]
Conoidea	*Raphitoma reticulata*[6]
Haliotidea	*Haliotis tuberculata*[3]
Muricoidea	*Cymbium* spp.[1]
Naticoidea	*Naticarius hebraeus*[6], *N. intricatoides*[6]
Patelloidea	*Patella caerulea*[3], *P. vulgata*[3]
Trochoidea	*Calliostoma granulatum* (granulated top shell)[6] , indet.[6]
Bivalvia	indet.[1,5,7]
Arcoida	*Arca noae*[3], *Barbatia barbata*[3], *Glycymeris glycymeris*[3]
Pectinoida-Anomioidea	*Anomia ephippium*[3]
Limoida	*Limaria tuberculata*[3]
Mytiloida	*Modiolus barbatus*[3], *Mytilus galloprovincialis*[9], *Mytilus* spp.[3]
Euheterodonta-Solenoidea	*Ensis ensis*[9]
Veneroida	*Acanthocardia tuberculata*[3], *Callista chione* (as *Pitaria chione*)[3], *Cardium* spp.[3], *Chamelea gallina*[3], *Donax semistriatus*[3], *Timoclea ovata*[3], *Venerupis geographica*[3], *Venus verrucosa*[3]
Echinodermata	
Ophiuroidea	indet.[1,5]
Polychaeta	*Laetmonice hystrix* (as *Hermione hystrix*)[4], indet.[1,5]
Foraminifera	indet.[1]

3.7.2 Predators

Coastal fish (*Epinephelus marginatus, Serranus* sp., *Atherina presbyter*) attracted to *O. vulgaris* egg masses during hatching periods have been observed preying on paralarvae (Villanueva and Norman, 2008). Further, paralarvae of 6.5–18 mm TL have been recorded in the stomach contents of albacore (*Thunnus alalunga*) (Bouxin and Legendre, 1936).

Predators of subadult and adult *O. vulgaris* include fish, marine mammals, birds, man, and other cephalopod species (Hanlon and Messenger, 1996). *Octopus vulgaris* has been found in the stomachs of bottlenose dolphin (*Tursiops truncatus*) (Blanco *et al.*, 2001), Risso's dolphin (*Grampus griseus*) (Blanco *et al.*, 2006), and Mediterranean monk seal (*Monachus monachus*) (Pierce *et al.*, 2011) in the Mediterranean Sea. Marine mammal predators of *O. vulgaris* in Galician waters include common dolphin (*Delphinus delphis*), long-finned pilot whale (*Globicephala melas*), and sperm whale (*Physeter macrocephalus*) (Table 3.3, see also at González *et al.*, 1994a; López, 2002; Santos *et al.*, 2004a, 2013, 2014).

Table 3.3. Known predators of *Octopus vulgaris* in the Mediterranean Sea and Northeast Atlantic.

Taxon	Species	References
Cephalopoda	Common cuttlefish (*Sepia officinalis*)	Alves et al. (2006)
	Veined squid (*Loligo forbesii*)	Rocha et al. (1994)
Chondrichthyes	Bull ray (*Pteromylaeus bovinus*)	Capapé (1977)
	Smooth-hound (*Mustelus mustelus*)	Saïdi *et al*. (2009)
Osteichthyes	Dusky grouper (*Epinephelus marginatus*)	Reñones *et al.* (2002)
	Silver-cheeked toadfish (*Lagocephalus sceleratus*)	Kalogirou (2011)
Pinnipedia	Mediterranean monk seal (*Monachus monachus*)	Pierce *et al.* (2011)
Cetacea	Bottlenose dolphin (*Tursiops truncatus*)	González *et al*. (1994a), Blanco *et al.* (2001), Santos *et al*. (2007)
	Common dolphin (*Delphinus delphis*)	González *et al*. (1994a), Santos *et al.* (2004a, 2013)
	Harbour porpoise (*Phocoena phocoena*)	Santos *et al*. (2004b)
	Long-finned pilot whale (*Globicephala melas*)	González *et al*. (1994a), López (2002), Santos *et al*. (2014)
	Risso's dolphin (*Grampus griseus*)	López (2002), Blanco *et al.* (2006), Bearzi *et al.* (2011)
	Striped dolphin (*Stenella coeruleoalba*)	Sollmann (2011)
	Sperm whale (*Physeter macrocephalus*)	González *et al*. (1994a)

3.8 Other ecological aspects

3.8.1 Parasites

Hochberg (1983) noted that *O. vulgaris* was one of only two species in which parasites had been studied in detail. In the genus *Octopus*, parasites identified included viruses, fungi, sporozoans, ciliates, dicyemids, digeneans, cestodes, hirudineans, and copepods. He noted that two species of the protist *Aggregata* are known in *O. vulgaris*: *Aggregata octopiana*, reported by Schneider (1875), and *A. spinosa*, described by Moroff (1906). Ciliates found in *O. vulgaris* include *Chromidina coronata.*

González *et al.* (2003) recorded a range of parasite species in *O. vulgaris* from Galicia (more than half of which were also found in *Eledone cirrhosa*): *Aggregata octopiana*, which, according to Gestal *et al.* (2007), is a dangerous pathogen in cultured octopus; *Dicyema typus* (a mesozoan); *Lecithochirium* sp. (a digenean trematode); *Phyllobothrium* sp. and *Scolex pleuronectis* (both cestodes); *Pennella* sp. (a copepod); *Octopicola superbus* (Maxillopoda); and two genera of nematode, *Cystidicola* sp. and *Anisakis simplex sensu stricto.*

3.8.2 Contaminants

As *O. vulgaris* is an important fishery resource, the propensity of cephalopods to accumulate certain metals, notably cadmium, is relevant to human health. Seixas *et al.* (2005a) reported mercury levels from octopuses on the Atlantic coast of Portugal. As expected, the greatest concentrations were in the digestive gland. Although mercury concentrations were slightly higher in samples from Cascais (near Lisbon) than in Viana do Castelo, consistent with the higher concentrations recorded in seawater at Cascais, they were within the range of values legally defined as safe for human consumption. However, cadmium concentrations were above the legal limit for human consumption in samples from Viana in 2002, and two animals also had lead concentrations that exceeded legal limits (Seixas *et al.*, 2005b). In another study based in Portugal, Raimundo *et al.* (2004) found that cadmium concentrations were greatest in octopuses from the north of the country. Storelli *et al.* (2012) measured lead, mercury, and cadmium levels in a range of seafood products in Italy (sources from both within and outside Europe), and found the greatest cadmium concentrations in cuttlefish and octopuses, noting that some of the values were close to the legal limits for human consumption. The highest cadmium concentration recorded in *O. vulgaris* was 0.64 mg g^{-1} wet weight.

3.8.3 Environmental effects

Although the biology and ecology of adult *O. vulgaris* are generally well documented, there are only a few studies on the effect of physical oceanography on the life cycle of the species. The first such studies were made in waters off Great Britain involving the influence of sea surface temperatures on the reproduction and abundance of adults and the effects of currents on their distribution (Rees, 1950; Rees and Lumby, 1954). Garstang (1900) had previously speculated that a “plague” of octopuses in the English Channel at the end of the 19th century was related to warm summers and mild winters, but, considering subsequent “plague” years, Rees and Lumby (1954) concluded there was no close association between high abundance and warm summers. In the Gulf of Cádiz (southern Iberian Peninsula), a negative correlation was found between rain and abundance (Sobrino *et al.*, 2002). Off Tunisia, there is a strong association between low sea surface temperature and abundance, and in the hot season, rainfall also has a positive effect on production (Chédia *et al.*, 2010). Strong upwelling conditions, interpreted from satellite images, have been related to strong recruitment of *O. vulgaris* in Mauritanian waters (Faure *et al.*, 2000). In coastal upwelling areas off West Africa, catches of adult *O. vulgaris* during summer are significantly correlated with the upwelling intensity during the previous winter, indicating the influence of oceanographic conditions on octopus paralarvae and juveniles and the subsequent effects on the fished adult populations (Caverivière and Demarcq, 2002). In the same region, exceptional oceanographic conditions favouring the survival of paralarvae and juveniles also seem to be the origin of demographic explosions of *O. vulgaris* (Caverivière, 1990; Diallo *et al.*, 2002). A similar relationship between upwelling intensity and adult catches has been found. On the northwestern Iberian coast (Otero *et al.*, 2008), wind stress structure (which is related to upwelling) during spring–summer (prior to the hatching peak) and autumn–winter (during the planktonic stage) affected the early life phase of this species, and explained up to 85% of the year-to-year variability of the subsequent adult catch. The dynamics of coastal upwelling areas seem to favour paralarva transport to the open ocean during upwelling episodes and concentration at the coast under upwelling relaxation or downwelling conditions (González *et al.*, 2005; Otero *et al.*, 2008).

3.9 Fisheries

European vessels fish for *O. vulgaris* mainly in three areas: the Northeast Atlantic, the Mediterranean, and the eastern central Atlantic off West Africa, although landings into the EU from the latter area (mainly by Spain) have dwindled dramatically as the fishery has increasingly been exploited mainly by Moroccan vessels. The estimated landings for this species were 72 801 t from the eastern central Atlantic in 2008, mostly from western Saharan and Mauritanian waters (and only a small fraction was landed in Europe). This compares with 21 581 t from the Northeast Atlantic and 17 010 t from the Mediterranean (FAO, 2010a). The most recent data available from FAO (Fishstat database) indicate a sharp drop in eastern central Atlantic octopus catches in 2010 (down to ca. 55 000 t), although landings from the Northeast Atlantic and Mediterranean in 2010 were at levels similar to those in 2008. Note that landings data reported to the FAO for the eastern central Atlantic and, to a lesser extent, the Mediterranean have normally been for octopuses in general (i.e. including an unspecified proportion of *Eledone* spp.).

In the Mediterranean, *O. vulgaris* overtook *Sepia officinalis* as the most important fished cephalopod species in the late 1970s. However, octopus landings in the Mediterranean have declined fairly consistently since the mid-1980s, and indeed *O. vulgaris* was overtaken as the most important landed cephalopod by *S. officinalis* in 2007 (FAO, 2011). The total octopus landings from the Mediterranean in 2010 were 25 300 t, of which 10 300 t were recorded as common octopus and 7000 t as *Eledone* spp. (FAO, 2011). Estimated total landings of octopods from the ICES area of the Northeast Atlantic in 2010 were ca. 16 600 t, mostly by Portugal and Spain (ICES, 2012), comparable with the 18 300 t recorded for the Northeast Atlantic in the FAO dataset. Although reported total landings have fluctuated from year to year (between 9000 and 18 600 t over the preceding decade), total octopod landings in 2000 and 2010 were similar (ICES, 2012).

Octopus vulgaris is taken throughout the year as a target species in bottom trawls and small-scale coastal fisheries using hand-jigs, pots, trammelnets, and traps in depths between 20 and 200 m. Although the majority of landings arise from offshore trawl fisheries, artisanal fisheries have high local economic and social importance in southern Europe (Pereira, 1999).

In the Gulf of Cádiz, *O. vulgaris* is landed by virtually all the artisanal fleets in the region. The main gears used vary from port to port. For example, in Conil, where more than 50% of the artisanal catches of this species are landed, most are taken by a type of hook and line (*chivos*). Elsewhere in the area, trawls, gillnets, traps, pots, and other types of hooks and lines are used (Silva and Sobrino, 2005). The size range of octopuses captured depends on the size and type of pot used (see Sobrino *et al.*, 2011). In Galicia, ca. 80–90% of landings are by octopus traps (*nasas de polbo*), with most of the remainder caught using traps targeted at other species. In 2008, 1458 vessels were licensed to use *nasas de polbo* (Tasende *et al.*, 2009). Otero *et al.* (2005) used interview data to estimate catches of *O. vulgaris* by the artisanal fleet in Galicia and showed that true landings are approximately double those reported in official statistics. In the Thracian Sea, octopuses are targeted using pots and taken as bycatch in trammelnets (Lefkaditou *et al.*, 2004).

The importance of the species as a resource has led to a requirement for its molecular identification in fishery products (e.g. to detect substitution of *Eledone cirrhosa*). Espiñeira and Vieites (2012) reported a method to identify fresh, frozen, and processed *O. vulgaris* using real-time PCR (polymerase chain reaction).

Octopus vulgaris is the most abundant and ubiquitous cephalopod species on the Saharan Bank (Northwest Africa from 21 to 26°N). In that area, there are probably two stocks: one off Dakhla (26–23°N) and the other off Cap Blanc (21–19°N) (Murphy *et al.*, 2002). Genetic data indicate the presence of multiple stocks in European waters, with distinct differences between the eastern and western Mediterranean, and Northeast Atlantic and Sahara Bank (Boyle, 2000; Maltagliati *et al.*, 2001; Casu *et al.*, 2002; Cabranes *et al.*, 2008; P. R. Boyle *et al.* unpublished FAIR-CT96-1520 project data).

Although there is no routine assessment of *O. vulgaris* stocks in European waters, exploited cephalopod stocks in the Saharan Bank fishery (an essential resource for many years for a sector of the Spanish fleet) have been assessed under the auspices of the Fisheries Committee for the Eastern Central Atlantic (e.g. FAO, 1979, 1982, 1987) using production models. The methodology continues to be updated to take advantage of developments in available techniques (e.g. Ono *et al.*, 2012).

Cephalopod landings in the European Union are not subject to quota limits. As most octopuses are landed by small-scale fisheries, the activity is mainly regulated at the regional level. Hence, the Galician regional government requires all fishing boats to be licensed. Vessels can use a maximum of five gears, although only one per day, and within specified zones. Fishing is permitted only Monday–Friday, and there are also closed seasons. Minimum landing sizes apply (Tasende *et al.*, 2009). In the case of octopus, a closed season may or may not be imposed.

3.10 Aquaculture

Rearing of *O. vulgaris* is limited to ongrowing subadult individuals captured from the wild, using tanks and cages mainly in Spain, but also in other European Mediterranean countries (Rama-Villar *et al.*, 1997; Iglesias *et al.*, 2000; Aguado and García García, 2002; García García and Aguado Giménez, 2002; Chapela *et al.*, 2006; Rodríguez *et al.*, 2006; Mazón *et al.*, 2007; García García *et al.*, 2009; Domingues *et al.*, 2010; García *et al.*, 2011). On the northwestern Spanish coast, commercial viability is enhanced using readily available mussel-culture rafts as platforms from which to suspend cages. Using fish and crustacean fishery discards as feed, wild subadults can be grown from 800 g to 2.5 kg in 4 months. However, sourcing wild animals for ongrowing from the small-scale fishery would represent an undesirable increase in fishing pressure on the resource and is currently permitted only for pilot schemes. The culture of paralarvae of this species is still under development. At scales other than experimental, the culture of paralarvae is still proving a serious bottleneck to production owing to inadequate artificial diets and high mortality (Navarro and Villanueva 2000, 2003; Villanueva *et al.*, 2004; Iglesias *et al.*, 2004, 2006, 2007; Okumura *et al.*, 2005; Seixas *et al.*, 2010). The lack of a standardized culture method and the absence of appropriate live food to meet paralarval requirements have been identified as two possible causes of this mortality (Iglesias *et al.*, 2007).

Iglesias *et al.* (2004) were able to culture *O. vulgaris* experimentally through the complete life cycle, using both *Artemia* and crustacean zoeae as live prey, with 31.5% of paralarvae surviving after 40–45 d, survivors reaching 9.5 ± 1.9 mg dry weight at this point. The octopuses reached a weight of 0.5–0.6 kg at 6 months of age and a final weight of 1.4–1.8 kg at 8 months, the time at which they reached maturity and began to spawn. Moxica *et al.* (2006) also reared *O. vulgaris* to the adult stage. Using enriched *Artemia* as food, they obtained 67% paralarva survival and a dry weight of 1.89 mg after 1 month of culture. In that case, *Artemia* was cultured with *Isochrysis galbana* and further enriched with *Nannochloropsis* sp. Several other authors have also reported successful results from adding *Nannochloropsis* sp. to the culture tank and as food for *Artemia* (Hamasaki and Takeuchi, 2000; Hamasaki and Morioka, 2002; Fuentes *et al.*, 2011). Seixas (2009) indicated that *Isochrysis galbana* mixed with *Rhodomonas lens* provided the best microalgal combination because of the high level of polyunsaturated fatty acids (PUFAs) (in *Isochrysis galbana*) and very high level of proteins (in *Rhodomonas lens*).

These studies have together shown that a mixed live diet of enriched *Artemia* and crustacean zoeae is the most balanced diet for producing the best growth and survival results in the paralarva phase, achieving dry weights threefold higher than obtained from feeding with *Artemia* enriched with microalgae. Nevertheless, this approach is currently not transferable to a commercial scale owing to the limited availability of live zoeae.

3.11 Future research, needs, and outlook

Important topics for future research include investigations on early life stages and the influence of environmental conditions on wild octopus populations. Further, the development of inert diets to feed the paralarvae or microencapsulated products to produce enriched *Artemia* with a similar nutritional composition to crustacean zoeae is important for solving the paralarva rearing problem.