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Cephalopod paralarvae and upwelling conditions off Galician waters (NW Spain)

Francisco Rocha, Ángel Guerra, Ricardo Prego and Uwe Piatkowski[1]

Instituto de Investigaciones Marinas (CSIC), C/Eduardo Cabello 6, 36208 Vigo, Spain and [1]Institut für Meereskunde, Universität Kiel, Düsternbrooker Weg 20, D-24105 Kiel, Germany

Abstract. A total of 103 cephalopod paralarvae were sampled during June 1995 in Galician waters (NW Spain). Samples were taken with Bongo nets of 300 and 500 μm mesh size at 48 sampling stations along 10 transverse transects ranging from 80 to 600 m water depth. Paralarvae of loliginid squid were most abundant (40%). The *Rhynchoteuthion* paralarvae of ommastrephid squid accounted for 25%, whereas sepiolids comprised 23% of the total sample. Octopods were scarce, at only 6.6%. Other cephalopod families accounted for 5%. Sizes of paralarvae ranged from 1.0 to 7.1 mm mantle length. Temperature and salinity distribution showed the presence of an intense upwelling during the survey period. The sampling data obtained before and during the presence of upwelled water off Rías of Pontevedra and Vigo (southern zone) showed that paralarval cephalopod abundance and distribution were closely related to the upwelled Eastern North-Atlantic Central Water (ENACW).

Introduction

The life cycle of most nektonic cephalopod species starts with planktonic stages that have been poorly studied and inadequately described (Sweeney *et al.*, 1992). This is mainly due to the relative inefficiency of nets for sampling young forms, taxonomic problems and the difficulty in rearing young cephalopods (Vecchione, 1987). The study of early life stages in cephalopod development is important for: (i) identification of paralarvae; (ii) understanding the entire life cycle of the species; and (iii) determining the importance of recruitment for each species.

Several studies have been carried out to examine the abundance and distribution of cephalopods in relation to major oceanographic features, mainly in ommastrephid squid. The life cycle of these species is closely related to oceanic current systems, where egg masses, paralarvae and, in some cases, juveniles are transported by the currents from cephalopod spawning areas to their feeding grounds (e.g. Trites, 1983; Dawe and Beck, 1985; Parfeniuk *et al.*, 1992; Saito and Kubodera, 1993). On the other hand, changes in the abundance, distribution and catches of adult *Loligo opalescens*, *Loligo vulgaris reynaudii* and *Todaropsis eblanae* have been related to the presence of upwelling phenomena (McInnis and Broenkow, 1978; Rasero, 1994; Roberts and Sauer, 1994). However, little evidence has been found to date about the effect of upwelling events on paralarval abundance and distribution.

The Atlantic waters off the northwestern Iberian Peninsula (Galicia) are a suitable area for the study of this type of relationship. Firstly, because the 80 cephalopod species found in the area (Guerra, 1992) constitute commercial fisheries accounting for 3000 tonnes landed annually (Guerra *et al.*, 1994; González *et al.*, 1996). Secondly, because summer meteorological conditions are favourable for upwelling in Galician waters (Fraga, 1981; Bode *et al.*, 1994), where a water mass located between 70 and 500 m depth, the south-flowing Eastern North-Atlantic Central Water (ENACW), is seasonally upwelled along the Galician coast. This upwelling also affects the Galician Rías, especially in the south, where the upwelled water greatly increases the primary production and the estuarine circulation (Prego and Fraga, 1992; Prego, 1993; Alvarez-Salgado *et al.*, 1996).

This paper examines the distribution and abundance of paralarval cephalopods off the Northwest Iberian coast in relation to seasonal upwelling of the region. Further, it provides new information on the spawning grounds of commercially important cephalopods near the Galician coast.

Method

During cruise no. 208 of R/V 'Poseidon', a zooplankton sampling programme was conducted along the entire coast of Galicia (NW Spain) from 1 to 11 June 1995. Ten transects consisting of five stations each, except for transect 7 with three stations, were made across the continental shelf and the slope. These stations were situated at water depths of 80, 120, 200, 400 and 600 m (Figure 1).

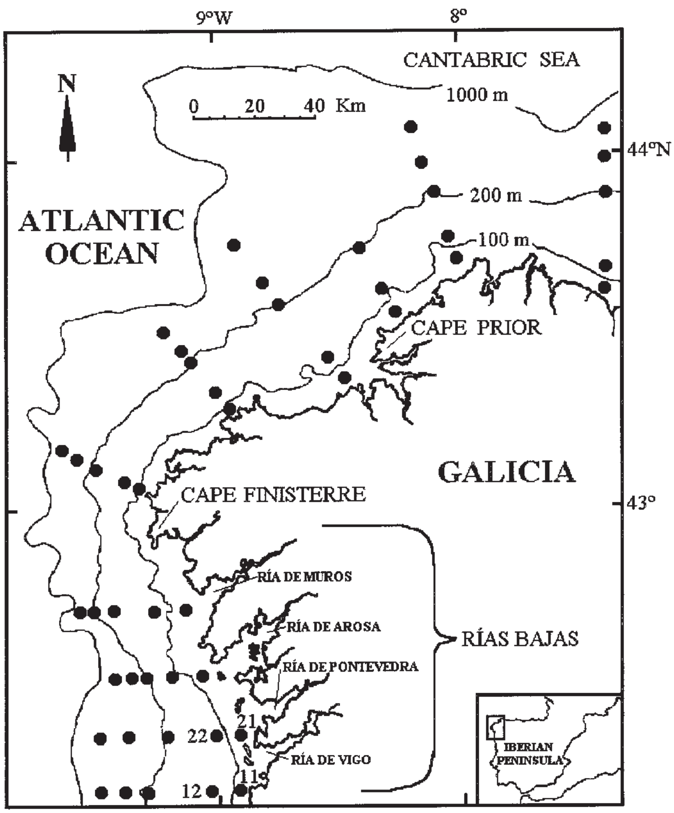

Fig. 1. Sampling area studied from 1 to 11 June 1995. Stations 11, 12, 21 and 22 were sampled at the beginning (1–2 June) and repeated at the end (9–11 June) of the cruise. Closed circles are sampling stations.

Forty-eight oblique hauls were carried out from close above the bottom to the surface with Bongo nets of 300 and 500 µm mesh. At a ship speed of 3 knots, the Bongo net was lowered close to the sea floor at 0.7 m s^{-1}, then stabilized near the bottom for a period of 10 min and hauled up at 0.5 m s^{-1}. When the bottom depth exceeded 200 m, the net was kept at ~200 m depth for ~10 min. Eight additional hauls were undertaken at stations 11, 12, 21 and 22 (Figure 1) at the end of the cruise (9–11 June).

Vertical temperature–salinity profiles were obtained at each station with a SEA-BIRD 19 CTD. Meteorological conditions were recorded with the ship's equipment.

Unpreserved cephalopod paralarvae were sorted on board and identified to the lowest possible taxonomic level. The mantle length (ML; in mm) of all individuals was recorded. Specimens were then stored in 70% ethanol for subsequent detailed identification in the laboratory following Sweeney *et al.* (1992) and Guerra (1992).

Results

Table I shows the station numbers on each of the 10 transects and the number of paralarvae caught.

Table I. Sampling stations where cephalopod paralarvae were caught

Transect	Sampling station	Date of 1995 (day/month)	Hour	Bottom depth (m)	Latitude (N)	Longitude (W)	Number of paralarvae
1	12	01/06	16:55	122	42º07.1′	09º01.8′	2
1	13	01/06	20:10	232	42º07.7′	09º20.9′	1
2	21	02/06	08:33	84	42º17.4′	08º57.4′	1
2	25	02/06	16:10	900	42º18.1′	09º28.6′	1
3	33	03/06	12:10	199	42º30.1′	09º21.4′	4
3	34	03/06	13:45	485	42º29.6′	09º25.3′	1
4	41	04/06	08:43	98	42º42.0′	09º12.6′	1
4	42	04/06	10:05	121	42º42.8′	09º18.7′	1
4	43	04/06	13:00	290	42º42.6′	09º32.7′	1
6	62	08/06	19:21	128	43º05.3′	09º22.0′	9
8	81	08/06	14:05	100	43º17.7′	09º02.1′	1
9	91	07/06	07:07	90	43º25.0′	08º35.3′	1
9	92	07/06	09:20	129	43º27.0′	08º41.7′	2
10	101	06/06	21:31	80	43º35.3′	08º22.2′	2
10	102	06/06	22:55	120	43º37.5′	08º21.6′	1
11	112	06/06	16:20	129	43º49.2′	08º08.0′	1
13	131	05/06	11:30	96	43º46.4′	07º30.9′	5
13	132	05/06	13:03	120	43º47.5′	07º30.4′	1
Additional hauls							
2	21	09/06	22:23	98	42º16.6′	08º59.3′	8
2	21	10/06	15:55	98	42º16.9′	08º58.9′	8
2	21	10/06	16:45	95	42º16.3′	08º59.4′	4
2	22	10/06	18:28	131	42º18.4′	09º06.1′	3
1	12	11/06	06:21	123	42º07.3′	09º02.0′	9
1	11	11/06	07:44	95	42º06.8′	08º58.0′	7
1	11	11/06	09:12	95	42º12.3′	08º57.8′	15
1	12	11/06	11:01	129	42º13.0′	09º04.3′	13

Cephalopod species

A total of 103 paralarvae and one juvenile of *Teuthowenia megalops* (ML = 150 mm) were caught (Table II).

The paralarvae of loliginid squid were the most abundant (40.4%) group. The *Rhynchoteuthion* paralarvae of ommastrephid squid accounted for 25%, whereas sepiolids comprised 23% of the total sample. The presence of octopods, particularly *Octopus vulgaris*, was scarce, representing only 6.6% of the paralarvae collected. The other cephalopod families accounted for 5%.

The size–frequency distribution of the three most abundant groups with size ranges between 1.0 and 7.1 mm ML is shown in Figure 2.

Oceanographic conditions during the first 9 days of the cruise

Research cruise dates coincided with prevailing NE winds ranging from 19 to 15 m s^{-1} causing an intense upwelling affecting the entire coast of Galicia. The upwelled subsurface ENACW differed between north and south of Cape Finisterre during the first 9 days (1–9 June) of the cruise (Figure 3). It can be observed from the temperature–salinity diagrams (Figure 3) that upwelling had not yet reached the most northeastern part of the Cantabric Sea and the southern part (Rías of Pontevedra and Vigo) of the Galician coast. The upwelled subsurface sea

Table II. Cephalopod species taken off the Northwest Iberian coast

Species	No.
Sepioidea	
Sepiolidae	
Sepiolidae ind.	1
Rondeletiola minor	3
Sepiola atlantica	1
Sepiola aff atlantica	1
Sepiola sp.	5
Sepietta sp.	13
Teuthoidea	
Teuthoidea ind.	2
Loliginidae	
Loligo forbesi	6
Loligo vulgaris	18
Loligo sp.	11
Alloteuthis sp.	7
Enoploteuthidae	
Abralia veranyi	2
Ommastrephidae	
Rhynchoteuthion	26
Cranchiidae	
Teuthowenia megalops	1
Octopoda	
Octopodidae	
Octopus vulgaris	6
Octopus sp.	1
Total	104

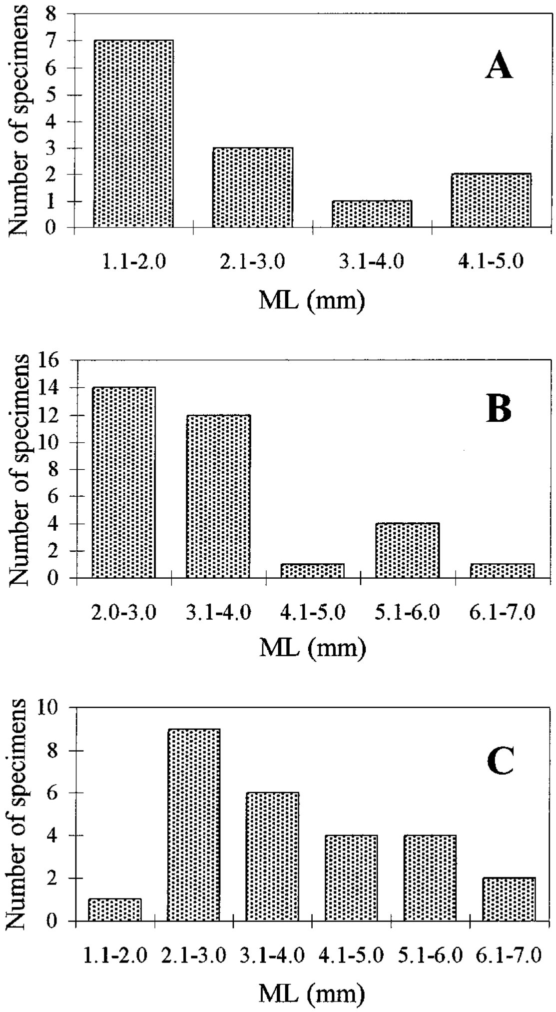

Fig. 2. Size–frequency distribution of *Sepietta* sp. (**A**), *Loligo* spp. (**B**) and *Rhynchoteuthion* (**C**) paralarvae.

water during this period (1–9 June) is clearly indicated by the surface temperature (Figure 4). The greatest upwelling intensity occurred near Cape Finisterre, where a typical plume of cool water (<14°C) was moving away from the coast.

Paralarval distribution during the first 9 days of the cruise

Figure 4 shows the distribution and abundance of cephalopod paralarvae collected in the 48 hauls carried out in relation to surface temperature during the first 9 days of the cruise. Loliginid paralarvae were found on the shelf stations (80, 140, 200 m). Their distribution extended through the entire Galician shelf

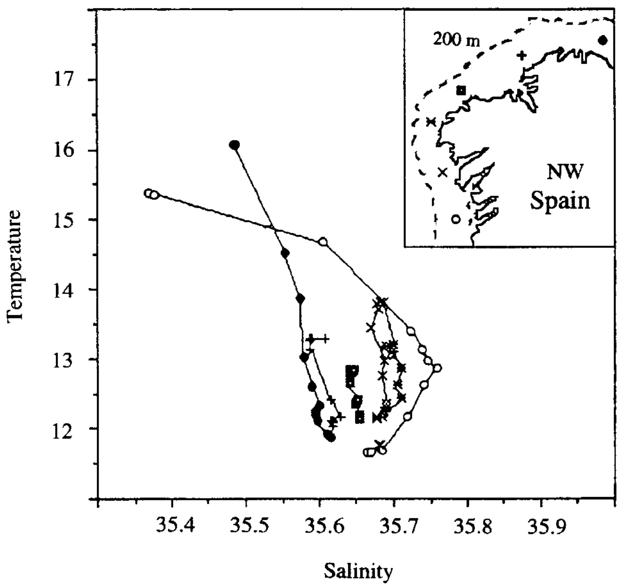

Fig. 3. Temperature versus salinity diagram showing the variation of the water column off the coast of Galicia in different sampling stations from 1 to 9 June 1995. Open circles, 1 and 2 June; X, 3 and 4 June; closed circles, 5 June; +, 6 June; squares, 7 June; asterisk, 9 June.

(Figure 4A). Octopod paralarvae were only present in the western waters of Galicia (south of Cape Finisterre) from 600 to 80 m depth (Figure 4A). *Rhynchoteuthion* appeared on the shelf south of Cape Prior. These paralarvae were more abundant off Cape Finisterre (Figure 4B). Sepiolid paralarvae showed a spatial distribution similar to that of rhynchoteuthions (Figure 4B). Figure 5 shows that the majority of specimens collected, irrespective of which group they belonged to, were found in the cold ENACW.

Comparative abundance of paralarvae and oceanographic conditions

Towards the end of the cruise (9–11 June), the upwelling event reached the southern part of the Galician coast off the Rías of Pontevedra and Vigo. Then, a single layer of water was formed. The entire water column was formed by the same water mass characterized by a homogeneous temperature and salinity (Figure 6A and B). Taking note of this, eight additional hauls (Table I) were made off both Rías, repeating twice each of the stations (11, 12, 21 and 22) visited at the start of the cruise (1–2 June). In this way, a picture of the paralarval abundance and oceanographic conditions before and during the presence of upwelled water was obtained for this zone. A significant increase in paralarvae was found coinciding with the upwelling of ENACW off these Rías (Figure 6C and D). The paralarvae found in this additional sampling accounted for 63.5% of all the individuals obtained during the cruise. Of these, loliginids showed the highest abundance

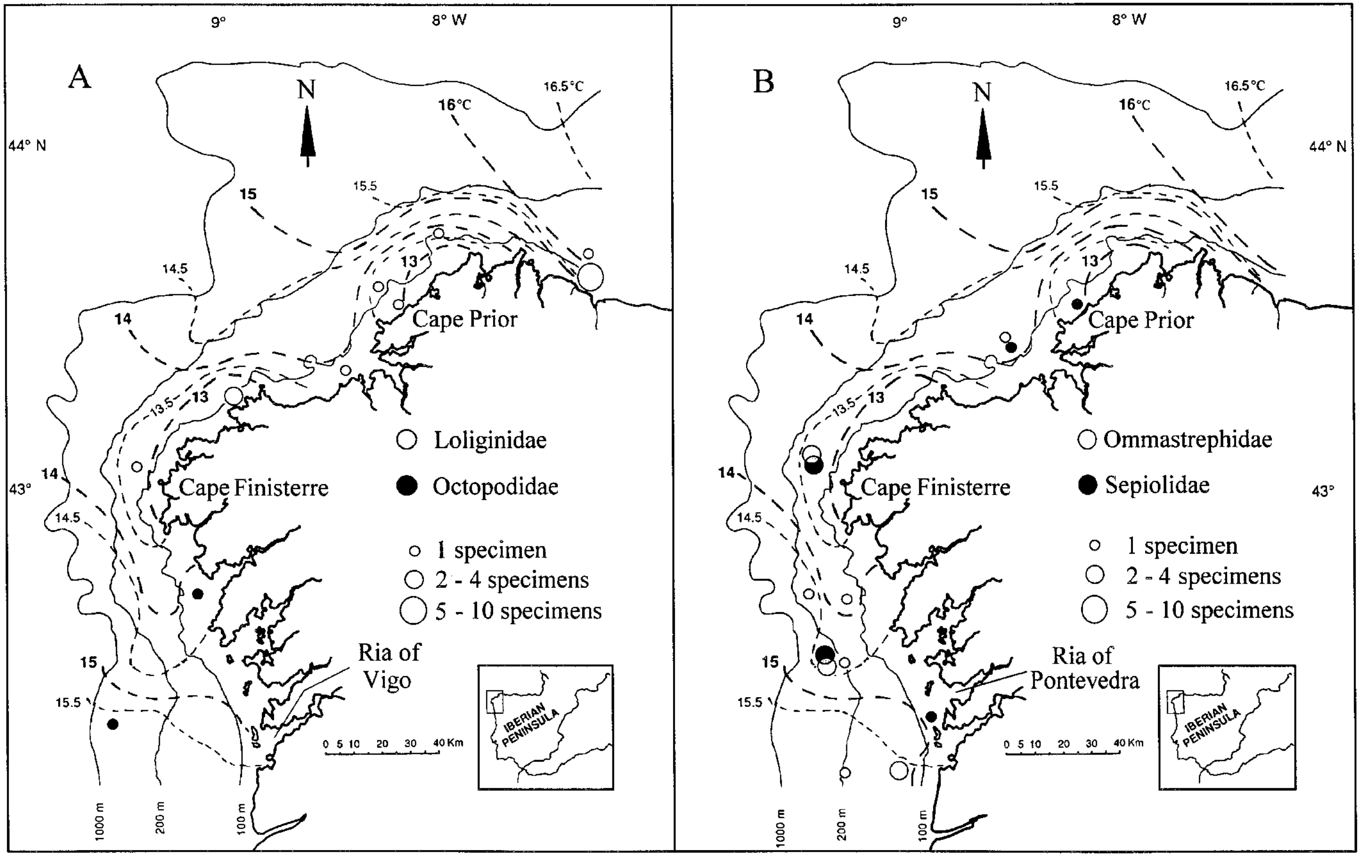

Fig. 4. Location and relative abundance of Loliginidae and Octopodidae paralarvae (**A**) and Ommastrephidae and Sepiolidae paralarvae (**B**) off the Galician coast from 1 to 9 June 1995. Continuous line, depth (m); dotted line, surface water temperature (°C).

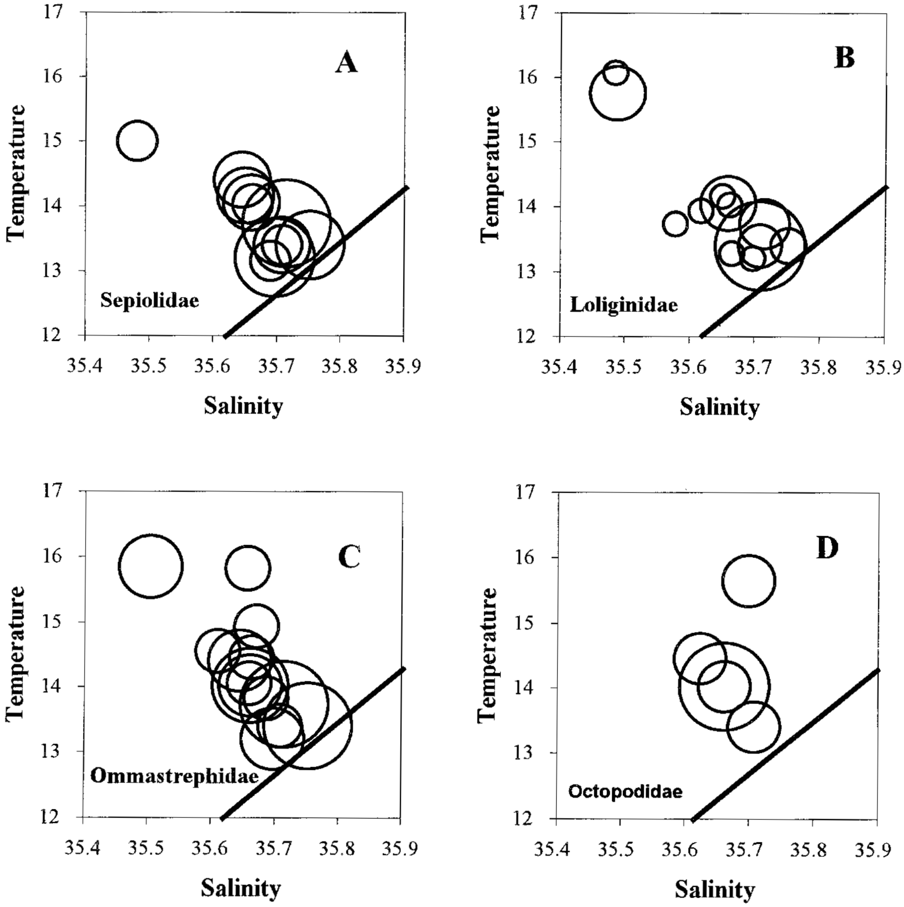

Fig. 5. Abundance of the four major groups of cephalopod paralarvae in relation to temperature and salinity of the surface water at the sampling stations. The size of the circles indicates the relative abundance of paralarvae. Line, ENACW mass.

Table III. Increase in the number of cephalopod paralarvae collected off the Rías of Pontevedra and Vigo in conditions before (1–2 June) and during (9–11 June) the presence of upwelled water

	Before upwelling	During upwelling
Loliginidae	0	29
Ommastrephidae	2	15
Sepiolidae	1	14
Octopodidae	0	7
Others	0	1
Total	3	66

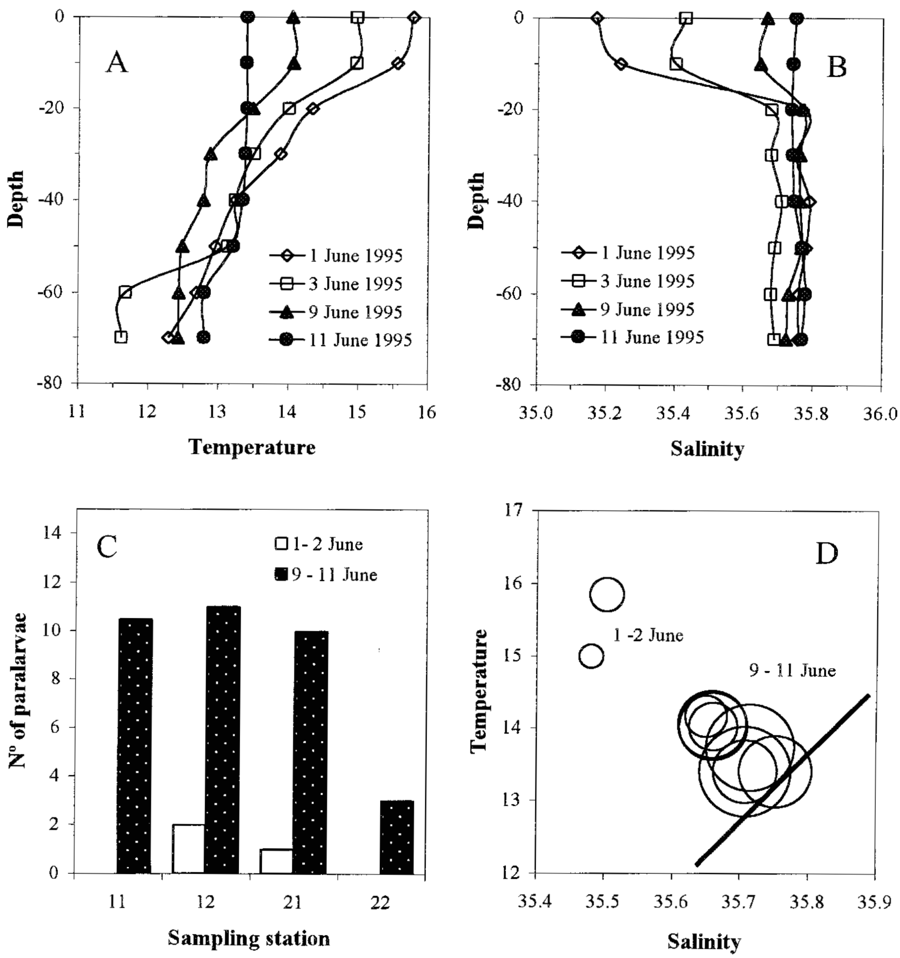

Fig. 6. Oceanographic conditions and abundance of paralarvae occurring before (1–2 June) and during (9–11 June) the presence of upwelled water at four sampling stations (11, 12, 21 and 22) off the Rías of Pontevedra and Vigo. (**A**) Temperature versus depth. (**B**) Salinity versus depth. (**C**) Average number of cephalopod paralarvae found at sampling stations. (**D**) Abundance of paralarvae in relation to temperature and salinity of the surface water. The size of the circles indicates the relative abundance of the individuals in each sample.

(43.9%), followed by rhynchoteuthions (22.7%), sepiolids (21.2%) and octopods (10.6%) (Table III).

Discussion

The paralarval cephalopods sampled during the cruise belong to common adult species present in Galician waters (Guerra, 1992). *Rhynchoteuthion* specimens collected may be *Illex coindetii* and/or *Todaropsis eblanae* paralarvae, the most abundant ommastrephid squids in Galician waters (González *et al.*, 1996). The early stages of these species are still not described.

It is well documented that species such as *Loligo vulgaris*, *L.forbesi*, *Todaropsis eblanae*, *Illex coindetii* and *Octopus vulgaris* are abundant and reproduce in these waters, showing a hatching peak in later spring and summer (Guerra, 1992; Guerra and Rocha, 1994; González and Guerra, 1996; Rasero, 1996). The presence of an annual upwelling during late spring and summer (Fraga, 1981) may account for this hatching peak which coincides with a high presence of prey. Further, the high variability of adult biomass observed in these species over the years might be explained by the different intensity of upwelling influencing the paralarval survival rate and recruitment.

In Californian and South African waters, the distribution, abundance and catches of *L.opalescens* and *L.vulgaris reynaudii* are temporally related to the presence and intensity of upwelling conditions (McInnis and Broenkov, 1978; Roberts and Sauer, 1994). However, the authors do not discuss the relationship between upwelling and paralarval abundance and distribution. Rasero (1994, 1996) suggests that the possible correlation observed between the abundance of *Todaropsis eblanae* catches (1973–1989) and upwelling intensity in Galician waters is due to the increased survival of hatchlings and pre-recruits when the abundance of prey increases, arising from the higher productivity caused by upwelling. Contrary to this, upwelling has been reported to reduce *L.opalescens* catches in Californian waters (McInnis and Broenkow, 1978). As low temperatures cause decreasing growth rates, juvenile stages of squid are prolonged and the period of higher mortality becomes more extended, resulting in a poor recruitment (McInnis and Broenkow, 1978).

The relationship between paralarval abundance and upwelled water found in this study shows that upwelling seems to be advantageous for new hatchling survival, as indicated by Rasero (1994). However, the effect of low temperature on growth rates and mortality affecting the abundance of juvenile stages needs to be clarified further for each cephalopod species. Rasero (1994) concludes that the balance between primary production increase and temperature decrease in the upwelling areas presents spatial and temporary changes, and affects different species in different ways.

Although paralarvae were found throughout the sampled area, most of them were concentrated in the stations located near the coast, on the shelf, off the Rías of Pontevedra and Vigo. This may be related to different hydrographic conditions prevailing off the Galician coast during the upwelling (Prego and Bao, 1997). Thus, in the northwest zone in the Cape Prior area, ENACW coming from the Cantabric Sea moves in a north–south direction, upwelling near the coast. This water mass is driven off the coastline and westwards by the wind force exercised on the surface waters (Prego and Varela, 1998). Paralarvae are transported by this cross-circulation towards the open sea (Figure 7). At the Atlantic coast south of Cape Finisterre (Rías Bajas), however, ENACW moves in a west–east direction, upwelling near the coast. This upwelled water mass is moved at the sea surface westwards again. As cephalopod paralarvae show intense vertical migrations (Sweeney *et al.*, 1992; Piatkowski *et al.*, 1993), the current system off the Rías

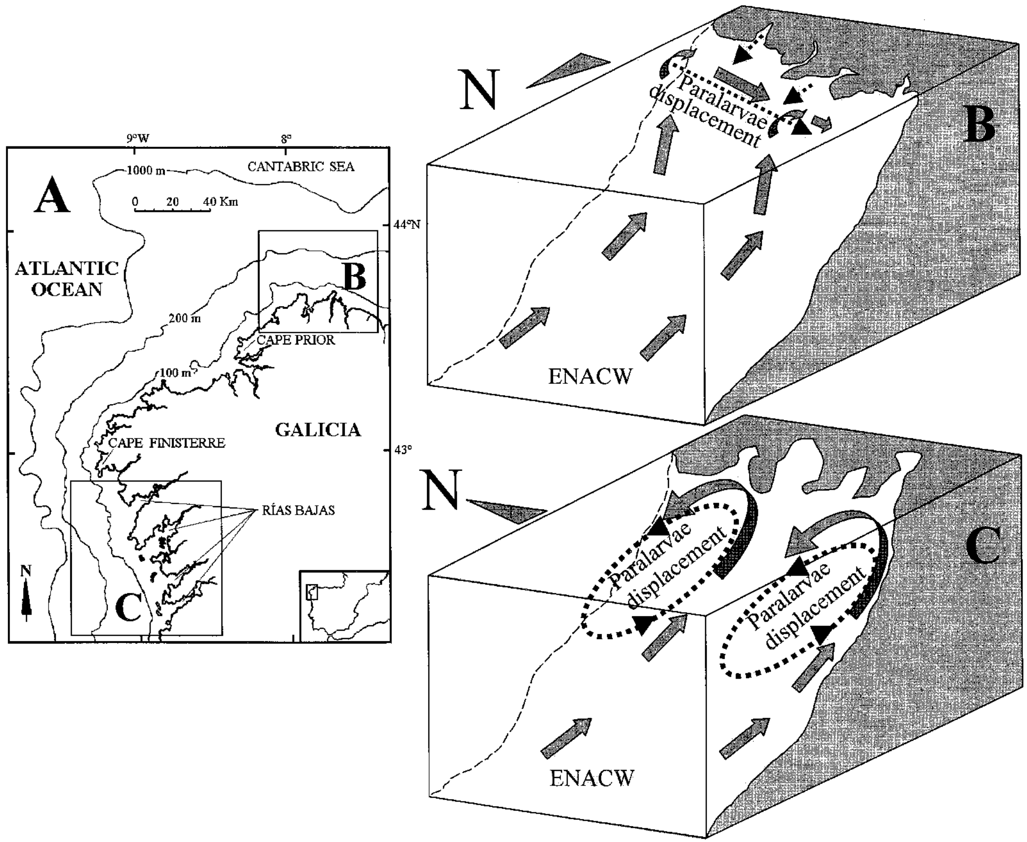

Fig. 7. Hypothetical diagram of the relationship between the distribution and movement of cephalopod paralarvae (dotted line) and the movement of ENACW during upwelling (thick continuous line) north of Cape Prior (**B**) and off the Rías of Vigo and Pontevedra (**C**) in Galician waters (**A**).

Bajas during upwelling helps the maintenance of paralarvae in a circulatory cell, allowing them to return towards the coast (Figure 7). This could explain the major abundance of the cephalopod paralarvae found off Rías Bajas in comparison to the Cape Prior area. However, no dense concentrations of cephalopod paralarvae have been found to date and nothing is known about their distribution during periods of low or absent upwelling.

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