Journal of Fish Biology (2005) **67,** 1475–1480
doi:10.1111/j.1095-8649.2005.00818.x, available online at http://www.blackwell-synergy.com

BRIEF COMMUNICATIONS

Temporal patterns of breeding and recruitment in *Nerophis lumbriciformis* (Pisces; Syngnathidae) related to seawater temperatures

N. M. MONTEIRO*†‡, V. C. ALMADA§ AND M. N. VIEIRA*†

**Departamento de Zoologia e Antropologia da Faculdade de Ciências da Universidade do Porto, Praça Gomes Teixeira, 4099-002 Porto, Portugal, †CIIMAR, Rua dos Bragas 177, 4050-123 Porto, Portugal and §ISPA, Rua Jardim do Tabaco 34, 1149-041 Lisboa, Portugal*

(Received 21 October 2004, Accepted 26 April 2005)

The breeding season of *Nerophis lumbriciformis*, a cold water pipefish, was positively correlated with seawater temperatures <15·5° C, whilst recruitment occurred at the end of the upwelling season, when seawater temperature attained its maximum values. The observed alterations in seawater temperatures, with steady year-round increases, and the consequent alteration of the upwelling regime, may have dramatic consequences in the maintenance of *N. lumbriciformis* populations, by reducing the breeding period and simultaneously contributing to the transport of pelagic larvae northwards due to specific sea currents that occur outside the upwelling season.

Key words: distribution; *Nerophis lumbriciformis*; recruitment; reproduction; temperature; upwelling.

Portuguese rocky shores provide excellent opportunities to study biogeographical processes. A gradient can be observed along the Portuguese coast where many warm and cold water species decrease in abundance (northwards or southwards, respectively) or present their geographical limits of distribution (Boaventura *et al.*, 2002). Located near the southern limit of their geographical distribution (Dawson, 1986), Portuguese populations of *Nerophis lumbriciformis* (Jenyns) currently face numerous problems, such as continuous habitat reduction (Eurosion, 2003) and increasing seawater temperatures (Lemos & Pires, 2004). These factors are probably responsible for the gradual regression of many boreal marine species, both animal and algal, whose southern limit of distribution on the Portuguese coast as described by Ardré (1969) has dramatically changed over the last four decades. The exact mechanisms responsible for these clearly oriented geographical alterations are yet to be fully understood.

‡Author to whom correspondence should be addressed. Tel.: +351 22 3401514; fax: +351 22 3401511; email: nmonteir@fc.up.pt

In this work, data were collected for *c.* 50 months, allowing for the precise delimitation of *N. lumbriciformis* recruitment and breeding season. Since reproduction seems to be inhibited at temperatures >16° C (Monteiro *et al.*, 2001), the implications for the distribution of *N. lumbriciformis* are discussed taking into account the observed increase in seawater temperatures (Lemos & Pires, 2004) and consequent alterations in the upwelling regime in the Portuguese coast, one oceanographic process that may impact larval dispersal and recruitment.

Data were collected in an intertidal rocky shore area, in northern Portugal (Fig. 1), during two time periods. The first ranged from March 1997 to November 1999 while the second ranged from June 2002 to December 2003. Data emerging from the first sampling period allowed for the preliminary characterization of the breeding season of this pipefish (Monteiro *et al.*, 2001).

During each visit, always performed during spring tides due to the vertical distribution of this species (Gibson, 1972), a thorough examination of the undersurface of boulders, rockpools and crevices was carried throughout the entire sampling area trying to minimize changes in the habitat. Fish were captured by hand, total length (L_T) was measured to the nearest mm, the sex was visually determined and, for pregnant males, the number of eggs was recorded.

In order to detect a relationship between (1) the breeding seasons (percentage of pregnant males) calculated for the two time intervals, (2) breeding and seawater temperatures, (3) the number of juveniles and adult males or females and (4) the percentage of juveniles and the percentage of breeding males, product moment correlations were used. Mann–Whitney *U*-tests were conducted in order to detect differences in the percentage of pregnant males (and their absolute numbers) during months where seawater temperatures reached values above or

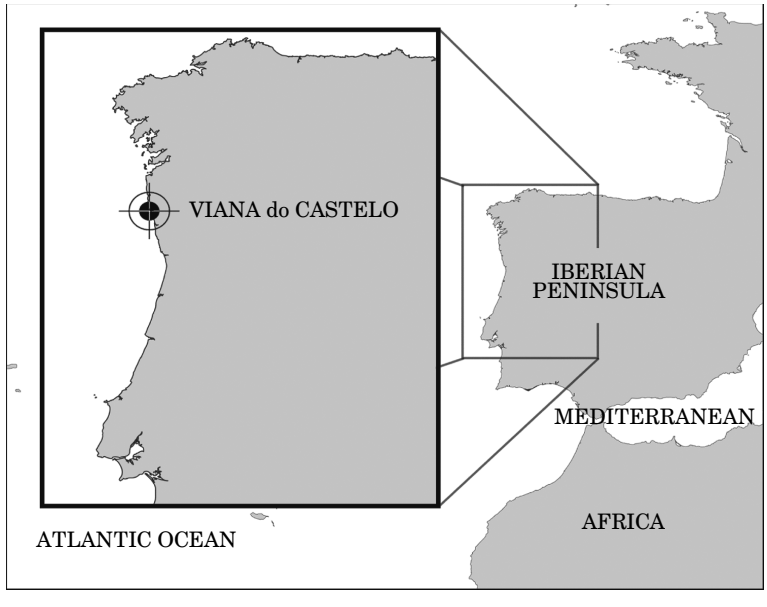

FIG. 1. Location of sampling site, in Viana do Castelo, northern Portugal (41°41, 17 N; 8°50, 35 W).

below 15·5° C and, also in the number of juveniles recorded during or out of the upwelling season. All statistical analyses were conducted using Statistica 6.1 (StatSoft).

A total of 953 individuals were analysed (247 females, 310 males and 396 juveniles) during the 50 month sampling period. Females of this sexually dimorphic pipefish species were, on average, larger than males (female: $n = 247$, mean ± s.d. $L_T = 12{\cdot}14 \pm 1{\cdot}35$ cm, range = 8·2–15·1; male: $n = 310$, mean ± s.d. $L_T = 11{\cdot}39 \pm 1{\cdot}31$ cm, range = 8·2–14). The reproductive season (percentage of pregnant males) described by Monteiro *et al.* (2001) was reconfirmed (product moment correlation, $n = 8$, $r = 0{\cdot}810$, $P = 0{\cdot}015$) when compared with data gathered between 2002 and 2003 (considering the 8 months for which there were comparable data for the two study periods). Pregnant males were found throughout the year, with a marked reduction during the end of summer and beginning of autumn [Fig. 2(a)]. From January to June more than 60% of the males were carrying eggs, whilst in October and November that value dropped to *c.* 16%. The percentage of pregnant males was found to be inversely correlated with the average seawater temperature of the preceding month (product moment correlation: $n = 12$, $r = -0{\cdot}830$, $P < 0{\cdot}001$). This result stands if the absolute number of pregnant males is used instead of the respective percentage (product moment correlation: $n = 12$, $r = -0{\cdot}604$, $P < 0{\cdot}05$). The

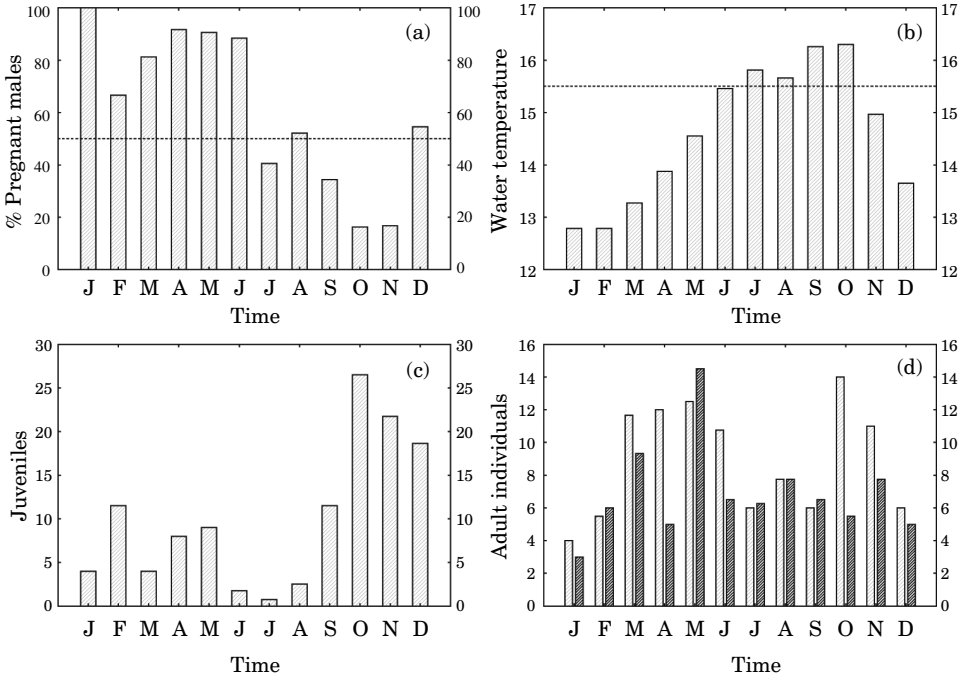

FIG. 2. (a) The breeding season of *Nerophis lumbriciformis* as the percentage of males carrying eggs, (b) mean monthly surface water temperature in northern Portugal, (c) mean number of captured juveniles and (d) the mean number of monthly captures of adult individuals [males (□) and females (▨)].

average number of eggs per breeding male was *c.* 51 ($n = 165$; mean ± S.D. = 50 ± 12, range = 4–84).

In Portugal, the highest water temperatures occur between July and October, attaining values >15·5° C [Fig. 2(a), (b)]. During this period, mating and spawning significantly decreased when compared with the values observed out of this warm period (Mann–Whitney *U*-test, $n_1 = 4$, $n_2 = 8$, $P < 0{\cdot}001$). This conclusion is supported either if the percentage of pregnant males is considered or their absolute numbers (Mann–Whitney *U*-test, $n_1 = 23$, $n_2 = 13$, $P < 0{\cdot}05$). As incubation lasts *c.* 30 days (Monteiro *et al.*, 2003), the percentage of pregnant males was taken as an indicator of spawning intensity during the previous month.

Juveniles appeared in the intertidal zone by September, attaining maximum numbers in October to November [Fig. 2(c)], and then slowly disappeared from the sampling area, following a different pattern from the number of captured adults in each month (product moment correlation, juveniles *v.* males: $n = 12$, $r = 0{\cdot}326$, $P > 0{\cdot}05$; juveniles *v.* females: $n = 12$, $r = 0{\cdot}156$, $P > 0{\cdot}05$) [Fig. 2(c), (d)]. The percentage of juveniles was found to be negatively correlated with the percentage of pregnant males (product moment correlation, $n = 12$, $r = -0{\cdot}640$, $P < 0{\cdot}05$).

The recruitment seemed to be closely related with the end of the upwelling regime off the Portuguese west coast (Lemos & Pires, 2004) (Mann–Whitney *U*-test, $n_1 = 5$, $n_2 = 5$, $P < 0{\cdot}05$), as observed when the number of juveniles captured from September to January was compared with the number of juveniles observed during April to August. The smallest captured individual was 4·1 cm (captured in September) and presented a cryptic uniform dark red and brown colouration, typical of small *N. lumbriciformis*. Juveniles were often associated, during the low tide, with stranded red algae such as *Gelidium sesquipedale* or *Pterocladia capillaceae* and could sometimes be observed, underneath boulders, near the lower limit of the *Chthamalus* belt, thus presenting a broader vertical distribution than adults.

The breeding season of *N. lumbriciformis*, together with the recruitment of juveniles to the intertidal, is correlated with seawater temperatures and, consequently, with the typical upwelling regime of the Portuguese coast. Breeding takes place during the whole year, but with a marked reduction during months where water temperature reaches values >15·5° C. At this temperature, upwelling ceases (Coelho *et al.*, 2002) and newly formed onshore currents driven by south-west and west winds contribute in moving larvae into the intertidal zone, where they arrive after a pelagic life phase. After hatching, *N. lumbriciformis* larvae, with a translucent colouration and a primordial marginal fin typical of pelagic larvae, display positive buoyancy, searching for food near the surface (Monteiro *et al.*, 2003). It is likely that, at this delicate stage, larvae may avoid the turbulence of the intertidal, moving away from the intertidal (or being moved by the typical offshore currents that occur during the upwelling season). Russell (1976) concluded that, in England, the pelagic phase lasted *c.* 1–2 months, ending when the juveniles reach a size of 30 mm. If the delay between the peak of spawning and the peak of juvenile recruitment to the shore is considered, it seems likely that the pelagic phase, in Portuguese waters, lasts *c.* 4 months. This conclusion is probably less contradictory with the findings of Russell (1976) than it could appear at first sight. The smallest juveniles collected in this study were

> 40 mm. If, instead of hand-collecting, other methods of sampling small fish were used, it is not unlikely that smaller fish could be found, so the exact size at which the young reach the shore and at what developmental stage need further investigation.

Increasingly higher coastal water temperatures, as registered from 1941 onwards, with mean year-round increases of 0·01° C (Lemos & Pires, 2004) may have dramatic consequences in the distribution of southern populations of *N. lumbriciformis*, since the breeding period (positively correlated with water temperatures <15·5° C) will be reduced, thus contributing to the northward movement of the southern geographical limit of this species.

Reproductive strategies of several pelagic fishes are often adapted to the frequency and intensity of coastal upwelling events and alterations in the normal regimes may have a negative impact in larval recruitment through increased mortality due to transport into unfavourable areas (Santos *et al*., 2001, 2004). The observed relationship between the upwelling season and breeding and recruitment may also be important for benthic species with a pelagic early life history, such as *N. lumbriciformis*.

The velocity at which geographical boundaries are changing could be further accelerated with shorter upwelling seasons, due to the northward transport observed off the Portuguese coast (outside the upwelling season) thus reducing local recruitment by displacing pelagic larvae northwards, namely into the Galician region, in north-west Spain (Fig. 1). Similar trends are already visible in algal species that share the same habitat with *N. lumbriciformis*, such as many brown algae typical of cold waters (*e.g. Laminaria sacharina* and *Himantalia elongata*) that greatly reduced their geographical distribution in the Portuguese continental coast during the last four decades (Ardré, 1969; N.M. Monteiro, pers. obs.).

We would like to thank everyone who helped during the fieldwork, especially S. Quinteira, J. Bacelo and J. Salgueiro. V. Almada participation was partially supported Programa Plurianual. N. Monteiro was supported by Fundação para a Ciência e a Tecnologia (FCT) PhD grant (SFRH/BD/2747/2000). We would also like to thank two anonymous referees for through their suggestions and criticism helped improve the manuscript.

References

Ardré, F. (1969). Contribution a l'étude des algues marines du Portugal. *Portugaliae Acta Biologica (Serie B)* **10,** 137–532.

Boaventura, D., Ré, P., Fonseca, L. C. & Hawkins, S. J. (2002). Intertidal rocky shore communities of the Continental Portuguese Coast: analysis of distribution patterns. *Marine Ecology* **23,** 69–90.

Coelho, H. S., Neves, R. J. J., White, M., Leitão, P. C. & Santos, A. J. (2002). A model for ocean circulation on the Iberian coast. *Journal of Marine Systems* **32,** 153–179.

Dawson, C. E. (1986). Syngnathidae. In *Fishes of the North-eastern Atlantic and the Mediterranean* (Whitehead, P. J. P., Bauchot, M. L., Hureau, J. C., Nielsen, J. & Tortonese, E., eds), pp. 628–639. Paris: UNESCO.

Gibson, R. N. (1972). The vertical distribution and feeding relationship of intertidal fish on the Atlantic coast of France. *Journal of Animal Ecology* **41,** 189–207.

Lemos, R. T. & Pires, H. O. (2004). The upwelling regime off the west Portuguese coast, 1941–2000. *International Journal of Climatology* **24,** 511–524.

Monteiro, N. M., Almada, V. C., Santos, A. M. & Vieira, M. N. (2001). The breeding ecology of the pipefish *Nerophis lumbriciformis* and its relation to latitude and water temperature. *Journal of the Marine Biological Association of the United Kingdom* **81,** 1031–1033.

Monteiro, N. M., Almada, V. C. & Vieira, M. N. (2003). Early life history of the pipefish *Nerophis lumbriciformis* (Pisces; Syngnathidae). *Journal of the Marine Biological Association of the United Kingdom* **83,** 1179–1182.

Russell, F. S. (1976). *The Eggs and Planktonic Stages of British Marine Fishes*. London: Academic Press.

Santos, A. M. P., Borges, M. F. & Groom, S. (2001). Sardine and horse mackerel recruitment and upwelling off Portugal. *ICES Journal of Marine Science* **58,** 589–596.

Santos, A. M. P., Peliz, A., Dubert, J., Oliveira, P. B., Angélico, M. M. & Ré, P. (2004). Impact of a winter upwelling event on the distribution and transport of sardine (*Sardina pilchardus*) eggs and larvae off western Iberia: a retention mechanism. *Continental Shelf Research* **24,** 149–165.

Electronic Reference

Eurosion (2003). *Trends of Coastal Erosion in Europe*. *Eurosion Project, Final Version Report*. Available at: http//www-eurosion.org