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# Bathymetric distribution and growth rates of *Eunicella verrucosa* (Cnidaria: Gorgoniidae) populations along the Marseilles coast (France)

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SUMMARY: Gorgonians are important organisms in the Mediterranean Sea, where they form rocky benthic communities. Four main species (3 Holaxonia and 1 Scleraxonia) are predominant in infra- and circalittoral communities of the northwestern Mediterranean basin. Other species, such as *Eunicella verrucosa* (Pallas, 1766), are more rarely encountered. The expansion to unusually shallow bathymetric levels has been noted in the region of Marseilles (France) (between 20 and 40 m depth). A ten-year monitoring of colonies was used to assess the growth rate according to age (size): from 3.33 cm year$^{-1}$ (height <15 cm) to 0.62 cm year$^{-1}$ (height >40 cm).

*Keywords*: *Eunicella verrucosa*, Mediterranean Sea, growth rate, population structure.

RESUMEN: DISTRIBUCIÓN BATIMÉTRICA Y TASAS DE CRECIMIENTO DE LAS POBLACIONES DE *EUNICELLA VERRUCOSA* (CNIDARIA: GORGONIIDAE) A LO LARGO DE LAS COSTAS DE MARSELLA (FRANCIA). – En las comunidades mediterráneas, las gorgonias son especies emblemáticas que aportan estructura a las comunidades bentónicas de fondos rocosos. En la cuenca noroccidental, cuatro especies son abundantes en las comunidades infra y circalitorales. Otras especies se encuentran más raramente. Es el caso de *Eunicella verrucosa* (Pallas, 1766). Esta especie se ha extendido a niveles batimétricos inusuales en la región de Marsella (Francia) (entre 20 y 40 m). El seguimiento durante 10 años de colonias ha permitido estimar que la tasa de crecimiento es diferente según la edad (tamaño), variando de 3.33 cm año$^{-1}$ (altura colonias <15 cm) hasta 0.62 cm año$^{-1}$ (altura colonias >40 cm).

*Palabras clave*: *Eunicella verrucosa*, mar Mediterráneo, tasas de crecimiento, estructura de la población.

## INTRODUCTION

In the Mediterranean Sea, gorgonians include around 20 species, inhabiting a wide bathymetric range (from the infralittoral to the bathyal stages) (Carpine and Grasshoff 1975, Grasshoff 1992). In the northwestern basin, four species (three Holaxonia [*Eunicella singularis*, *E. cavolinii* and *Paramuricea clavata*] and one Scleraxonia [*Corallium rubrum*]) may be frequently encountered up to depths of around 100 m, forming locally dense populations (Carpine and Grasshoff 1975, Weinberg 1978, Gili *et al.* 1989). Gorgonian assemblages contribute greatly to the Mediterranean sublittoral seascape, providing biomass and structural complexity (Gili and Coma 1998, Ballesteros 2006), and an additional aesthetic value of sublittoral communities (Bianchi *et al.* 1995).

In contrast, the gorgonian *Eunicella verrucosa* (Pallas, 1766) is more rarely observed. This species is found in both the Atlantic Ocean and the Mediterranean basin (Carpine 1963, Carpine and Grasshoff 1975, Weinberg 1976, Mistri 1995, Vafidis 2009). In the Atlantic, it is present from Scotland to Angola (Grasshoff 1992). It colonizes rocky beds at depths ranging from 2 to 60 metres and is a major heritage species (Lafargue 1969, Hiscock 2003, IUCN 2010). In the Mediterranean, its distribution varies widely from one area to another. *E. verrucosa* is well-represented in the Alboran sea and along the Moroccan and Algerian coasts (Grasshoff 1992, Claude Reveret unpublished data), but is found sporadically in the northwestern basin: in Italy and France (Provence and Côte d'Azur, western coast of Corsica) and along the Spanish coasts (Berdar and Cavallero 1980, Balduzzi *et al.* 1992, Calvín Calvo 1995, Cocito *et al.* 2002, Coppo *et al.* 2009). In the northern part of the western Mediterranean, it is mainly found on the hard substrates of the lower circalittoral (35 m depth) up to the upper limit of the bathyal stage (200 m depth) (Carpine and Grasshoff 1975, Grasshoff 1992); its presence at shallower depths is rare (e.g. Gulf of Genoa; between 20 and 30 m depth) (Rossi 1959, 1961, Cocito *et al.* 2002).

Numerous studies of population dynamics, growth rate, reproduction and feeding ecology have been conducted on Mediterranean gorgonians, and in particular on *Eunicella singularis*, *Paramuricea clavata* and *Corallium rubrum* (Weinberg 1978, 1979, Vélimirov and Weinbauer 1991, Coma *et al.* 1995, Mistri and Ceccherelli 1993, 1994, Garrabou and Harmelin 2002, Tsounis *et al.* 2006, Linares *et al.* 2007). Other studies have focused on distribution, autecology and growth of *Leptogorgia sarmentosa* (Weinberg 1978, Weinberg 1979, Francour and Sartoretto 1992, Mistri and Ceccherelli 1993). However, although recent studies have been launched on the ecology and structure of *Eunicella verrucosa* populations along the coast of Great Britain (Munro and Munro 2003, Munro 2004), little or no data are available on the biology of this species in the Mediterranean.

In the early 1990s, colonies of *E. verrucosa* were observed in the region of Marseilles (south-east France). These observations were surprising in terms of shallow bathymetric range (depths between 25 and 35 m) and colony density, which was unusually high in some locations. Additional colonies were subsequently observed at depths of up to 75 m. Colony monitoring over a 10-year period at a single site yielded new data on the population dynamics and growth rates of *E. verrucosa* in the Mediterranean, the results of which are presented in this article. On the basis of these results, we have examined various hypotheses related to the settlement and expansion of this species at uncommon bathymetric levels in the northwestern Mediterranean basin.

## MATERIALS AND METHODS

### Site description

In the early 1990s, only six colonies of *Eunicella verrucosa* had been observed at a depth of 26 m to the east of Maire Island—one of the four main islands of the Riou archipelago (Fig. 1). This archipelago situated off the Massif des Calanques (south-east France, 43°10N-05°25E) is attached to an Urgonian limestone formation extending into high cliffs plunging into the sea and interspersed with deep fjords, known as *calanques* (Froget 1974). The geomorphology of this massif defines the bathymetry of the surrounding sea beds, with underwater cliffs reaching depths of up to 75 m.

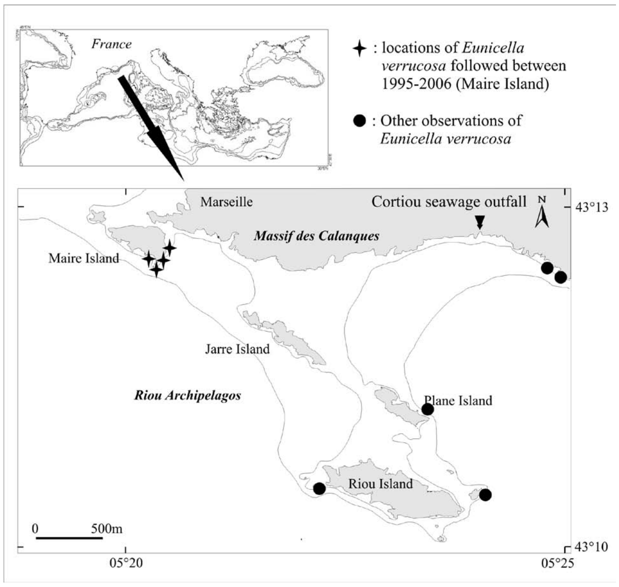


Fig. 1. – Study zone and location of *Eunicella verrucosa* population monitored between 1995 and 2006.

A sewer outlet was installed along this coast in the Calanque de Cortiou in 1899, and is now used to discharge waste water from the city of Marseilles and surrounding towns. Since 1987, this waste water has been treated by a water treatment plant sized for 1.6 million equivalent inhabitants.

### Acquisition of quantitative data

An initial search for *E. verrucosa* was undertaken in the Marseilles region between 1993 and 1995 by SCUBA divers, at depths of between 20 and 80 m (using air up to 60 m and a TRIMIX mixture below that depth). Based on these initial surveys, a more detailed study was conducted between 1995 and 2007 to determine the distribution of this species on the eastern and southern faces of the Maire Island at depths of 20 to 40 m (Fig. 1). Twenty bathymetric transects of 100 m length were visited every three years. Along these transects, the maximum height (h) and width of the observed *E. verrucosa* colonies was noted in situ, using a decimetre with a millimetre scale.

Finally, between 1997 and 2006 the monitoring of 15 colonies of various sizes (5 to 40 cm in height), marked in situ using small numbered plates attached to their base with a plastic ring, was used to determine colony growth rate versus height.

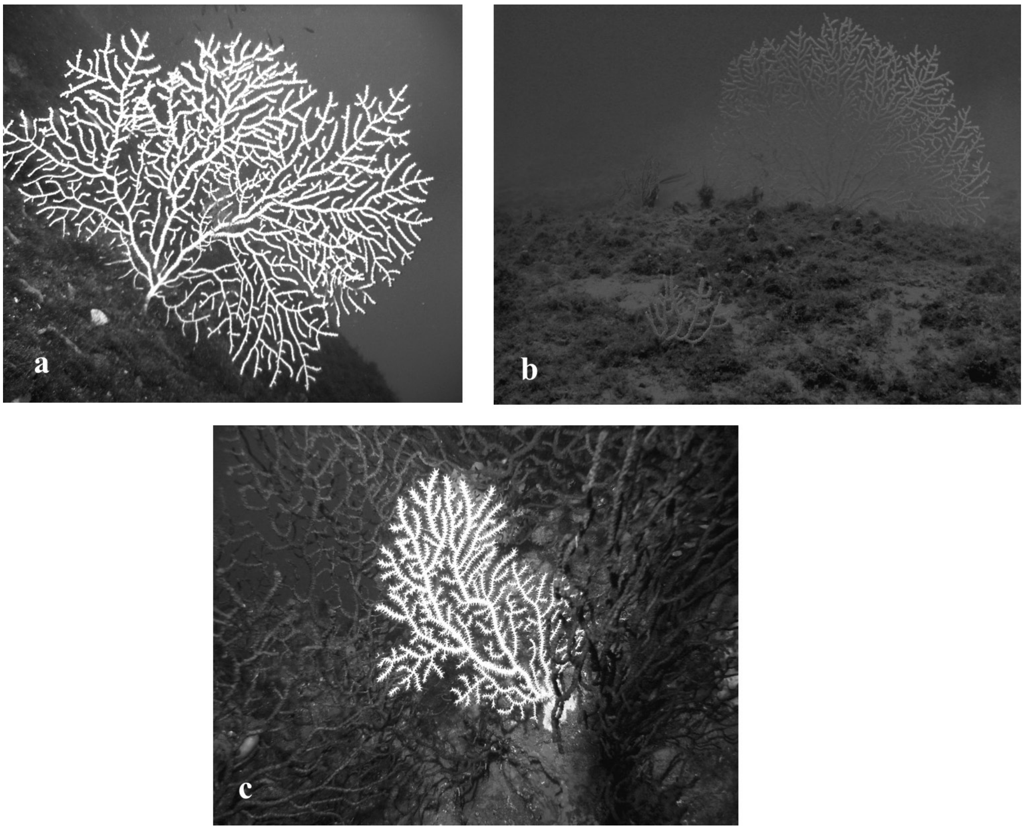


FIG. 2. – *Eunicella verrucosa* and associated benthic communities observed around Maire Island; a, large *E. verrucosa* colony (h: 49 cm) settled on tilted rock (–36 m); b, large and young colony observed on horizontal rock (–30 m); c, *Eunicella verrucosa* locally associated with *Paramuricea clavata* (–33 m).

**Statistical treatment**

The effect of depth on colony distribution throughout the archipelago and around Maire Island was analyzed by the non-parametric Kruskall-Wallis test and post-hoc differences were analysed by means of the NKS test using STATISTICA® software. Finally, the relationship between growth rate and size (height) was estimated using linear regression and the age of the colonies in relation to height was estimated using the Von Bertalanffy growth function (Crisp 1984).

## RESULTS

**Presence and demographic structure of the *E. verrucosa* population observed in the Marseilles region**

Seventy-three colonies of *Eunicella verrucosa* were observed at 22 and 75 m depth in the study zone (Massif des Calanques and Riou archipelago). The observed *E. verrucosa* colonies were fixed on rocky limestone substrates, bioconcretion substrates or small pebbles sunk in the soft sediment present at the foot of underwater cliffs colonized by *Paramuricea clavata* and *Eunicella cavolinii* populations (Fig. 2a to 2b). However, several *E. verrucosa* colonies were observed on the rock faces, amid the *P. clavata* populations characterizing the circalittoral hard bottom substrate in the study area (Fig. 2c), or together with *Leptogorgia sarmentosa*. Among the species associated with the hard bottom substrate colonized by *E. verrucosa*, the perforating sponge *Cliona viridis* with locally encrusting shapes (beta shape) was noted at 25 and 40 m depth. A Rhodophyta originating from the Indo-Pacific (Norris 1992) (*Womersleyella setacea* (Hollenberg) R.E. Norris, RHODOMELACEA), was also collected. Lastly, two molluscs (*Tritonia nilsodneri* and *Neosimnia spelta*) and one crustacean (*Balssia gasti*) were observed on *E. verrucosa* colonies.

Most sea fans (58.9%) were located between 30 and 40 m depth, though a significant number (17.8%) were found at 20 to 30 m depth. The *E. verrucosa* population observed in this area included predominantly small colonies (10-20 cm in height) and average-height colonies (20-30 cm in height), these two classes representing 72.5% of the overall population. The tallest colonies (>30 cm in height) represented 20% of the total observed population. In general, juvenile colonies (<10 cm in height) were located adjacent to tall colonies (1 m radius). *E. verrucosa* colony height differed significantly according to depth (Kruskall-Wallis test, H(3.74)=12.717, $P<0.006$; Fig. 3). As a general rule, below 50 metres, colonies were larger

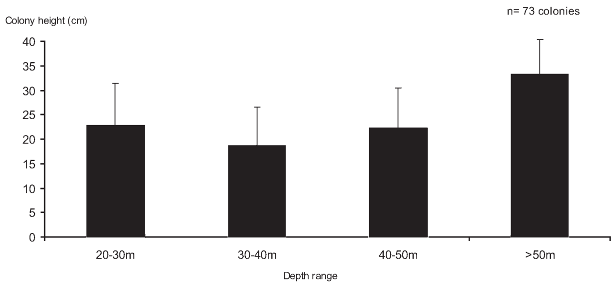


FIG. 3. – Variation of mean height colony of *Eunicella verrucosa* along depth gradient (vertical bar: mean ± SE).

(33.2±7.0 cm; mean±SE), whereas colonies at shallower depths tended to be smaller (19.9±10.7 cm; mean±SE). The differences in *E. verrucosa* colony height were particularly noticeable in the 30 to 40 m depth range, where most of the observed colonies were located, and in the depth range below 50 m (non-parametric NKS test, $P<0.05$).

Between 1995 and 2007, 95% of the observed colonies showed little or no necrosis (maximum bare surface lower than 10%). However, on two occasions in winter (February 1997 and March 2001), we noted the presence of 5 colonies with 50% to 75% surface necrosis. These colonies, situated at depths of 25 to 30 m, did not exceed 20 cm in height and necrosis was recent (few or no epibionts attached to the bare corneous branches).

## Growth rate

Biannual growth measurement on 15 colonies of varying sizes (between 5 and 40 cm) was used to estimate the growth rate (GR) of *Eunicella verrucosa*.

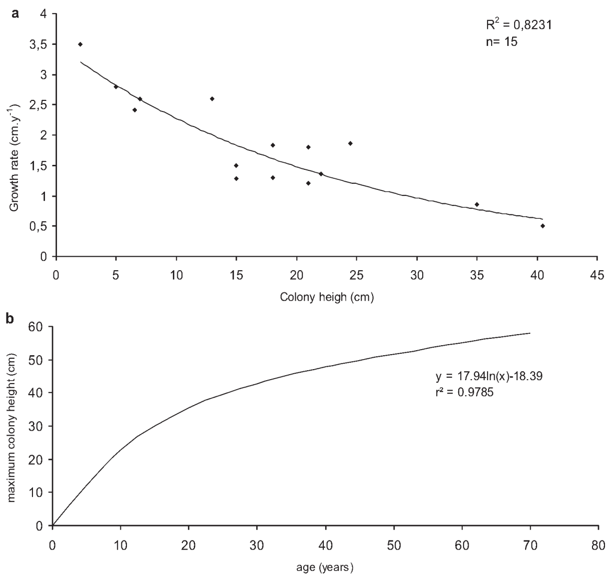


FIG. 4. – Evolution of growth rate of *Eunicella verrucosa*. a, evolution of growth rate according to colony size; b, estimation of maximum height according to colony age (Von Bertalanffy growth function).

GR decreased with colony height (H), according to the following function ($r^2$=0.8231) (Fig. 4a):

$$GR = 3.4733\, e^{-0.0434H} \qquad (1)$$

where GR is expressed in cm year$^{-1}$ and H in cm

For colony height less than 15 cm, *E. verrucosa* grew at a rate of 3.33±0.61 cm year$^{-1}$, whereas colonies between 15 and 40 cm grew at 1.47±0.40 cm year$^{-1}$. The GR for the tallest colonies monitored during the study (40 cm in height) dropped to 0.62±0.22 cm year$^{-1}$. The Von Bertalanffy growth function obtained from Equation (1) and used to establish a relationship between height (H) and age of colonies ($r^2$=0.9785; Fig. 4b) was:

$$H = 17.94\ln(t)-18.39$$

According to this equation, the tallest observed colonies (42.5 cm) in the Riou archipelago and Massif des Calanques areas can be estimated to be at least 35 years old. Similarly, in the small Maire Island population, the predominant height class (10-20 cm) corresponds to colonies aged 5-10 years.

# DISCUSSION

## Distribution of *Eunicella verrucosa* in the Mediterranean Sea

*Eunicella verrucosa* is a gorgonian usually found in the western Atlantic, from Great Britain to Angola (Grasshoff 1992), and also in the western basin of the Mediterranean (Carpine and Grasshoff 1975). Although it is frequently encountered near the Gibraltar Straits, it is much rarer throughout the rest of the basin. It is mainly present at 40 to 50 m depth along the northwestern coasts (Carpine and Grasshoff 1975). The observations of *Eunicella verrucosa* reported in this study correspond to a general trend of bathymetric expansion of species from various taxonomic groups since the early 1990s. This is the case for various Echinodermata, regularly observed in recent years along French coasts at shallow depths: *Centrostephanus longispinus, Chaetaster longipes*, *Peltaster placenta* and *Ophidiaster ophidianus* (Francour *et al.* 1994, Harmelin and Ruitton 2010). In the northwestern basin, these species are normally associated with lower circalittoral and bathyal stages, meeting up near the surface in the western Mediterranean basin (Tortonese 1984, Zibrowius 1991, Özaydin *et al.* 1995). Two Labridae, *Lappanella fasciata* and *Acantholabrus pallonii*, observed infrequently and typically at depths exceeding 100 m (Quignard 1966, Quignard and Pras 1986), also appear to have risen to much shallower bathymetric levels (Sartoretto *et al.* 1997) in the last 15 years. Lastly, *Gobius vittatus*, considered as a rare species until the early 1990s, is now commonly found from depths of 10 m (Le Mesa and Vacchi 1999, Francour *et al.* 2005).

In the northern Adriatic, its abundance varies with the seasons and is correlated with temperature (Kovacic and Arko Pijevac 2008).

The previously-described species are generally found in shallow waters in the southwestern or eastern Mediterranean basin and in deep waters in the northwestern basin. In this geographical area, the shift in the upper distribution limit could be due to the global warming affecting the Mediterranean, corresponding in this case, to the thermophilic character attributed to these species (e.g. Francour *et al.* 1994, Astraldi *et al.* 1995). However, in addition to the increase in average surface water temperature, another reason for the rising of deep species could be the relative stenothermia of sea water linked to smaller inter-seasonal temperature variations. Indeed, deep Mediterranean waters situated under the seasonal thermocline are characterized by a stable temperature (around 13°C) and we could hypothesize that the rising of species living at this bathymetric level therefore implies a trend towards stable surface temperatures (Laubier and Emig 1993).

*Eunicella verrucosa* observations around Maire Island (unusual depth and abundance) are to be coupled with increasing observations of *Leptogorgia sarmentosa* along the coast of Provence (Francour and Sartoretto 1992 and unpublished data). These two gorgonians are typically found in environments with relatively high turbidity and on beds fed with fine particles (Grasshoff 1992). A change in the environmental conditions (a rise in general turbidity and sediment inputs) could also explain the appearance of *E. verrucosa* at unusual bathymetric levels. The presence of a surface sewer (the Cortiou sewer serving 1.6 million equivalent inhabitants), whose waste water discharges are carried up to Maire Island, where they are blocked against the island's eastern face, induced a rise in organic matter inputs and fine particle hypersedimentation. The impact of these inputs is witnessed, for example, in the presence of large colonies of *Cliona viridis* (Beta shape), a suspension feeder perforating the coralligenous formations (Carballo *et al.* 1996).

These environmental changes could favour the installation of larvae of deep spawners (spawning below 80 m) due to frequent upwellings caused by the Mistral (north-westerly) wind in the region of Marseilles (Rouch 1941). Upwellings can generate currents sufficiently strong to carry larvae of deep-water organisms over great distances (Pradal and Millet 2006). *Eunicella verrucosa* larvae, which are lecithotrophic and probably have a short lifespan, are dispersed over small distances around the spawning colonies (<1 km) (Munro and Munro 2003). However, artificial substrate monitoring has shown that *Eunicella verrucosa* colonization can be fairly rapid (less than 3 years) (Hiscock *et al.* 2010). The very-narrow continental shelf located along the coasts of Provence leads to depths of around 100 m within close proximity of the coast, where *E. verrucosa* populations emitting planulae likely to colonize shallow bathymetric levels may be established.

Lastly, the study of the small population situated to the east of Maire Island tends to confirm an expansion, coupled with the regular recruitment of new *E. verrucosa* colonies. This recruitment could be due to the installation of planulae emitted by the large colonies located at deeper depths (below 80 m, Luc Vanrell, pers. comm.) and carried to shallower depths by upwellings generated by the Mistral wind. The maintaining of new recruits may hence be linked to the maintaining of new environmental conditions.

**Growth rate evaluation**

Gorgonian colony height is a robust parameter that is taken into account to estimate the average growth rate of gorgonian colonies (Coma *et al.* 1998). *Eunicella verrucosa* growth rates estimated in the Mediterranean (0.6 to 3.5 cm year$^{-1}$) are of the same order of magnitude as those measured in other geographical areas, but slightly lower than those measured in the English Channel (1 to 4.5 cm year$^{-1}$; Munro and Munro 2003). They are also equivalent to those noted in other Mediterranean gorgonians living at similar depths: 1.8 to 2.7 cm year$^{-1}$ for *Paramuricea clavata* (Mistri and Cecherelli 1994, Coma *et al.* 1998), 2.2 cm year$^{-1}$ for *Eunicella singularis* (Weinberg and Weinberg 1979) and 2.57 cm year$^{-1}$ for *Leptogorgia sarmentosa* (Mistri and Ceccherelli 1993). Gorgonians are colonial suspension feeders that feed on plankton and on dissolved and particulate organic matter (Ribes *et al.* 1999, Ribes *et al.* 2003, Tsounis *et al.* 2006). In colonial Anthozoa, food availability favours higher growth rates by affecting metabolic functions (Marschal *et al.* 2004, Coma *et al.* 1998, Skoufas *et al.* 2000, Mortensen and Buhl-Mortensen 2005). In summer, food scarcity leads to restricted metabolic activity (aestivation), making gorgonians vulnerable to thermal stresses (Coma *et al.* 2000). The lower *E. verrucosa* growth rates noted in the Marseilles region compared with other regions (English Channel) could hence be explained by oligotrophy in the Mediterranean basin. However, our monitoring area is exposed to urban waste discharges, including a large quantity of organic matter (Arfi *et al.* 2000), which could favour faster-than-expected growth. This continuous input could also explain the absence of necrosis in *E. verrucosa* colonies present in this zone during the massive gorgonian mortality episodes of 1999 and 2003, when other Mediterranean regions were affected (Perez *et al.* 2000, Laubier 2001, Garrabou *et al.* 2009). Finally, growth of *E. verrucosa* decreased with colony age. This evolution in growth rate according to age is a constant in gorgonians (e.g. Mistri and Ceccherelli 1993, Mitchell *et al.* 1993, Coma *et al.* 1998, Andrews *et al.* 2002) and in numerous marine colonial sessile invertebrates. A study on growth rings in *Eunicella verrucosa* showed that it can live up to an age of around 100 years (Hisckock unpublished data). This longevity correlates with the estimated ages of the tallest colonies observed in the study zone (35 years for colonies measuring 42 cm in height).

To conclude, the spreading of several deep species in shallow zones raises questions regarding the monitoring of environmental conditions on the basis of long-term data, such as temperature and turbidity. Cross-referencing these data may allow us to determine whether species such as *Eunicella verrucosa* are potential indicators of environmental variations. It is vital to take these species into account in order to assess the evolution of biodiversity in coastal areas in the framework of global change. Moreover, biodiversity assessment aimed at preservation is a main part of the Marine Strategy Framework Directive (MSFD) adopted by all EU member countries.

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