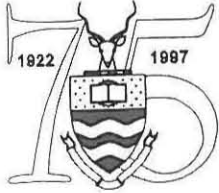


# On the co-occurrence of two exotic, invasive marine organisms: the brown seaweed *Sargassum muticum* (Yendo) Fensholt and the Spirorbid tube worm *Janua* (*Neodexiospira*) *brasiliensis* (Grube), in association with the indigenous eelgrass, *Zostera marina* L. and Wrack, *Fucus serratus* L. in the south-west Netherlands and the Channel Islands, Europe

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*Janua* (*Neodexiospira*) *brasiliensis*, an immigrant spirorbid, has extended its range in Europe. Once restricted to Portsmouth Harbour, south coast of Britain, the tubeworm has subsequently established isolated, but well-developed, populations in a small saline canal in the south-west Netherlands and in an intertidal outflow channel from the Jersey Power Station at St. Helier in the Channel Islands. In Portsmouth Harbour, where *J. brasiliensis* was first discovered as an European immigrant species, the tubeworm is associated with another introduced organism, the brown seaweed *Sargassum muticum*; in the south-west Netherlands *J. brasiliensis* develops most prolifically upon the marine angiosperm *Zostera marina*, whilst at St. Helier the brown wrack *Fucus serratus* has become most heavily colonized. Both new sites of establishment are influenced by seasonally elevated seawater temperatures (25°C), which may be responsible for the notable, localized population developments on *Z. marina* and *F. serratus* (mean settlement densities of 29.7 ± 2.5 and 55.1 ± 3.5 individuals per cm<sup>2</sup> respectively were recorded).

**Keywords:** Polychaeta, spirorbids, *Sargassum muticum*, *Zostera marina*, *Fucus serratus*, marine angiosperm, invasive biota, introductions, North Sea, Netherlands, Channel Islands.

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## Introduction

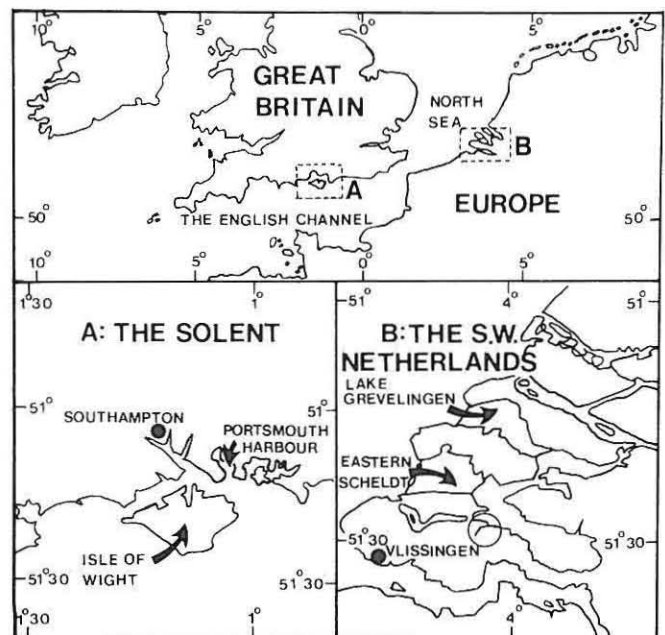
*Janua* (*Neodexiospira*) *brasiliensis* (Grube) (Polychaeta: Spirorbidae), has increased its range of distribution into, and within, European waters (Knight-Jones *et al.* 1975a; Critchley & Thorp 1985). Prior to this report *J. brasiliensis* was known only from two geographically isolated localities within Europe (Figure 1). The first, Portsmouth Harbour, south coast of Britain is thought to be the initial site of establishment (Knight-Jones *et al.* 1975a; Gray 1978); the second, Goes Canal, island of South Beveland, south-west Netherlands (Critchley & Thorp 1985). At both sites the animal was epiphytic upon another introduced species, viz. the Japanese, brown seaweed: *Sargassum muticum* (Yendo) Fensholt.

Knight-Jones *et al.* (1975a) and Gray (1978) described the thallus of *S. muticum* as being the preferred substratum for attachment of *J. brasiliensis* larvae in Portsmouth Harbour. Critchley and Thorp (1985), however, reported its occurrence on *S. muticum* thalli as significant, but indicated that the leaves of *Zostera marina* L. (eelgrass) were numerically the preferred substratum in Goes Canal. This paper reports the recent discovery of another well-developed, isolated, population of *J. brasiliensis* in the Channel Islands, U.K.. The occurrence of the tubeworm as an epibiont is discussed, together with the influence of localized, seawater temperature elevations promoting the successful establishment and development of *J. brasiliensis*.

## Material and Methods

Collections of *J. brasiliensis* were preserved in either 70% alcohol or 4% formalin in seawater (neutralized with sodium tetraborate). Settlement densities were determined using a 1 cm grid. The mean of 10 replicates is given with a variation of one standard error (± 1 S.E.).

Seawater temperatures within Goes Canal (at a water depth of c. 50cm) were recorded for the months of May to November 1982 using a thermocouple linked to a digital thermometer reading to 0.1°C accuracy. Eastern Scheldt seawater temperatures were obtained through the Delta Institute, Eastern Scheldt Research



**Figure 1** The position of Portsmouth Harbour, south coast of Britain Lake Grevelingen and the Eastern Scheldt south-west Netherlands and the Channel Islands. Goes Canal is encircled on the island of South Beveland.

Programme. The mean ( $\pm 1$  S.E.) of a minimum of 14 recordings is given for each monthly seawater temperature (Table 1). Seawater temperature for the Channel Islands and power-station discharge rates were obtained from the Jersey Electricity Company (Mr John Thow, pers. comm.) and the Department of Agriculture and Fisheries (Jersey; Dr S. Bossy, pers. comm.).

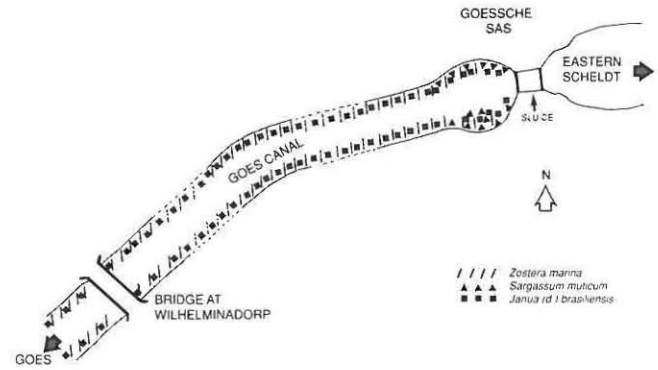
## Field Observations

### 1) Goes Canal, south-west Netherlands

The non-tidal, saline Goes Canal links the town of Goes with the Eastern Scheldt (see Critchley & Thorp 1985); Nienhuis (1982) reported that salinity ranged between 27°–29°C and water level fluctuated between 10–30 cm in the canal. Entrance to the canal was controlled by sluice gates at Goessche Sas. Figure 2 indicates the distribution of *Janua brasiliensis*, *Zostera marina* and *Sargassum muticum* in the area of Goessche Sas between 1982–1986. *Zostera* was distributed along the length of the canal. It occupied a 1–2 m wide band adjacent to each bank and was attached within a mud/silt substratum in depths of 1–1.5 m. In contrast, attached *S. muticum* plants were confined to the canal basin at Goessche Sas, in water depths of 0.5–0.8 m. Individual plants were attached to scattered hard substrata (rubble and dyke building blocks) in the canal channel, otherwise *S. muticum* was largely restricted to the canal walls. *J. brasiliensis* was widely distributed within the canal, occurring at Goessche Sas on the concrete walls, rubble and building blocks, shells of living *Littorina* spp., *S. muticum* and also on *Z. marina* plants to a distance slightly beyond the bridge at Wilhelminadorp. Greatest settlements of *J. brasiliensis* were found close to the sluice gates.

When first discovered in 1982, the high density of the calcareous tubes of *J. brasiliensis* conferred a 'white crystalline' appearance on the eelgrass leaves. The weight of tubes caused the leaves to sag and many to lie on the muddy bottom of the canal.

*Janua* tubes covered 50–85% of the available *Zostera* leaf area, with a maximum density of 29.7 ( $\pm 12.5$ ) individuals per cm<sup>2</sup> (Figure 3). Spirorbid settlement occurred over the entire leaf surface. *J. brasiliensis* settlement on *Sargassum* was usually less than half that on *Z. marina*; the animals were confined largely to the basal holdfast/main axis and the lower regions of the primary



**Figure 2** The distribution of *Zostera marina*, *Sargassum muticum* and *Janua brasiliensis* within Goes Canal (as far as Wilhelminadorp), 1982–1986.

laterals.

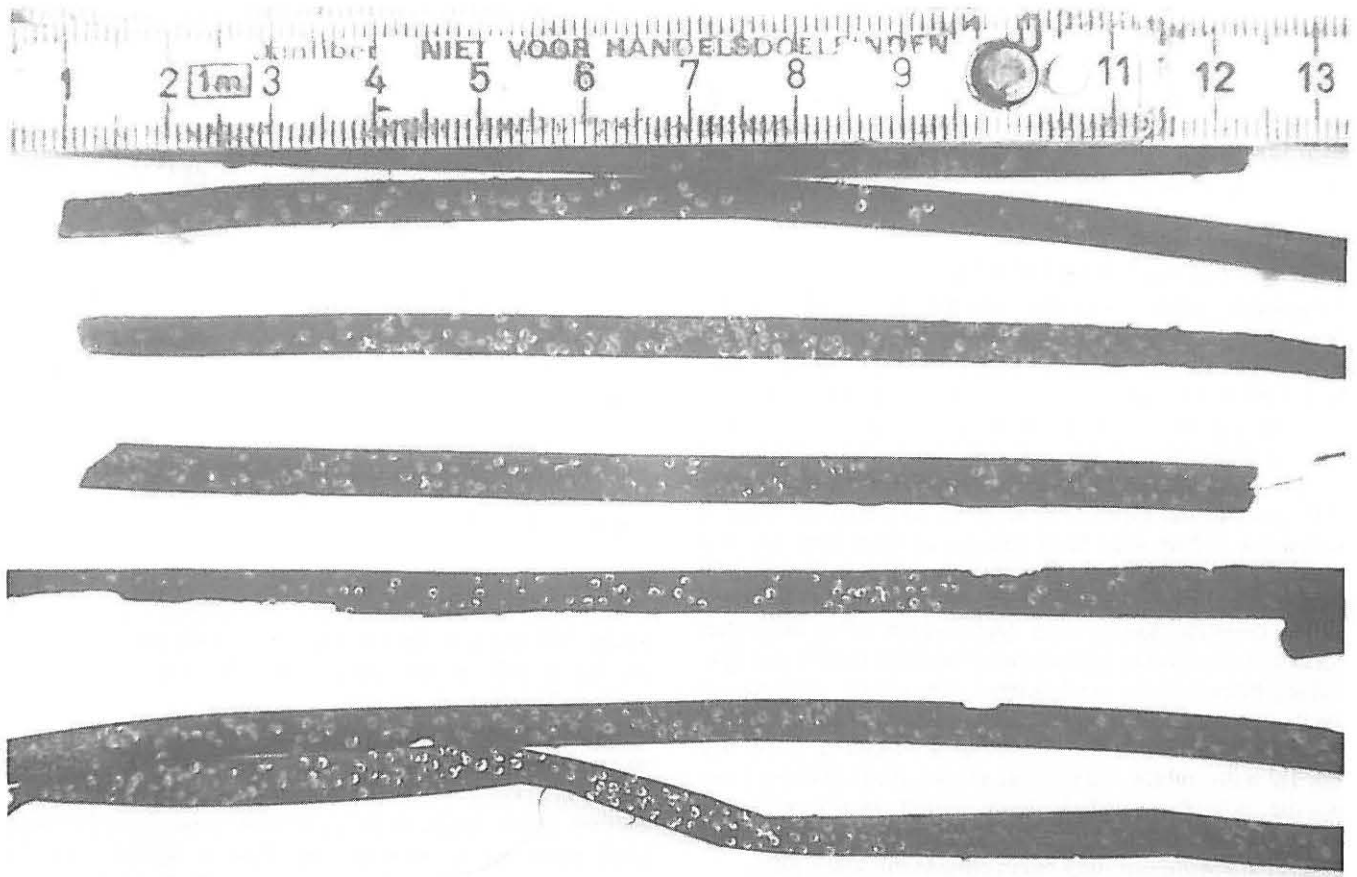
Settlement and survival of *Janua* on the canal walls was very patchy, influenced by the grazing activity of littorinids and possibly fish as well as topography. Here tubeworm densities were less than 5 individuals per cm<sup>2</sup>.

Maximum densities of *J. brasiliensis* in Goes canal walls were observed mid-April to early July 1982, at which time the primary laterals of *S. muticum* became detached from their main axis. The buoyant fronds floated in the canal basin until washed onto the canal banks, or released into the Eastern Scheldt when the sluice-gates were opened. From August 1982 there was also fragmentation/detachment of *Z. marina* leaves which, with their heavy settlement of spirorbid tubes, sank to the muddy bottom of the canal banks where the leaves rapidly dehydrated or decomposed resulting in the death of attached tubeworms. The *J. brasiliensis* population consequently declined and by September 1982 the only tubes remaining were confined to the canal walls and the perennial holdfast/main axes of *S. muticum* plants.

Surprisingly, *Janua* was not associated with *Sargassum* populations either in Lake Grevelingen or on the Wadden Sea island of Texel (see Critchley *et al.* 1987 for localities). The high settle-

**Table 1** Seawater and air temperatures recorded in the Eastern Scheldt and Goessche Sas

Month	Seawater temperature of Eastern Scheldt (°C)			Maximum seawater temperature (°C) (> 50 cm) Goessche SAS	Air temperature of Eastern Scheldt area (°C)	
	Mean monthly	Maximum	Minimum		Maximum	Minimum
January	1.3 ( $\pm 0.1$ )	4.5	-1.2		11.0	-2.0
February	2.8 ( $\pm 0.2$ )	4.0	1.7		10.0	-1.0
March	5.0 ( $\pm 0.3$ )	6.8	3.0		12.0	-5.0
April	8.4 ( $\pm 0.1$ )	10.8	6.0		17.0	0.0
May	11.8 ( $\pm 0.7$ )	17.1	9.1	20.5	27.0	6.0
June	18.6 ( $\pm 0.3$ )	20.4	17.2	24.2	28.0	9.0
July	20.1 ( $\pm 0.2$ )	22.1	18.2	29.7	32.5	10.0
August	19.8 ( $\pm 0.5$ )	22.7	16.2	30.0	30.0	11.0
September	17.6 ( $\pm 0.3$ )	19.0	16.1	26.5	28.0	9.0
October	13.4 ( $\pm 0.4$ )	16.4	11.2	20.1	22.2	1.0
November	9.5 ( $\pm 0.5$ )	12.0	5.9	10.0	17.0	-5.0
December	5.0 ( $\pm 0.2$ )	6.0	4.0		11.0	-3.0



**Figure 3** Settlement of *Janua brasiliensis* on leaves of *Zostera marina*. Leaves could be encrusted with 50–85% cover of tube worms

ment densities recorded for *Janua* in 1982 were not sustained and population density stabilized at  $< 0.5$  individuals per  $\text{cm}^2$  of *Zostera* leaf (Professor P.H Nienhuis pers. comm.)

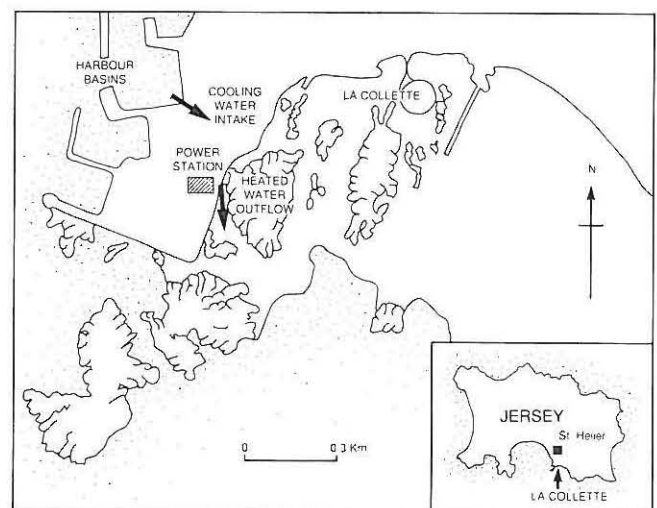
2) New record of *Janua brasiliensis* in the English Channel *Sargassum muticum* was first recorded from the island of Jersey in 1980 at St. Helier (Critchley *et al.* 1983). Since April 1981, marine biology field courses from the School of Biological Sciences, University of Portsmouth (formerly Portsmouth Polytechnic) have taken place on Jersey. Initially, studies were largely confined to Portlet Bay in the southwest of the island, with a number of rock pools being monitored at both Corbiere Point and Elizabeth Castle. Subsequently investigations were extended to include Gifford Bay on the north coast and Archirondel to the west and, in October 1987, the intertidal area adjacent to the out-flow channel from the Jersey Power Station at La Collette, St. Helier, was examined for the first time (Figure 4).

As part of the field course investigations the incidence and spread of *S. muticum* have been monitored at all these sites (Farnham pers. obs.). In addition a wide range of epiphytic organisms has been identified from not only *S. muticum*, but also a range of other algae including *Corallina officinalis* L., *Fucus serratus* L., *Halidrys siliquosa* Lyngb., *Himantalia elongata*, *Laminaria digitata* Lamour. and *L. hyperborea* (Gunn.) Foslie. In light of the association of the invasive tube-worm *J. brasiliensis* with *S. muticum* in both Portsmouth Harbour, S. England (Knight-Jones *et al.* 1975a) and the Eastern Scheldt, south-west Netherlands (Critchley & Thorp 1985) particular attention was given to the determination of epiphytic spirorbids in the Channel Islands.

While spirorbids contributed significantly to the epiphytic fauna of the above algae, they comprised only the indigenous species, *Spirorbis corallinae* de Silva & Knight-Jones, *S. spiror-*

*bis* (L.), *S. inornatus* L'Hardy and Quievreux and *Janua (Janua) pagenstecheri* (Quatrefages) at all sites apart from La Collette. At La Collette, however, the *S. muticum* population was notable for bearing, not only the indigenous *J. pagenstecheri*, but also the exotic *J. brasiliensis*.

The occurrence of the sub-tropical *J. brasiliensis* at La Collette was of significance in view of the close proximity of the *S. muticum* 'host' plants to the cooling-water (seawater) outflow channel from the power-station. However, *S. muticum* plants were notably absent from the outflow channel itself. Settlement of germlings of the alga was probably being discouraged by the



**Figure 4** The La Collette study area, Jersey, Channel Islands, showing the relative positions of the water intake and flow (arrows) from Jersey Power Station.

flow within the channel (see Norton & Fetter 1981). A small number of *S. muticum* individuals occurred adjacent to the channel, largely confined to shallow pools and, in October 1987 and 1988 when the area was investigated, only the perennial, basal portions of *S. muticum* remained (due to natural annual die-back). It was noticeable that while *J. brasiliensis*, was common on *S. muticum* close to the channel, it was absent from plants as little as 10–15m distant.

The State of Jersey prosecute a programme of clearing 'drift algae' from popular 'amenity' beaches and dumping them in less popular areas. The area adjacent to the power station outflow channel became one of the dumping areas, notably in 1989–90. In October 1991 investigation of the La Collette site revealed an absence of *S. muticum* plants, probably as a result of 'smothering'. Within the fast-flowing outflow channel, 40–50 m below the retaining wall of the holding channel, however, luxuriant plants of *Fucus serratus* were observed with a noticeably rich (maximum density 73 per cm<sup>2</sup>, mean 55.1 ± 3.5 per cm<sup>2</sup>) epiphytic population of spirorbids which were identified as *J. brasiliensis* (Figure 5). Furthermore, in February 1991, the power-station switched from the use of direct chlorination (liquid chlorine), to 'Actibrom', for cleaning purposes (Mr J. Thow, Jersey Electricity Company pers. comm.). This may have also contributed to the successful establishment of *J. brasiliensis* in the power-station outflow.

### 3) Seawater and Air Temperatures from the Eastern Scheldt and Goessche Sas

Table 1 provides mean monthly and maximum/minimum seawater temperatures and maximum/minimum air temperatures for Eastern Scheldt for the period January to December, 1982. Seawater temperatures for Goessche Sas are also given. During the

period May to October, 1982 (with maximum air temperatures of c. 32.5°C), it was observed that shallow water (c. 50 cm) temperatures within the canal basin at Goessche Sas were elevated by 3.4–7.6°C above the monthly maximum of the Eastern Scheldt. The data also show that during cold periods (i.e. November, 1982; minimum air temperature -5°C) the canal water temperature was comparable with that of the estuary.

### 4) Seawater temperature in the outflow channel of Jersey Power Station

As the demand for electricity is considerably greater during the winter months, it follows that the output of cooling water during the winter period will also be greater. In its passage through the power station the temperature of the seawater is raised above ambient by ca. 6°C in summer and 11°C in winter with only 8°C difference between these seasons respectively, thus providing a relatively stable, elevated thermal environment. (Bossy 1977; Mr J. Thow pers. comm.).

The effluent is discharged by overflowing the retaining wall of the 'holding pond' into the sea. At high tide discharge is directly into the sea adjacent to the retaining wall. During low tide periods, however, a fast-flowing torrent [10.5 million gallons per day (MGD) in summer; 25 MGD in winter], up to one metre deep is formed, initially confined within a natural channel, but spreading out with increasing flow and depth as it descends the shore.

### Discussion

#### 1) Dispersal of *Janua brasiliensis* to the south-west Netherlands and Channel Islands

The dates of the introduction of *J. brasiliensis* to the south-west Netherlands and Channel Islands remain unknown. Previous studies on *Sargassum* populations at both sites (viz. south-west



Figure 5 Settlement of *Janua brasiliensis* on fronds of *Fucus serratus* at La Collette, Jersey, Channel Islands.

Netherlands; Bom 1981; Verkuil 1984; Critchley *et al.* 1987 and Channel Islands: Critchley & Morrell 1984) did not note the presence of spirorbid worms. However, it is possible that *J. brasiliensis* was present at each site, in small numbers several years prior to its detection.

Critchley and Morrell (1984) and Critchley and Thorp (1985) suggested that the movement of pleasure-craft from Portsmouth Harbour, perhaps with *Janua* on the fronds of *Sargassum* caught in the steering gear, or additionally in the case of Jersey, the plying of cross-channel ferries directly between Portsmouth and St. Helier, could have been vectors for the direct transmission of the initial breeding stock which led to the development of isolated populations of both exotic organisms. Indeed the fact that the Jersey power-station water intake (Figure 4) comes directly from the harbour further supports the suggestion that, for *J. brasiliensis* at least, shipping provided the remote vector for transmission to the Channel Islands, which was then transferred via the power-station water system to the outflow channel where the spirorbid became established due to elevated seawater temperatures. Alternatively, it is possible that drifting fragments of *Zostera marina* and/or *S. muticum* might have been the dispersal vector for both migrant species, in tandem. Monniot and Monniot (1985) speculated that floating *Sargassum* was the dispersal agent for the alien ascidian *Perophora japonica*. If drift *S. muticum* was the vector giving rise to the widespread occurrence of the alien seaweed (Critchley *et al.* 1983; Belsher & Pommellac 1988) then a much wider occurrence of *Janua* might be predicted. However, the mere arrival of an exotic species does not ensure its successful establishment (Safriel & Ritte 1980, 1982; Ayal & Safriel 1983); the habitat requirements for the alien spirorbid may be more specific than those establishment of *Sargassum*. Thus, although the spirorbid may be widely dispersed, by virtue of its association with *Sargassum*, the successful establishment of *J. brasiliensis* only occurs at disjunct, isolated localities. Nevertheless, Critchley and Thorp (1985) considered that *Janua* was under-recorded in Europe, due to its normally inconspicuous nature, and new sites should be sought outside Portsmouth Harbour, Goes Canal and the Channel Islands.

## 2) Settlement and survival of *J. brasiliensis* in Goes canal and the outflow of Jersey Power Station

The basiphyte substrata colonized by *Janua brasiliensis*, in its three isolated European localities all have *Sargassum muticum* in common. However, the preferred basiphyte substratum has changed markedly with the establishment of new spirorbid populations outside of Portsmouth Harbour.

Indeed, *S. muticum* is the basiphyte in Portsmouth Harbour and has probably played an important role in dissemination of the tubeworm to the new sites. In Goes canal *J. brasiliensis* attached to *S. muticum* near the sluice gate but has spread beyond the *Sargassum* zone and colonized more densely the leaves of *Zostera* (a natural substratum for *J. brasiliensis* in South African waters: Knight-Jones & Knight-Jones 1974). Similarly, the greatest spirorbid densities were recorded on the brown seaweed *F. serratus* in the power station effluent channel on Jersey, an area where *S. muticum* is unable to survive.

It was noted that whilst *Janua* colonised almost the entire length of *Zostera* leaves, settlement on both *Sargassum* and *Fucus* was most dense on the basal, older, perennial regions of the thallus. Settlements of *J. brasiliensis* on the annual fronds of *Sargassum* which are cast at the end of the growth season, presumably contribute to dissemination. These observations might be indicative of an antifouling mechanism in the younger, actively growing regions of the brown algae (exudation of polyphenolic/tannin compounds; Conover & Sieburth 1964 1966; Glombitza *et al.* 1982; see also Morse 1992), thereby reducing the density of the spirorbid worm at the apices.

## 3) Reproductive activity of *J. brasiliensis* in conditions of localised, elevated seawater temperatures

The world distribution of *J. brasiliensis*, given by Knight-Jones and Knight-Jones (1974) and Knight-Jones *et al.* (1975a, 1975b), suggested a wide tolerance of environmental conditions. Moreover, its presence in the warm waters of East Africa, the Red Sea and the Marshall Islands indicates reproductive tolerance to elevated seawater temperatures. Gray (1978) reported that *J. brasiliensis* in Portsmouth Harbour began brooding in May/June and continued until September/October, with a maximum settlement of larvae in August/September. A number of authors have demonstrated the positive influence of elevated temperatures on both the early induction of reproductive maturity and reduction of the brood period, e.g. *J. brasiliensis* had a shortened breeding periodicity of  $13.33 \pm 8.1$  days at a mean seawater temperature of 14.8°C, becoming sexually mature only 30 days after settlement (Grey 1978). This rapid maturation contrasted with that of indigenous European spirorbids, very few of which become sexually mature in their first season (Thorp & Segrove 1975; Thorp 1991). Thus, it is likely that elevated seawater temperature in the shallow enclosed waters of Goes canal and the effluent channel at St. Helier resulted in both accelerated reproductive maturation and a decreased brood period in *J. brasiliensis*. The change of cleaning agent from chlorine gas to 'Actibrom' in the power-station cooling waters may have also influenced the settlement of *J. brasiliensis* in 1991. This aspect should be investigated further.

Indeed the confined nature of Goes canal may have further contributed to the successful establishment of *J. brasiliensis*. Crisp (1958) cited the enclosed nature of Southampton Water, southern Britain, with its slow exchange of estuarine waters as being conducive to the rapid increase in numbers of the Australasian barnacle *Elminius modestus* (Darwin). Thorp *et al.* (1987) reported a massive and localized proliferation of the alien, fouling serpulid *Hydroïdes ezoensis* Okuda also in Southampton Water.

The distribution of this worm of Japanese origin, however, remains largely restricted to Southampton Water, even more than 10 years after its introduction. Williams (1980) discussed the dominance of Southampton Water by planktonic algae, in contrast to benthic algal, dominance in the adjacent harbours of Portsmouth and Langstone, which may partially explain why filter-feeding, introduced species are more successful in the former locality.

The decline of *J. brasiliensis* densities in Goes canal is consistent with the often observed pattern of invasive organism population development, following, an initial spectacular performance (Elton 1958; Salisbury 1964). The population at St. Helier will be monitored to determine whether a similar decline of *J. brasiliensis* occurs there also.

## Conclusions

The present European distribution of *Janua brasiliensis* remains confined to semi-enclosed, isolated sites, two of which are influenced by some form of periodic elevation of seawater temperatures which seem to allow the sub-tropical tubeworm to breed in epidemic proportions and perhaps over-winter.

It seems likely that *Janua* will only be successful in such environments and the number of potential sites, is, therefore, limited. The outfalls of power stations, saline canals and lakes in Europe should be examined for the presence of these normally inconspicuous and often overlooked organisms.

In the course of its spread *J. brasiliensis* has changed its basiphyte host, from *S. muticum*; which appears to be one of its vectors for spread; to become more numerically successful on *Z. marina* and *F. serratus*. It is noteworthy that the number of spirorbid species able to co-exist is limited, even under

favourable conditions (Knight-Jones & Knight-Jones 1977). This is particularly important since *F. serratus* is a common basiphyte for the indigenous tube worm *Spirorbis spirorbis*. Establishment of *J. brasiliensis* in new, if restricted sites, particularly at high densities, could affect the success of indigenous spirorbids. A parallel here might be drawn with the success of *E. modestus* in Europe and its replacement of indigenous, intertidal barnacles (Jones 1961; Hiscock *et al.* 1978).

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