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Ficopomatus miamiensis (Polychaeta: Serpulidae) and *Styela canopus* (Ascidiacea: Styelidae), non-native species in Urías estuary, SE Gulf of California, Mexico

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Abstract: The polychaete *Ficopomatus miamiensis*, original from Florida, USA and the ascidian *Styela canopus*, common on the Atlantic coast of North America are reported for the first time in the Gulf of California, Pacific coast of Mexico, where they live attached to prop roots of the red mangrove (*Rhizophora mangle*) in Urías estuary. They had already been reported in the eastern Pacific, in Panama Bay (both species) and San Diego, California, USA (the ascidian). A two-year survey showed that *F. miamiensis* is euryoecious and that "reef"-like formations are favoured in unstable environments characterized by low oxygen and high organic matter concentrations, especially during winter. Density and distribution patterns suggest that *F. miamiensis* was accidentally introduced into Urías estuary together with commercial shrimp. Although no trend on the spatial and temporal distribution was observed in the case of *S. canopus*, it can be presumed that it arrived in the lagoon by navigation in ballast water (highly unlikely unless attached to debris in the ballast) or attached to ship hulls or sea chests.

Résumé: Ficopomatus miamiensis *(Polychaeta: Serpulidae) et* Styela canopus *(Ascidiacea: Styelida), espèces invasives de l'estuaire d'Urias, au Sud-Est du Golfe de Californie au Mexique*. Le polychète *Ficopomatus miamiensis* originaire de Floride, Etats-Unis et l'ascidie *Styela canopus*, commun sur la côte atlantique de l'Amérique du Nord, sont signalés pour la première fois dans le Golfe de Californie, sur la côte mexicaine du Pacifique. Ils vivent attachés aux racines aériennes du palétuvier rouge (*Rhizophora mangle*) dans l'estuaire d'Urías. Ils ont été déjà signalés sur la côte est du Pacifique, dans la baie de Panama (les deux espèces) et à San Diego, Etats-Unis (l'ascidie). Une étude de deux ans a démontré que *F. miamiensis* est une espèce euryèce et que des formations de type récifal sont favorisées dans des environnements instables caractérisés par de faibles concentrations en oxygène et par de hautes concentrations en matière organique, particulièrement en hiver. La densité et la distribution de *F. miamiensis* suggèrent que cette espèce a été introduite dans l'estuaire d'Urías par l'intermédiaire de l'eau utilisée pour le transport de crevettes d'élevage. Bien qu'aucune tendance sur la distribution spatiale et temporelle de *S. canopus* ne soit observée, il semble que son arrivée dans l'estuaire soit due à l'eau de ballast des navires ou attachée à la coque des bateaux.

Keywords: Inversive species, Mangroves, Urias estuary, Mexican Pacific.

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Introduction

Biological invasions consist of an extension of the species' distribution from their original range by natural, e.g. climatic, changes or voluntary or involuntary introduction by humans (Carlton, 1996). The dispersal of aquatic non-native species throughout the world increased remarkably during recent decades due to human activities, like aquaculture, aquarium trade, shipping (transport ballast water or attached to hulls) and incidental by-transportation (parasites or other organisms transferred together with cultured species) (Carlton, 1996; Chu et al., 1997; Dove & Ernst, 1998; Lambert, 2002). These invasions have often resulted in the successful establishment of many species into new habitats, sometimes with negative consequences such as predation or extinction of native species, source competition, propagation of diseases and the great economic costs caused by damage to fisheries and other human activities (Escalante & Contreras, 1984; Ruiz et al., 1997; Carlton, 1996; Magara et al., 2001).

Knowledge of non-native marine invertebrates in Mexico is scarce and this is mainly due to the lack of scientific and political interest. Specialists able to recognize exotic species in areas they are familiar with are generally rare. Introduction of exotic aquatic species into Urías estuary, close to the city of Mazatlán can be explained as been connected with harbour activities and semi-intensive shrimp farming. *Ficopomatus miamiensis* (Treadwell, 1934), a native of Florida, USA, and *Styela canopus* Savigny, 1816, common on the North American Atlantic coast as well as in southern California on the Pacific (Lambert & Lambert, 1998; 2003), are reported here for the first time in Urías estuary and the Pacific coast of Mexico.

Materials and Methods

Urías estuary is located close to the city of Mazatlán in the southeastern part of the Gulf of California, Pacific coast of Mexico. It is a shallow, saline, vertically mixed water body about 17 km long with an estimated area of 18 km^2 (Montaño-Ley & Páez-Osuna, 1990). The system has an average mixed tidal amplitude of 1.5 m and a positive gradient of salinity (negative estuary, as defined by McLusky, 1971) towards the interior during the drought season (November-May). The system changes to a negative gradient during the rainy season from June to October (Villalba-Loera, 1986). According to Alvarez-León (1980), the system can be divided into three different regions: "El Astillero", which includes the Mazatlán harbour sheltering also a fishing fleet and the most developed industrial zone of the city, "Urías", in the middle part of the estuary, and "La Sirena", located at the inner part of the lagoon and mostly bordered by the mangrove trees *Rhizophora mangle* Linnaeus, 1753, *Avicennia germinans* (Linnaeus, 1753), *Conocarpus erectus* Linnaeus, 1753 and *Laguncularia racemosa* (Linnaeus, 1753). These are better developed towards the inner portion (Agráz-Hernández, 1999). Tidal flats and flooding areas are found at this part of the system and some of them are used for shrimp farming. Water from the "El Confite" tidal channel is pumped to the "San Jorge" shrimp farm and mostly discharged to the "Barrón" channel. During 1997-98, the farm's pond area was extended from 150 to ca. 250 hectares (Salgado-Barragán & Hendrickx, 2002), and most of the new effluents are discharged to "El Confite" channel (Fig. 1).

Biological and environmental sampling was performed every three months from May 1993 to February 1995 at six stations located in "La Sirena" region (Fig. 1). Station 6 was not visited in May 1993. In the study area, *F. miamiensis* and *S. canopus* were found attached to the *R. mangle* aerial roots, which are almost the only hard substrata in this area. Roots were selected and cut above and below the level of the epibiont communities and each sampling unit consisted of two aerial roots. Selection of roots was made after a preliminary survey of the area which led to the random selection of two hanging roots among those of approximately the same length and diameter, thus avoiding collection of young, regenerating or broken aerial roots. No more roots were collected due to environment protection restrictions. The external area of each root was estimated by measuring the length and average diameter (5 measurements) of the collected section and the total sampling unit area was considered as the sum of the two areas. Ascidian and polychaete (tubes) density was expressed as individuals per square metre (ind.m^{-2}). Organisms attached to the mangrove roots were counted when abundance was lower than 500 individuals per sampling unit. When abundance was higher, density was estimated as the total number of attached specimens in a 5 cm root section extrapolated to the total area occupied by this species.

Ficopomatus miamiensis was identified according to Fauchald (1977) and ten Hove & Weerdenburg (1978), and *S. canopus* (= *S. partita*, sensu Kott, 1985), following Van Name (1945).

Water samples were collected at one-metre depth. Salinity was measured with a Goldberg refractometer (precision of ± 1) and the water temperature with a field thermometer (precision of ± 0.5°C). Dissolved oxygen (DO) was estimated using the modified Winkler method (Carpenter, 1965, APHA 1989). The dissolved organic matter was indirectly estimated by a 2-day Biological Oxygen Demand test (BOD) (Leynaud, 1979), which was carried out according to APHA (1989).

Pearson's correlation was calculated between *F. miamiensis* and *S. canopus* densities and the abiotic variables (salinity, temperature, DO and BDO) using the Microsoft Excel 97 program.

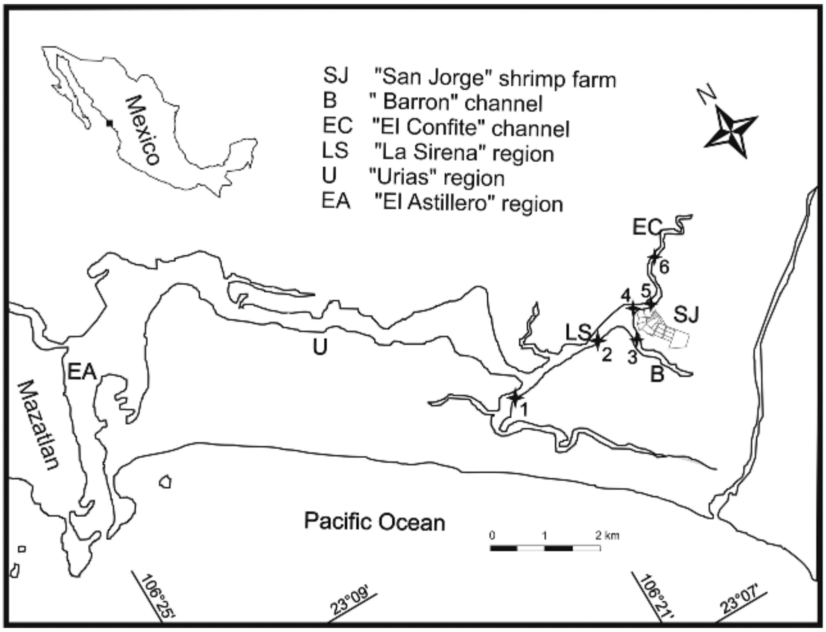

Figure 1. Study area and sampling stations.
Figure 1. Région d'étude et stations d'échantillonage.

Results

Phylum ANNELIDA
Class POLYCHAETA
Order Sabellida
Family Serpulidae
Ficopomatus miamiensis (Treadwell, 1934)

This species is characterized by the presence of an operculum without spines, which is spherical to fig-shaped, sometimes with a horny end-plate that may be flat or slightly convex. Collar chaetae are scarce, coarsely serrated and limbate (ten Hove & Weerdenburg, 1978). The tubes of our specimens reached 57 mm in length and usually had no collar-like rings as those from Barbados described by ten Hove & Weerdenburg (1978). There were no wide flaring "peristomes" as mentioned by these authors and shown in their figure 5b.

Around 8 300 *F. miamiensis* tubes were collected in 39 (83%) of the 47 sampling units. The species was found in all the stations, and a general trend of decreasing density was observed from station 6 (maximum 13 490 ind.m^{-2}) to 1 (maximum 233 ind.m^{-2}). The highest densities and "reef" like-formations, that partially covered the roots, were observed during November 1993, February 1994 and February 1995 at station 6. A sporadic absence of the species was observed at stations 1 to 4 over the study (Table 1).

Phylum CHORDATA
Subphylum UROCHORDATA (TUNICATA)
Class ASCIDIACEA
Order Stolidobranchia
Family Styelidae
Styela canopus Savigny, 1816

Styela canopus (= *S. partita*, sensu Kott, 1985) is a small sub-globose solitary species, generally reddish to brown. The test is very variable in thickness, but is thicker near the siphons. It has two gonads on each side of the body. Each comprises an elongated, sinuously curved ovary, having the end with the orifice directed toward the atrial siphon but not much produced into an oviduct. The ovary is bordered along each side by a small number of irregularly branched testes (Van Name, 1945). The characteristics of our specimens were consistent with this diagnosis.

A total of 591 specimens were collected in 13 (27.7%) of the 47 sampling units. This species was found in all the stations, but it was particularly scarce at stations 4 and 6. The highest densities were observed during May 1993 at stations 2 (1 136 ind.m^{-2}) and 5 (944 ind.m^{-2}). Individuals were completely absent at the study sites from November 1993 to August 1994 and only two (8 ind.m^{-2}) were collected during November 1994 (Table 1).

Relationship with the abiotic variables
Salinity and temperature varied according to the rainy-drought seasons, from hypohaline to hyperhaline conditions (salinity from 27 to 46) and from 31.5 to 22 °C, respectively. DO values varied from 1.62 to 4.46 mg.L^{-1} and BOD from 0.41 to 5.69 mg.L^{-1}. The lowest DO values were registered

Table 1. *Ficopomatus miamiensis* and *Styela canopus* densities and abiotic variables during the sampling period.
Tableau 1. Densité de *Ficopomatus miamiensis* et de *Styela canopus* et variables abiotiques pendant la période de prélèvement.

Station	Date	*F. miamiensis* (ind/m²)	*S. canopus* (ind/m²)	Temperature (°C)	Salinity	DO (mg/L)	BOD (mg/L)
1	May-93	6	98	28.4	41	2.8	1.08
	Jul-93	0	30	31.5	34	2.61	4.27
	Nov-93	164	0	24.5	30	3.12	0.41
	Feb-94	233	0	23	38	3.22	0.81
	May-94	78	0	27.7	40	2.77	0.98
	Aug-94	57	0	31	35	2.71	0.71
	Nov-94	17	0	25.5	37	3.22	0.58
	Feb-95	0	0	22.5	39	2.75	0.74
2	May-93	0	1136	27.4	41	3.28	0.87
	Jul-93	0	359	31.5	33	2.76	5.69
	Nov-93	85	0	24.7	29	3.39	0.55
	Feb-94	1824	0	22.8	38	3.37	1.21
	May-94	0	0	27.7	40	3.35	0.91
	Aug-94	84	0	31.5	35	3.15	1.92
	Nov-94	37	0	26	37	3.33	0.78
	Feb-95	107	7	23.4	41	3.6	0.81
3	May-93	16	82	26	43	1.83	1.56
	Jul-93	46	50	30	33	1.87	5.04
	Nov-93	31	0	24.5	27	2.41	0.82
	Feb-94	411	0	22	40	2.35	0.6
	May-94	0	0	26.5	46	1.91	1.62
	Aug-94	380	0	31	35	1.73	1.35
	Nov-94	47	0	25.2	38	1.95	1.88
	Feb-95	27	13	21.8	42	2.26	0.67
4	May-93	14	0	28	42	2.48	0.69
	Jul-93	0	0	30	33	1.82	5.48
	Nov-93	46	0	24.5	34	2.87	0.79
	Feb-94	25	0	23.8	40	4.06	0.67
	May-94	68	0	29	42	3.88	0.69
	Aug-94	345	0	31	36	4.08	0.96
	Nov-94	252	8	26.5	38	3.29	0.98
	Feb-95	0	0	24	43	3.49	0.58
5	May-93	225	994	27.5	41	2.61	0.92
	Jul-93	239	142	30	32	1.82	5.1
	Nov-93	1541	0	24	32	2.75	0.88
	Feb-94	607	0	23.2	40	3.17	0.67
	May-94	638	0	29.5	42	4.46	0.64
	Aug-94	2238	0	31.3	35	2.55	2.85
	Nov-94	178	0	26.2	38	3.02	1.21
	Feb-95	1085	221	23.5	42	2.96	0.45
6	Jul-93	365	0	30	32	1.62	4.87
	Nov-93	11435	0	24.5	33	2.29	0.73
	Feb-94	13490	0	23.8	40	2.95	0.75
	May-94	287	0	28.8	42	2.77	0.47
	Aug-94	1051	0	31.2	34	1.62	1.67
	Nov-94	118	0	26.1	38	2.26	0.76
	Feb-95	9579	10	23	42	1.68	0.49

at stations 3 and 6, while the highest were observed at stations 1, 2, 4 and 5, with seasonal variations. In general terms, the lowest BOD values were registered at stations 1, 4 and 6 (Table 1). Pearson's correlation (n= 47) was significant between density of *F. miamiensis* and temperature ($r = -0.494$; $P < 0.001$), DO ($r = -0.377$; $P < 0.01$) and BOD ($r^2 = -0.378$; $P < 0.01$), while *S. canopus* density was positively correlated with salinity ($r = 0.389$; $P < 0.01$) and temperature ($r = 0.326$; $P < 0.05$).

Discussion

Ficopomatus miamiensis and *Styela canopus* are reported here for the first time as non-native species in Urías estuary and the Pacific coast of Mexico. Only the harpacticoid copepod *Enhydrosoma lacunae* Jakubisiak has been previously reported by Gómez (2003) as an invasive animal species in this estuary.

During a study from 1993 to 1994 of the fauna associated with ponds of the "San Jorge" shrimp farm, *F. miamiensis* was first reported as *Ficopomatus* sp. (Hendrickx & Meda-Martínez, 2001). In 2001, H. ten Hove examined some specimens of our series and others collected more recently from aquaria containing shrimp from the same farm and identified them as *F. miamiensis*, based on the characteristics of their opercula and collar chaetae as described in ten Hove & Weerdenburg (1978).

Ficopomatus miamiensis is a tropical West Atlantic species, occurring from Florida and the Gulf of Mexico to the Antilles. Ten Hove & Weerdenburg (1978) presented a list of the previous collection localities. This species was later reported in Barbados (Kirkegaard, 1980), the Gulf of Mexico (Reyes-Barragán & Salazar-Vallejo, 1990) and the Mexican Caribbean (Bastida-Zavala & Salazar-Vallejo, 2000). In addition, there are two records of this species in brackish waters of the Pacific end of the Panama Canal (ten Hove & Weerdenburg, 1978). Thus, ours is the second record of the species in the Eastern Tropical Pacific.

The specimens of ascidians were originally identified by A. Hernández as *S. partita* (Stimpson, 1852) which, according to Kott (1985), is now a junior synonym of *S. canopus*. *Styela canopus* is widely distributed along the Atlantic coast of North America from Massachusetts to Curaçao, and in the eastern Atlantic, from the Channel Islands and western coast of France to Cape Verde Islands, including the Mediterranean Sea (Van Name, 1945). This author collected some specimens from Taboguilla Island, Bay of Panama, which appeared to belong to this species. In 1972, Lambert & Lambert (1998; 2003) found *S. canopus* in San Diego Bay (where ships coming through the Panama Canal are berthed), and they considered this to be the site of introduction of the species into southern California waters. According to these authors, the species is still restricted to southern California and rare north of San Diego Bay. This ascidian has also been found in the Indo West Pacific (Kott, 1985; Monniot & Monniot, 1994; Monniot & Monniot, 2001), at Hawaii (Godwin & Eldredge, 2001) and Guam (Lambert, 2002). Van Name (1945) and Lambert & Lambert (1998; 2003) reported this species from stones and marine artificial hard substrata like docks and boat hulls.

The introduction of *F. miamiensis* and *S. canopus* into Urías estuary may have occurred by means of passive transport in ballast water (very unlikely unless attached to debris in the ballast), attached to ship hulls or sea chests, or by the transport of shrimp for aquaculture purposes. Mazatlán Harbour, located in the “El Astillero” region, is one of the biggest ports in the Mexican Pacific coast where international ships berth. Both species occur on the American Atlantic coast and have been previously reported from the Pacific side of Panama; thus it would not be surprising that they had been passively transported through the Panama Canal. On the other hand, the American Pacific white shrimp *Litopenaeus vannamei* (Boone, 1931) has been widely cultured due to its easy handling, its disease resistance, and its fast growth. It was exported during the last decade to the Atlantic coasts of America and it is currently cultured from Florida, USA to Brazil. Lately, reproducing specimens have been reintroduced into Pacific coastal areas due to the increasing demand for larvae for culture purposes and because the Atlantic populations did not have most of the viral and bacterial diseases that decimated the Pacific cultures (Brandini et al., 2000; Samocha et al., 2002).

The presence of *F. miamiensis* in the vicinity of the “San Jorge” shrimp farm and its absence beyond “La Sirena” region into the lagoon (JSB, pers. obs.), suggest that their larvae were introduced into the farm together with shrimp larvae and spread to the surroundings through water outflow. This suggestion is supported by the fact that it has been collected from the shrimp farm (Hendrickx & Meda-Martínez, 2001) and is currently seen inside the ponds (JSB, pers. obs.). Moreover, during 1999, adults of *L. vannamei* were transferred from the same farm to be cultured at the Unidad Académica Mazatlán, ICML, UNAM and up to now, *F. miamiensis* is present there inside the aquaria in high density (S. Rendón, pers. comm.).

Styela canopus has been recently observed in Venados Island, off Mazatlán Bay (Hernández, pers. comm.), which suggests that it could have been introduced into the Mazatlán area via passive transportation by ships from southern California or Panama (cf. Lambert & Lambert, 1998); it could then have reached the study area by boats coming from Mazatlán Harbour. There is no evidence of the presence of this ascidian inside the “San Jorge” shrimp farm, but we do not discard the possibility that this species could also have been introduced into the “La Sirena” region by the same mechanism as that of *F. miamiensis*.

Environmental considerations

Ficopomatus miamiensis was found in temperatures ranging from 21.8 to 31 °C, which are consistent with data reported by Reyes-Barragán & Salazar-Vallejo (1990) in Veracruz, Mexico (17 to 32 °C). In the study area, the highest densities were observed during winter, as shown by the negative correlation between temperature and density.

Ficopomatus miamiensis has been considered a brackish species, found mostly in hypohaline conditions from 2 to 11 salinity (ten Hove & Weerdenburg, 1978; Kirkegaard, 1980). Nevertheless, it has also been reported in salinities of 31 by ten Hove & Weerdenburg (1978) and 32 by Reyes-Barragán & Salazar-Vallejo (1990). Our specimens were collected in salinities from 27 to 43, which explains the lack of correlation between density and salinity found here. The negative correlation of density with DO and BOD indicates that the abundance of this species was favoured by hypoxic and low organic matter conditions, as reflected by the high densities observed at station 6 and the low densities from station 3 (Table 1). The high salinity fluctuations and low oxygen conditions, as well as the scarcity of other species in samples with the highest densities of *F. miamiensis* (JSB, pers. obs.), confirm that “reef” masses are enhanced in unstable environments with low competition and predation, as pointed out by ten Hove (1979) for euryoecious serpulids.

During 2001-02, after the “San Jorge” shrimp farm was extended, a strong decrease in density of the serpulid was observed (JSB, pers. obs.) in the entire study area, especially at stations 5 and 6, where water from the new ponds area is currently discharged. A similar decrease occurred at station 3 during the 1993-95 survey. Thus, the normal growth of *F. miamiensis* could be affected by the presence of high amounts of organic matter or suspended particles in the water, since its filter feeding activity could be inhibited.

The highest *S. canopus* densities were observed at stations 1, 2, 3, and 5 during May and July 1993, the main cause of the positive correlation with salinity and temperature. No trend in spatial and temporal distribution of this ascidian was observed in the study area. Unfortunately, we have no data about *S. canopus* persistence in our study area after February, 1995.

The density and distribution of these non-native species in Urías estuary were closely related with seasonal environmental fluctuations. Nevertheless, the extension of the shrimp farm during 1997-98 seems to have had a negative effect on the abundance and distribution of the two species (JSB, pers. obs.)

We cannot yet evaluate the ecological impact of the two non-native species presumed to compete for space and food with native species. The only previous study on organisms associated with mangrove roots in Urías estuary covered molluscs and decapod crustaceans (Hubbard-Zamudio, 1983). Further organisms associated with the same substrate need to be studied before we can understand the local impact of these non-native species.

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