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Short communication

Range expansion of the North American alien amphipod *Gammarus tigrinus* Sexton, 1939 (Crustacea: Gammaridae) in Brittany, France

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Abstract

Since the first observation in September 2005 of *Gammarus tigrinus* in Brittany (Western France), the species' range has expanded slowly. By September 2008, the range of *G. tigrinus* expanded > 63.6 km to the North and 60.4 km to the West of that observed in 2005. *G. tigrinus* is thought to be responsible for the replacement of native *Gammarus pulex*. The relatively slow expansion rate of *G. tigrinus* in Brittany may result from either a low frequency of ship traffic, a known vector for the species, or from the species' slow acclimatisation to brackish waters. A number of simulated invasion scenarios are presented for the future dispersal of *G. tigrinus* in Brittany.

Key words: invasion, non-native species, colonization velocity, ship traffic, freshwater, Western Europe

The first record in Europe of the North American amphipod *Gammarus tigrinus* Sexton, 1939, a native of the east coast of (Bousfield 1958; van Maren 1978), was from the British Islands in 1931 (Sexton 1939). However the species probably arrived in Europe earlier (Hynes 1955) via ballast water exchanges in estuaries during the First World War by ships from the east coast of North America. The dispersal of *G. tigrinus* to rivers in other parts of Europe was accelerated by the species' intentional release as food for fish during 1957 into the salt-polluted rivers Werra and Weser in Germany (Schmitz 1960). During the same period, *G. tigrinus* were transported by ships to the Netherlands from Northern Ireland in 1960 (Nijssen and Stock 1966). The dispersal of *G. tigrinus* to other parts of Northern Europe has clearly been assisted by ship traffic and it has since become the dominant freshwater amphipod in the Netherlands (Pinkster 1977; Pinkster et al. 1992), with established populations in numerous areas, e.g. British Isles (Gledhill et al. 1993), the Baltic coast (Szaniawska et al. 2003; Jazdzewski et al. 2004), and Russia (Berezina 2007).

G. tigrinus was first recorded in North-Eastern France in 1991 (Dhur 1993) in the River Moselle, an oligohaline tributary of the River Rhine. Since then, the species has dispersed rapidly via canals that connected other river catchments, such as the rivers Saône and Rhône (in 1995; Fruget 2003) and in the upper Loire River (in 2003; Bollache et al. 2004). *G. tigrinus* was first reported along the Southern coast of Brittany in 2005 (Piscart et al. 2007), an area that was only recently colonised. *G. tigrinus* was observed in brackish and fresh waters where two native amphipod species (*Gammarus pulex* (Linneaus, 1758), *Gammarus zaddachi* Sexton, 1912) had been observed in the 1960s, suggesting that the North American invader had displaced to two native species (Gras and Maasen 1971). *G. tigrinus* demonstrates great environmental plasticity, which is evident in its ability to maintain populations in fresh waters several hundred kilometres from oligohaline waters. In view of this, Piscart et al. (2007) hypothesized that *G. tigrinus* is likely to invade most of the lentic waters of Brittany, expanding from its current distribution in the River Vilaine

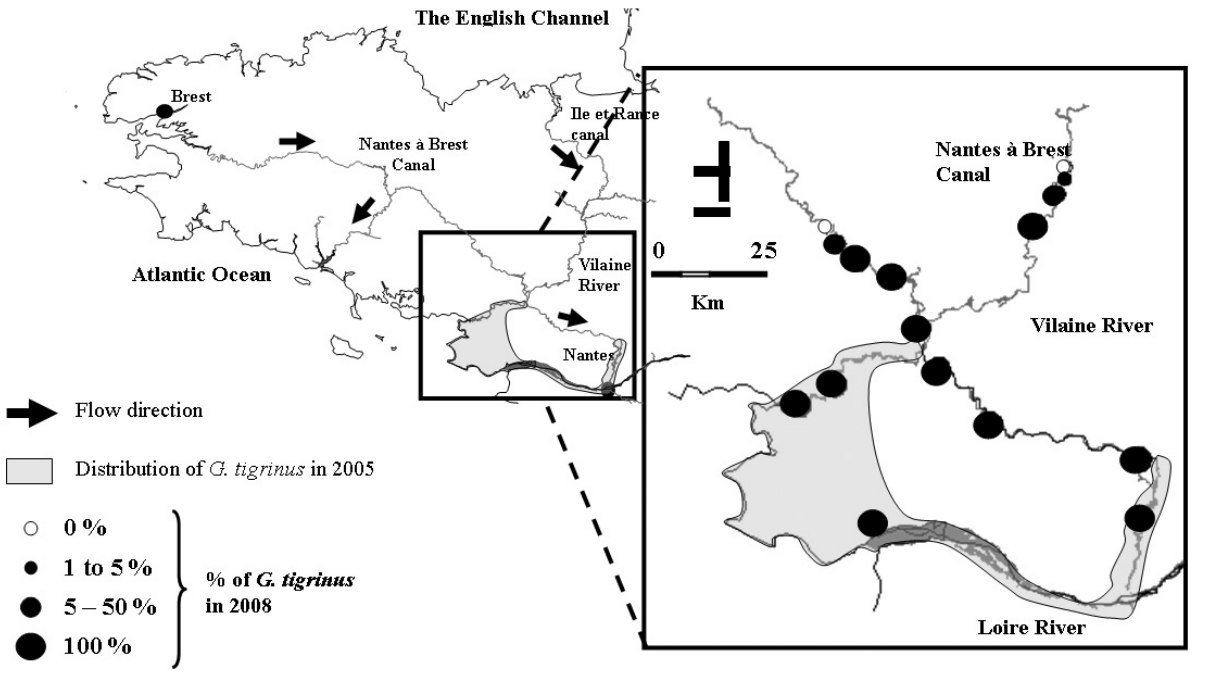

Figure 1. Distribution map of *Gammarus tigrinus* in February 2005 (grey area) according to Piscart et al. (2007) and in September 2008. The size of dots is proportional to the percentage of *G. tigrinus* relative to the native species *G. pulex*.

to the West via the 'Nantes à Brest' canal and to the North via the 'Ille et Rance' canal. The aim of the present study was to: 1) describe the range extension of *G. tigrinus* in Brittany, 2) estimate the colonization velocity in rivers, and 3) propose possible future scenarios of the species' dispersal. The monitoring of this species in Brittany is important because of the presence of several large harbours in this part of France, which may promote the extension of this species worldwide.

The distribution of amphipods was examined in September 2008 at sixteen sites on the River Vilaine and the Nantes à Brest canal where *G. tigrinus* was found in February 2005 (Figure 1). At each site, vegetation, stones and leaf litter (if present) were sampled to obtain a good estimation of the species density. At least 30 individuals were picked up on the field and stored in 96% ethanol. Water conductivity (at 25°C) was measured at each site using a portable apparatus Cond 330i (WTW™, Germany).

Species were identified using the taxonomic keys of Karaman and Pinkster (1977) and Gledhill et al. (1993). Biogeographical analyses were undertaken using ArcGIS v9.0 (ESRI, 2005) to draw the species distributions and to compute distances between sites colonized in 2005 and sites newly colonized in 2008.

As hypothesised by Piscart et al. (2007), we observed a clear range extension of *G. tigrinus* in the River Vilaine and the 'Nantes à Brest' canal (Figure 1), with the species observed at three new locations in the River Vilaine and seven in the 'Nantes à Brest' canal (Figure 1). At these new locations, the relative abundance of *G. tigrinus* (with regard to total amphipod numbers) ranged from 3.7 % at its Northern limit in the River Vilaine to 100% in sites located close to the species' previous 2005 range limit, where it has displaced the native *G. pulex* (Annex 1). The upstream colonization distances during the last 3.5 years were similar in the 'Nantes à Brest' Canal and in the River Vilaine (60.4 and 63.6 km, respectively), being on average 17.7 ± 2.3 km.year^{-1} (both locations combined). If this velocity is maintained in the close future, then most large waterways can be expected to have been invaded by *G. tigrinus* in the next 10 years (Figure 2).

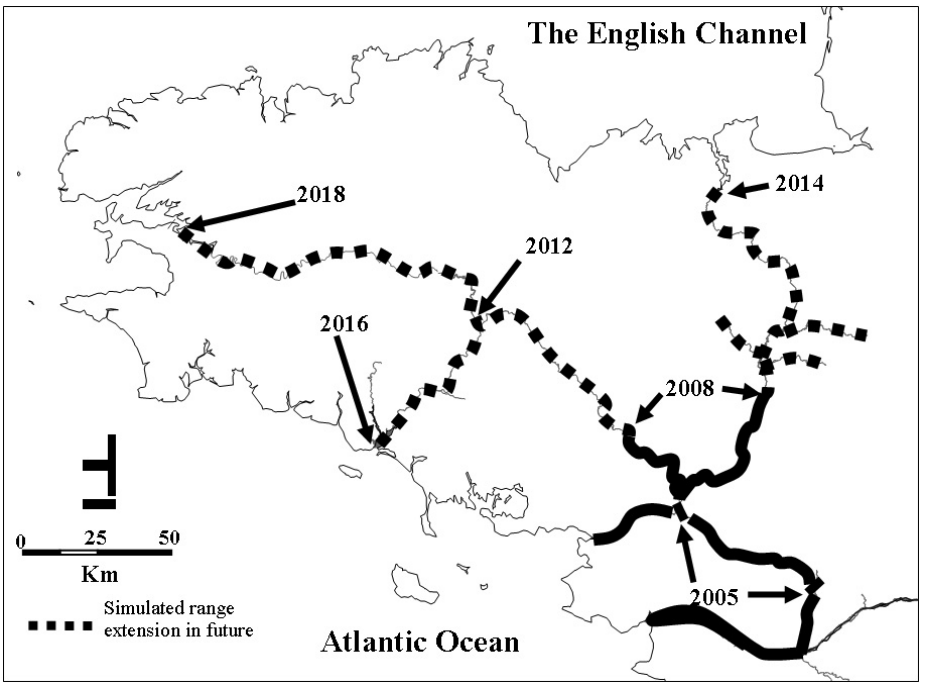

Figure 2. Simulated range extension of *G. tigrinus* in the main waterways of Brittany in the next 10 years. Numbers correspond to the limit of colonization at different dates.

We don't have a clear explanation to the replacement of the native *G. pulex* in Brittany, but previous studies realized in the Netherlands (Pinkster et al. 1977) and in Northern Ireland (Dick 1996) highlighted the role of the higher reproductive rate of *G. tigrinus* and its predation on juveniles and females *G. pulex*. However, the rate at which *G. tigrinus* is colonising Brittany is relatively slow compared to that of North-Eastern France, i.e. the combined catchments of the rivers Saône and Moselle between 1991 and 1995 encompass > 500 km (Fruget et al. 2003). The spread of *G. tigrinus* in Brittany (i.e. 17.7 Km per year) is also reduced compared to the spread of 40 km per year observed in the Rhine River by Pinkster et al. (1977). The extension of *G. tigrinus* in Europe is mainly linked to commercial ship traffic (Jazdzewski 1980), but this vector appears to be of little importance in Brittany, and in particular the River Vilaine, where there is relatively little ship traffic (mainly tourism). This contrasts the 'Nantes à Brest' canal and the eastern part of France, where commercial ship traffic is much more intensive.

Another explanation for the slow rate of freshwater invasions in Brittany may be related to the origin of the founder population. The Eastern part of France was invaded by a freshwater tolerant strain of *G. tigrinus* (Kelly et al. 2006), which has inhabited inland waters since 1960 (Nijssen and Stock 1966). Whereas, the distribution and dispersal of *G. tigrinus* in Brittany since 2005 suggests a recent introduction to the region, probably via the Saint Nazaire harbour (River Loire estuary; Figure 1), from a brackish water origin (e.g. ballast water transfer). *G. tigrinus* of brackish origin would be expected, initially, to spread slowly into fresh waters, with an increased dispersal rate once the population has adapted to the lower salinity levels (Kelly et al. 2006).

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Annex 1. Locations of sites, water conductivity at 25°C (µS·cm^{-1}) and the relative abundance (%) of *Gammarus* species observed in September 2008 in Brittany, France.

City	Water course	Location coordinates		Conductivity	*G. tigrinus*	*G. pulex*
		Longitude	Latitude			
Bourg des comptes	Vilaine	01°45'37" W	47°55'58" N	440	-	100
Plêchatel	Vilaine	01°45'27" W	47°53'56" N	452	3.7	96.3
St Malo de Phily	Vilaine	01°46'40" W	47°52'25" N	455	36.4	63.6
Guipry	Vilaine	01°49'43" W	47°49'08" N	472	100	-
Redon	Vilaine	02°06'13" W	47°38'09" N	370	100	-
Nivillac	Vilaine	02°18'00" W	47°32'02" N	329	100	-
Arzal (upstream the dam)	Vilaine	02°23'06" W	47°29'48" N	325	100	-
Peillac	Nantes à Brest canal	02°10'09" W	47°43'12" N	311	100	-
St Martin	Nantes à Brest canal	02°15'42" W	47°44'43" N	282	84.4	15.6
St Conjard	Nantes à Brest canal	02°18'56" W	47°46'11" N	324	9.5	90.5
St Laurent sur Ouste	Nantes à Brest canal	02°19'38" W	47°47'36" N	331	-	100
Fégréac	Nantes à Brest canal	02°02'48" W	47°34'15" N	376	100	-
Pléssé	Nantes à Brest canal	01°54'39" W	47°29'02" N	398	100	-
Nort sur Erdre	Nantes à Brest canal	01°32'18" W	47°26'13" N	391	51.4	48.6
Sucé sur Erdre	Nantes à Brest canal	01°31'34" W	47°20'21" N	343	100	-
Trignac	Bivet	02°11'07" W	47°18'24" N	2,800	100	-