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## **Demographic explosion of the brown shrimp *Penaeus aztecus* Ives 1891 (Decapoda: Penaeidae) in the central and northern Adriatic: implications for ecosystems and fisheries**

Francesco Tiralongo<sup>1-3\*</sup>, Homa Nik Zad<sup>4</sup>, Alberto Felici<sup>5</sup>

<sup>1</sup>Department of Biological, Geological and Environmental Sciences, University of Catania, Italy

<sup>2</sup>Ente Fauna Marina Mediterranea, Scientific Organization for Research and Conservation of Marine Biodiversity, Avola, Italy

<sup>3</sup>National Research Council, Institute of Marine Biological Resources and Biotechnologies, Ancona, Italy

<sup>4</sup>Cesenatico Fish Market, Italy

<sup>5</sup>School of Biosciences and Veterinary Medicine, University of Camerino, Italy

\*Corresponding author: francesco.tiralongo@unict.it

**Abstract** - *Penaeus aztecus* Ives 1891 is an invasive species of western Atlantic origin that has become established in different areas of the Mediterranean Sea. This study highlights a recent demographic explosion of this alien species in the Adriatic Sea. A considerable number of individuals (more than 20 per fishing vessel out of a total of 36 surveyed) were captured by trawling at San Benedetto del Tronto on 30 September 2024, the first fishing day following a 30-day fishing moratorium. Additional unusually high catches in other areas of the central and northern Italian Adriatic Sea occurred in the same period, further confirming a clear recent population surge of this species in the Adriatic. Our results suggest a rapidly growing population in this region of the Mediterranean. We discuss the possible causes of this sudden population increase, as well as the ecological and socio-economic impacts that the species may have on the region in the coming years.

**Key words:** biological invasions, invasive alien species, Mediterranean Sea, shrimps, range-expanding species.

**Riassunto** – Esplosione demografica di *Penaeus aztecus* Ives 1891 (Decapoda: Penaeidae) nell'Adriatico centrale e settentrionale: implicazioni per gli ecosistemi e per la pesca.

*Penaeus aztecus* Ives 1891 è una specie invasiva originaria dell'Atlantico occidentale che si è stabilita in diverse aree del Mar Mediterraneo. Questo studio evidenzia una recente esplosione demografica di questa specie aliena nel Mar Adriatico. Un numero considerevole di individui (più di 20 per imbarcazione, su un totale di 36 imbarcazioni esaminate) è stato catturato tramite pesca a strascico a San Benedetto del Tronto il 30 settembre 2024, il primo giorno di pesca successivo a un periodo di fermo biologico di 30 giorni. Ulteriori catture insolitamente abbondanti in altre aree dell'Adriatico centrale e settentrionale italiano sono state registrate nello stesso periodo, confermando una chiara e recente crescita della popolazione di questa specie nell'Adriatico. I nostri risultati suggeriscono la presenza una popolazione in rapida espansione in questa regione del Mediterraneo. Discutiamo le possibili cause di questo improvviso incremento della popolazione, oltre agli impatti ecologici e socio-economici che la specie potrebbe avere sulla regione nei prossimi anni.

**Parole chiave:** gamberi, invasioni biologiche, Mar Mediterraneo, specie aliene invasive, specie in espansione.

In the Mediterranean, since its first sighting in 2009 in the Bay of Antalya (Turkey) (Deval *et al.*, 2010), *Penaeus aztecus* has rapidly expanded its range within the eastern basin. It reached the Aegean Sea by 2013-2014 (Kevrekidis, 2014) and subsequently spread to the coasts of Israel and Egypt between 2017 and 2020 (Galil *et al.*, 2017; El Deeb *et al.*, 2020), as well as Libya by 2020 (Abdulraziq *et al.*, 2021). Concurrently, the species has also spread into the central and central-western parts of the Mediterranean (Kampouris *et al.*, 2018; Gönülal and Türetken, 2019; Abdulraziq *et al.*, 2021; Ugarković and Crocetta, 2021; Froglija and Scanu, 2023), reaching its southernmost western limit in the Gulf of Gabès, Tunisia (Ben Jarray *et al.*, 2019). A single specimen was also collected in the Gulf of Lion, France (Galil *et al.*, 2017). Moreover, the recent records from Spain represent the northernmost western and westernmost limits of *P. aztecus* in the Mediterranean Sea (Santos-Bethencourt *et al.*, 2023; Spinelli *et al.*, 2024).

With approximately 17,000 species, the Mediterranean Sea is recognized as one of the world's most significant biodiversity hotspots (Coll *et al.*, 2010). However, the region's native biodiversity is increasingly threatened by invasive alien species (IAS) (Zenetos *et al.*, 2017). One such species is the brown shrimp *P. aztecus* Ives 1891, a penaeid shrimp native to the northwestern Atlantic, with a distribution ranging from Massachusetts to the Gulf of Mexico and the north-western Yucatán (Pérez-Farfante & Kensley, 1997). This species typically inhabits sandy substrates at depths between 5 and 170 m, with peak abundance observed between 10 and 55 m (Williams, 1984; Froglija & Scanu, 2023).

However, most scientific reports only provide qualitative information about the presence of one or a few individuals of *P. aztecus*, without offering estimates of its relative abundance or, more importantly, information on the co-occurrence in fishing boat catches of the native shrimp *P. kerathurus* (Forskål 1775), with which the exotic species may compete for space and food resources.

This study aims to provide additional data on the abundance and presence of this species in various areas of the Italian Adriatic, where it has appeared more and more frequently in connection with the targeted fishing of the native *P. kerathurus*, possibly following a recent population explosion.

The ecological and socio-economic implications of this biological invasion are discussed.

On 25 September 2024, off the coast of Chioggia (northern Adriatic Sea), an unspecified number of *P. aztecus* individuals (total length >15 cm) were caught with trawls along with *P. kerathurus* individuals at a depth of about 20 m. At the fish market, they represented between 10-20% of the total catch of prawns compared to *P. kerathurus*.

On 30 September 2024, immediately following the 30-day fishing moratorium, multiple catches of *P. aztecus* were obtained off the coast of San Benedetto del Tronto (central Adriatic Sea) with trawls targeting the native *P. kerathurus*, during nighttime hours at depths ranging from 15 to 22 m. The fishing fleet of San Benedetto del Tronto counts 36 trawling vessels, and in the days following the fishing moratorium, all the fishing boats, for the first time, made exceptional catches of *P. aztecus* (more than 20 individuals per fishing vessels, with daily yields ranging from 1 to 3 kg during the first week). This was confirmed during informal interviews with local fishermen. Specimens observed by one of the authors (AF) had a total length of about 20 cm or more. On the same day and conditions, multiple catches of *P. aztecus* were obtained with trawls targeting the native *P. kerathurus* off the coast of Cesenatico (northern Adriatic Sea), at depths ranging from 15 to 20 m. All collected individuals (five in total) were adults, each having a length of 20 cm or more.

On 1 October 2024, a considerable but unspecified number of *P. aztecus* individuals (>15 cm in length) were caught using trawls in the Gulf of Trieste (northern Adriatic Sea), at a depth of about 20 m. The individuals of *P. aztecus* were observed among the native *P. kerathurus*, which was clearly numerically dominant (*P. aztecus* accounted for approximately 1% of the catches of *P. kerathurus*).

Fishermen from San Benedetto del Tronto declared a local market price for *P. kerathurus* ranging from 5 to 8 Euro/kg for small individuals (<12 cm), 10 to 14 Euro/kg for medium-sized ones (12-15 cm), and 14 to 20 Euro/kg for large specimens (>15 cm). Currently, *P. aztecus* is being sold together with *P. kerathurus* at the same price. Catches were dominated by small-sized *P. kerathurus* individuals, with approximately 94.1% of small individuals and 5.9% of medium and large ones per day per fishing boat.

Larger specimens of both species, *P. aztecus* and *P. kerathurus*, exceeded 20 cm in total length, with an abundance ratio at the fish market of about 1:10 in favor of *P. kerathurus*. In contrast to 2023, when very few *P. aztecus* were sporadically recorded, catches of *P. aztecus* have increased significantly in 2024 starting from the period between the end of September and the first days of October. However, in San Benedetto del Tronto and all other Adriatic areas reported here, the abundance of *P. aztecus* drastically decreased after approximately one week of fishing, returning to low levels. It is noteworthy that prior to 1988, *P. kerathurus* was not harvested in San Benedetto del Tronto and other nearby areas, with reports limited to the northern Adriatic. From 1990 onwards, small quantities started to be caught, though the gear was not initially suitable for their catch. Nowadays, *P. aztecus* individuals are commonly caught and available at the market, targeted by all professional fishermen in the area. When, temperatures drop in winter, operations with trawls targeting *P. kerathurus* can extend from the 15-20 m of the “warm season” to depths of up to 50 m. In this case too, fishermen reported catching *P. aztecus*, as if the species was undertaking a seasonal inshore-offshore migration similar to that of *P. kerathurus*.

The most comprehensive and updated review of *P. aztecus* records in the Mediterranean was recently provided by Spinelli *et al.* (2024). Exactly how this species was introduced into the Mediterranean Sea remains unclear. However, several studies have identified ballast water as the most likely vector for its introduction (Deval *et al.*, 2010; Nikolopoulou *et al.*, 2013; Minos *et al.*, 2015). Alternatively, illegal introductions have also been suggested (Cruscanti *et al.*, 2015). It is possible that *P. aztecus* entered the Mediterranean on multiple occasions and through various pathways (Frogliia & Scanu, 2023). Regardless of the introduction method, the species’ remarkable ability to rapidly colonize the basin (which has earned it the nickname "Atlantic sprinter") in just a few years highlights its status as one of the most invasive species in the Mediterranean.

The brown shrimp already represents an additional resource for Mediterranean fisheries, although still locally. For instance, it is caught in large quantities through bottom trawling and trammel nets in Turkey and Italy, where it is sold at high prices as a delicacy (Bakır & Aydin, 2016; Frogliia & Scanu, 2023; Spinelli *et al.*, 2024). In Italy, this new resource is particularly abundant from the year 2020 in the Gulf of Taranto and nearby areas of the northern Ionian Sea, where daily trawl yields can reach 40-50 kg/day. Special attention must be given to the ecological competition with the commercially important native shrimp, *P. kerathurus*. In fact, fishermen in the Gulf of Taranto are already reporting a significant decline in the native shrimp population, likely due to competition for similar resources between these congeneric species (Jaziri *et al.*, 2015). In the coming years, this situation could potentially unfold in the Adriatic Sea, where the “brown shrimp” was considered rare prior to this study (Fig. 1). This highlights

the urgency for targeted research to assess the impact of *P. aztecus* on native species and fisheries (including its positive commercial potential), and the marine ecosystem.

This initial abundance of *P. aztecus* may be the result of an "accumulation" effect due to the 30-day fishing moratorium, which allowed for greater aggregation and survival of individuals in the area. Indeed, as reported by fishermen from San Benedetto del Tronto, catches of this species have become sporadic again (with few or no individuals per day over the past five years) already a week after fishing resumed. However, further studies on a larger spatio-temporal scale are needed to assess the actual abundance of this species and to fully understand its ecological and socio-economic impact on Adriatic ecosystems. Similar attention should also be put on species with dramatic invasive potential, such as the blue crab *Callinectes sapidus* Rathbun 1896, which shares its native range in the Western Atlantic Ocean with *P. aztecus* (Falsone *et al.*, 2020; Tiralongo *et al.*, 2021; Marchessaux *et al.*, 2023). In conclusion, based on the evidence provided, we hypothesize the recent establishment of a *P. aztecus* population in the surveyed areas of the Adriatic Sea.

Our study also highlights the valuable role that citizen science and fishermen's knowledge can play in the monitoring and early detection of non-indigenous species in the Mediterranean (Azzurro & Tiralongo, 2020; Perzia *et al.*, 2022; Osca *et al.*, 2020; Tiralongo *et al.*, 2019, 2020; Al Mabruk *et al.*, 2021). This emphasizes the importance of the continuity of research and monitoring of biological invasions and the updating of the distribution of non-indigenous species over time.

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Fig. 1 - New records of *Penaeus aztecus* from the Mediterranean Sea (Italian Adriatic Sea) in areas where the presence and increase in abundance of this species have been confirmed through trawl fishing catches: (1) Gulf of Trieste, 1<sup>st</sup> October 2024; (2) Chioggia, 25<sup>th</sup> September 2024; (3) Cesenatico Fish Market, 30<sup>th</sup> September 2024: comparison between the native *P. kerathurus* (above) and *P. aztecus* (below); (4) San Benedetto del Tronto, 30<sup>th</sup> September 2024. / Nuove segnalazioni di *Penaeus aztecus* nel Mar Mediterraneo (Mar Adriatico italiano) in aree dove la presenza e l'aumento di abbondanza di questa specie sono stati confermati tramite catture effettuate con la pesca a strascico: (1) Golfo di Trieste, 1<sup>o</sup> ottobre 2024; (2) Chioggia, 25 settembre 2024; (3) Mercato ittico di Cesenatico, 30 settembre 2024: confronto tra il nativo *P. kerathurus* (sopra) e *P. aztecus* (sotto); (4) San Benedetto del Tronto, 30 settembre 2024.