Assessment of the Red Swamp Crayfish, *Procambarus Clarkii* (Girard, 1852) in Northwest of Morocco: Spread and Evolution of the Population on Agricultural Products——Case of Rice Fields

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***Abstract*—Gharb (northwest) is the area in Morocco where rice planting is very important due to its considerable water resources. The area is crossed by the tributaries of the Sebou river over a length of about 225 km before flowing into the Atlantic Ocean at Mehdia city in Morocco. Recently, an invasive classified crayfish has been introduced: the red swamp crayfish *Procambarus clarkii*. Colonization by this species has been monitored over the past three years in the study area. A survey was conducted between 2016 and 2018, to establish a geographical expansion of the species in the Gharb area, the evolution of the population in the rice fields, and to identify some impacts of this species on rice field. The results support the hypothesis of faster colonization downstream. It rapidly colonized the Gharb area and the evolution of its population in the rice fields between 2016 and 2018 is considered explosive, the main stages of this colonization can be summarized as follows: In 2016: explosive phase, In 2017: slowdown of the explosive phase, In 2018: return to the explosive phase.**

***Index Terms*—*Procambarus clarkii*, propagation map, Gharb, Sebou River, rice fields, Morocco**

I. Introduction

The red swamp crayfish *Procambarus clarkii* (Girard,1852), is a species from the northeast of Mexico and the central south of the United States (Louisiana) [1], actually is widely regarded to be the most invasive of all crayfish species [2] and has spread from its native range to all continents except Australia and Antarctica [3]. Human activities such as agriculture, aquaculture, recreation and transportation promote the spread of species across their natural dispersal barriers, a process which has been accelerated due to globalization [4]. As a result, the red swamp crayfish become nowadays the most cosmopolitan freshwater crayfish species in the world [5]-[7].

Procambarus clarkii is omnivorous and its diet is classified as selective and successive, it attacks preferably aquatic grass until exhaustion. Then mollusks, frog tadpoles, eggs and young fish follow each other [8]. With regard to native species, Louisiana crayfish adopt an aggressive behaviour, it compete with other species, attacking them to the point of extinction [9]. It is a very harmful, introducing this species is an ecological error [10]. This invasive crayfish is a polytrophic keystone species that can exert multiple pressures on ecosystems [11].

The red swamp crayfish *Procambarus clarkii* (Girard, 1852), was first introduced in Africa, Kenya around 1960, and then into Portugal in the late 1970s [12], [13] and their numbers increased without control, invading most of the rice fields and wetland areas [14], where no native species of crayfish were present. Then a few years later the species was observed in Spain [15]. Thanks to massive imports of live crayfish from these countries [5], the species was introduced into France in 1976 [16] where it is freely sold to consumers.

In Morocco, the first observations date back in 2008 in the Sidi Allal Tazi town in irrigation canals, fields of culture and the Sebou River. Since then, red swamp crayfish took advantage of the presence of water to propagate to two ways. Sebou River streams have allowed a rapid propagation to South areas, on the one hand. On the other hand, Red swamp crayfish followed irrigation channels to reach the rice fields. This propagation has continued in the area of the Gharb where many cases were seen since 2008 [17].

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This study takes place in the Gharb area (Northwest of Morocco), where several individus of *Procambarus clarkii* have been found in rivers, water sources, wells, irrigation canals, dikes, crop fields, and dams. Everywhere it's appeared resistant to different living conditions, and easily colonizes various habitats [18], [19].

The Gharb region is one of the most important plains in Morocco in terms of agriculture. Its participation in national agricultural production by 100% of the production of rice, oilseeds 48%, sugar 33% and citrus fruits 25% [20]. The first experiments on rice in the Gharb area date back to 1934. Currently, the rice area is about 12,000 ha, mainly in the lower Sebou basin. Irrigation is provided by pumping into the Sebou River [21].

The red swamp crayfish affects the rice growing, by causing water loss, damage to rice field and ditches [22]-[25], direct consumption of rice seed and plants, and clogging of pipes [26]. Consumption is the most important cause of rice destruction [27] and a consumption peak is observed during the second week of rice development [28]. Although seedlings are more affected than seeds, at high crayfish densities the majority of both items are heavily affected [29]. A recent economic analysis on invasive species in France shows that, among 600 invasive species (fauna and flora), *Procambarus clarkii* is the fifth invasive species classified according to the level of presence and impacts, especially its impact on rice-growing [30].

The survey carried out in Morocco since 2016 has made it possible to monitor the evolution of the red swamp crayfish population and it dispersion in the Gharb area.

The objective of this study was to understand how this species was introduced into the Gharb area, to identify the new points of presence of this species in 2017 and 2018, to establish a propagation map, to identify the different ways that the crayfish takes to spread in the area.

The results of this study can be used by natural resource managers, wetland conservators, researchers, and local population to help them to locate *Procambarus clarkii*. Also to identify the vectors that move it to across the boundaries, illustrate the importance of limiting its expansion in wetlands and prohibiting the movement of this invasive species across borders or into new ecosystems and the need for measures by authorities within the framework of a national management plan.

II. Materials and Methods

A. Study Area

The Gharb area is located into central of Morocco, in the Rabat-Salé-Kenitra region that spreads over an area of 17,570 km^2, 2.5% of the area of the kingdom of Morocco (Fig. 1). It is bounded on the north by the Tangier-Tetouan region, on the east by the Fez-Meknes region, on the southwest by the Casa-Settat region, on the southeast by the Beni Mellal-Khénifra region, and on the west by the Atlantic Ocean [21]. The Gharb area is located in the northwestern part of Morocco. Crossed from east to west by the Sebou River, the Gharb extends about 50 miles (80 km) along the Atlantic coast and reaches some 70 miles (110 km) inland (Fig. 1).

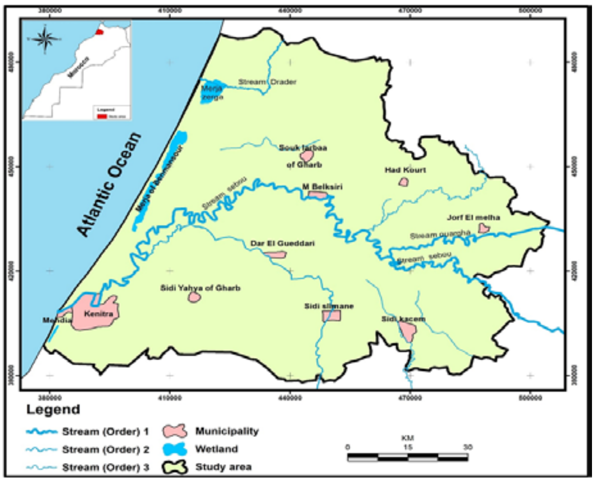

Figure 1. Location of the Gharb area (Regional Office for Agricultural Development of Gharb, Morocco, 2016).

The area is crisscrossed by tributaries of the Sebou River for a length of approximately 225 km before flowing into the Atlantic Ocean at Mehdia. Along its route, the Sebou intercepts several tributaries, the most important of which are the wadis Inaouène, Lebène and especially Ouergha on the right bank and wadis R'dom and Beht on the left bank. The Gharb area has considerable water resources, estimated at 6.75 billion cubic metres, whose part reserved for irrigation is 3.5 billion cubic metres.

The area enjoys a Mediterranean climate with an oceanic influence; it belongs to the subhumid bioclimatic stage at temperate winter with a semi-arid tendency in internal zones. In addition, the area has a wide range of soil type. The Gharb area is favorable to rice growing due to many ecological factors like climate, soil and water quality (Fig. 2).

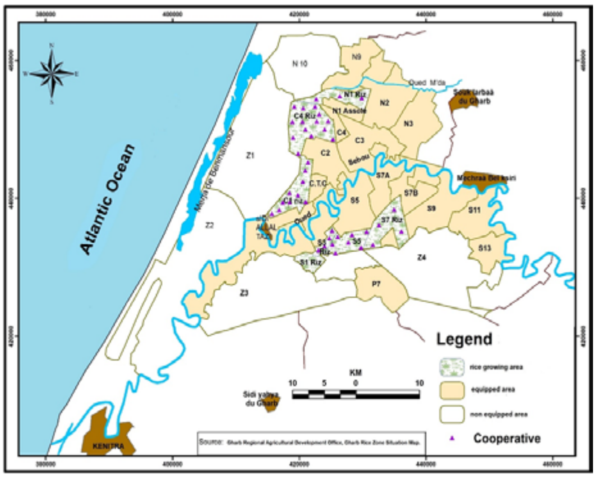

Figure 2. Spatial situation of rice-growing areas of the Gharb and cooperatives in the rice sector (modified card, Regional office for Agricultural Development of Gharb, Morocco).

In the Gharb area, rice growing amounts to 12,000 ha. There are seven rice-growing sectors in the Gharb plain, which includes 40 cooperatives (Fig. 2).

B. Sampling Methods and Materials

To study the presence, spread of *Procambarus clarkii* in the Gharb and its impacts on rice growing, sampling was carried out in the study area.

To collect the first information on the presence of the species, the date of first observation and its spread in the Gharb area an anonymous survey questionnaire was used. Nine hundred eleven (911) people were interviewed in the Gharb area, including 627 rice farmers, 186 local people and 98 fishermen between April 2015 and December 2018. A total of 882 people confirmed the presence of *Procambarus clarkii* and 89 people confirmed the absence of this species in their areas.

The evolution of *Procambarus clarkii* population in the rice fields required 36 field trips in the Gharb area during three years due to one field trip per month. The red swamp crayfish populations were caught per unit of effort (p.u.e.) once a month, from January 2016 to December 2018.

To estimate the evolution of the red swamp crayfish population in rice fields, we used the manual fishing technique to catch crayfish. It was necessary to wait for the crayfish to start moving on the surface of the earth to capture it for one hour in three periods during the day at 7am, 2pm and 7pm.

In the dikes, two methods were used depending on the dimensions of the dike. For dikes and rivers with a narrow width (less than 3 m) and shallow depth (less than 0.30 m), it is possible to explore the dikes by hand to catch crayfish.

Conversely, in dikes and watercourses (more than 0.30 m), it would be difficult to capture the practice by hand. It is therefore necessary to use another fishing technique, using a landing net.

The abundance of individuals of the species in the holes will calculate by using the number of individuals of the species within the holes and the number of holes per surface unit.

In the middle of randomly selected rice fields, the fields team measured seventy plots in the shape of 1 m² (ten plots in each rice sector), then counted the number of holes dug by crayfish in each square, then counted the number of crayfish present in each hole.

Using this equation: $N.C/m^2$ = average (N.C.H) * average ($N.H/m^2$) and N.C/ha = $N.C/m^2$ * 10 000 with: (N.H) is a number of holes, (N.C.H) is a number of crayfish present in each hole and (N.C) is a number of crayfish.

The irrigation water lost per irrigation operation will calculate by using the dimensions of the holes and the number of holes per surface unit. In fact, we supposed that a hole can be considered as an impermeable cylinder. Which implies each hole loses a quantity of water equivalent to its volume per irrigation operation.

III. Results and Discussion

A. Propagation of Red Swamp Crayfish (Procambarus clarkii) in Gharb Area

According to the questionnaire survey conducted among local people, farmers, fishermen and regional NGOs since 2015, Procambarus clarkii has been observed for the first time in the Sidi Allal Tazi irrigation channels and Sebou River in 2008. From there, the species started to spread along two different paths.

By following the river downstream, it colonised the Fouwarate wetland and several rural communes (Mnasra, Ouled Slama, Mograne, and Benmansour, Sidi Mohamed ben Mansour, Sidi Al Kamel and Dar Gueddari). The spread of that direction is rapid as evidenced by the arrival of the species in the Fouwarat in Kenitra in 2010/2011. In water it can rapidly spread across a watershed according to the environmental conditions [31]. Several studies reported crayfish were more likely to move downstream or to spread downstream at higher rates [32]-[36] which seem to be confirmed by the results of this study.

The second way of the species spreading is the irrigation canals. The red swamp crayfish pass through these canals to disperse into the rice fields. The species reach the Merja wetland, Canal Nador and several rural communes (Souk Telet El Gharb, Sidi Mohamed Lahmar, Mechra Bel Ksiri, Houafate and Sefsaf). However, the spread in that direction is less rapid than the first one. In fact, the species should wait for the filling of the irrigation canals to continue their dispersion. The species arrived successively in Beht River in 2010, Canal Nador in 2011 and Drader River in 2012.

Between 2008 and 2016, *Procambarus clarkii* has colonized 15 communes including 35 sites in the Gharb zone, three rivers among the tributaries of Oued Sebou and two Ramsar wetlands of international importance (Fig. 3).

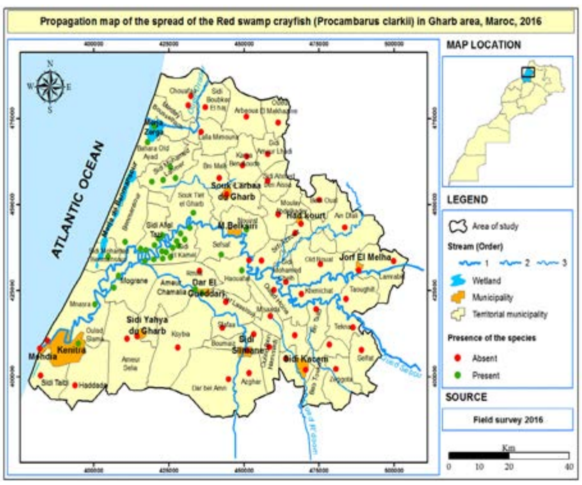

Figure 3. Propagation map of the spread of the red swamp crayfish (*Procambarus clarkii*) in the Gharb area, 2016, Morocco.

In 2017, the species arrived at several locations by multiple routes. Following the Drader wadi, the red crayfish in the marshes have arrived in Lalla Mimouna, Sidi Boubker el haj and chaouafaa. It also arrived in the artificial irrigation river in Souk Larbaa commune and Bni Malek commune via Sidi Mohamed Lahmar. The Sebou River helped it to join Sidi Mouhamed Chelh, Ouled Hcine and Sfafaa rural communes. Farmers of Sidi Azouz commune which use the stream of Ouarga water to irrigate confirmed the presence of the species in their fields. Also, the famers of M'saada commune who use the R'doom stream water to irrigate confirmed the same in their fields (Fig. 4).

Between 2016 and 2017, the red swamp crayfish has dispersed towards the east and south of the Gharb by taking advantage of the Sebou River, irrigation canals and human activities. The spread of *Procambarus clarkii* is easy by overland, this species has the ability to exit the water and moves over-land to distances up to 1 km [37], [38] and able to survive out of the water for more than 10 hours under summer conditions [39].

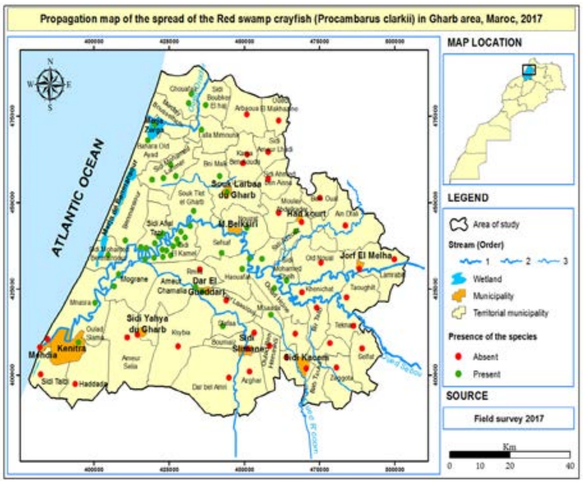

Figure 4. Propagation map of the spread of the red swamp crayfish (*Procambarus clarkii*) in the Gharb area, 2017, Morocco.

In 2018, the species had spread to others places and the lack of intervention favours the trend. According to fishermen of the Oued al Makhazin rural municipality, the presence of the crayfish in their area is very recent. In the same time, local farmers of Jorf el Melha, El Mrabih and Ouled Noual discovered the species throw irrigation water from Ouargha River. Farmers of Bir Talib, Tkna, Taoughit and Khénichat communes use Sebou river water to the irrigations and they confirmed the presence of the crayfish in their fields. Also, the species followed the Ouargha river throw Bir Taleb to reach Zegotta commune. The R'doom River helped the crayfish to reach Sidi Kacem while the oued Beht helped it to reach the Boumaiz, Sidi Sliame, Dar Bel Amri communes according to their local populations and fishermen (Fig. 5).

The people surveyed confirmed that the species has been recently introduced into their regions by people generally for commercial reasons.

The species has not yet succeeded to colonizing the entire Gharb region. However, the problem is that this species exits the water searching for new areas during the first rains after strong decreases of water level [40]. This means that the area colonized by *Procambarus clarkii* will be larger in a few years.

The results of the survey in 2018 and sampling show that this species is currently absent in twenty-one territorial municipality, one municipality (Mhedia), and one wetland Ramsar site (Sidi boughaba).

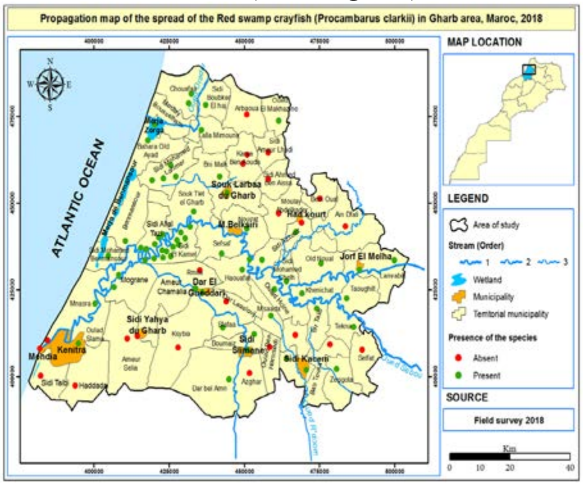

Figure 5. Propagation map of the spread of the red swamp crayfish (Procambarus clarkii) in the Gharb area, 2018, Morocco.

It is difficult to determine to what extent the spread of *Procambarus clarkii* in Gharb area is natural, but most likely a large proportion, especially inter-catchment movements are due to deliberate and accidental introductions by humans. As the discarding of individuals in a living state in water in several places for marketing purposes. After a while, this species adapts, reproduces and spreads to other areas due to favourable conditions such as rain, humidity and temperature. The spread is connected to the live discarding of live individuals to water [41], also to the external transport (ectozoochory) of juveniles by water birds [42], [43], also helps the rapid spread of *Procambarus clarkii*.

B. Monitoring of Population Trends of Procambarus Clarkii in the Gharb Rice Fields

Below is a table of the averages of collected measurements in the Gharb rice fields from January 2016 to December 2018 (Table I).

TABLE I. DATA ON THE AVERAGE NUMBER OF INDIVIDUALS PER HOLE AND NUMBER OF HOLES PER M² COLLECTED IN THE RICE FIELD FROM JANUARY 2016 TO DECEMBER 2018.

Year	Average hole diameter in (cm)	Average hole depth in (m)	Average number of individuals in the holes	Average number of holes per m^2	calculation of Abundance of *Procambarus clarkii* in the rice fields (species/ m^2)	Calculation of Abundance of *Procambarus clarkii* in the rice fields (species/ha)
2016	3,43	1,82	1.57	0.97	1.5229	15229
2017	2,427	1,993	1.52	0.91	1.3832	13832
2018	2,675	2,162	2.05	1.60	3.2800	32800

Through these data, it will be possible to estimate the abundance of *Procambarus clarkii* per m^2. Using the equation mentioned in the methodology. The results found for each year can be multiplied by 12000 ha to obtain an estimate of the abundance of the species throughout the rice area (Table I).

According to rice farmers, dozens of *Procambarus clarkii* individuals have been observed in their fields for several years. They noticed that in 2016 the number of the red swamp crayfish individuals increased in their fields. That is why the year of 2016 was considered an explosive.

In 2017: slowdown of the explosive phase is the result of a combination between physical control (picking) and chemical control by rice farmers to reduce the number of Procambarus clarkii in their fields.

In 2018: the number of Procambarus clarkii individuals increased again because of its voluntary introduction into irrigation channels by the local population in order to reproduce and use it later as fishing bait. Which means 2018 is a return to the explosive phase.

C. The Impact of Procambarus Clarkii on Rice Growing

The red swamp crayfish are digging holes in rice fields and dikes. These galleries serve as habitat but also a way to escape in case of attack. These holes have important dimensions can reach maximum average depths of 2,162 m in 2018 and maximum diameters of 3,43 cm in 2016 (Table I). The rice-growing areas in Europe have been largely affected by crayfish habitats; mainly due to their digging behaviour [22].

The burrowing behaviour of the red crayfish can also cause damage to earthen dykes, levees, and water control structures of the irrigated agricultural system [44].

In addition, Water quality in particular dissolved oxygen and turbidity, can be heavily affected by burrowing activity of *Procambarus clarkii*, and this was experimentally demonstrated in laboratory and outdoor studies [45], [46]. The presence of these drifts induces a loss of water which increases in parallel with the number of holes dug in the Gharb rice field. These water losses can be calculated using field data and others collected from the Gharb Regional Agricultural Development Authority.

This calculation method will not take into consideration the horizontal infiltration along the hole, the soil permeability rate and the water holding capacity of each soil type.

Calculation of water loss:

A hole is supposed to be an impermeable cylinder; R is a radius (medium) of hole.

The volume of a hole is V = Pi* R2* P; with: R = diameter/2, P is a depth (average) of hole, Pi = 3.14 and Using the data from Table I.

That is, when an irrigation operation is carried out in the rice field, each hole resulted in a loss of water equivalent to 1680.8 cm^3 in 2016, 920.78 cm^3 in 2017 and 1214.43 cm^3 in 2018. To determine the water loss in m2, simply multiply the results found by the average number of holes per m^2 (Fig. 6).

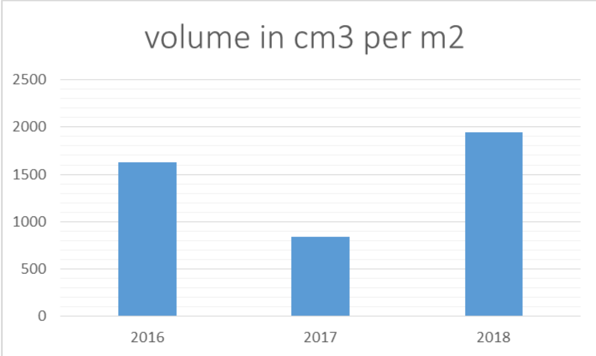

Figure 6. Water loss in cm^3 per m^2 caused by the red swamp crayfish (*Procambarus clarkii*) in Gharb rice field, Morocco.

This graphe correspond to the volume of water lost per m2 through the holes during an irrigation operation. By unit conversion, we obtain a water loss of 16,304 m^3/m^2 per irrigation operation in 2016, for 2017 there is a loss of 8.37 m^3/m^2 and 19.43 m^3/m^2 in 2018. The decrease in water loss observed in 2017 is due to the decrease in the abundance of crayfish in rice fields in that year by the crayfish collection campaign that rice farmers have done this year (Fig. 6). However, these calculations do not take into account water losses in dikes or water leaks from flooded fields.

The single biggest water problem worldwide is scarcity. In much of the world, existing water supplies are insufficient to meet all of the urban, industrial, agricultural, and environmental demands. For this reason, every drop of water lost in an area is a loss throughout the earth. On a global basis, agriculture is the largest user of water, accounting for approximately 80% of global consumption [47], [48].

Therefore, it has become essential to find solutions for agricultural problems that cause water loss and apply conservation strategies to reduce water losses and to develop a sustainable agriculture [49].

Procambarus clarkii has a serious impact on the Gharb rice fields due to its rapid life cycle, dispersal capacity, excavation activities and high population density. According to Gharb rice farmers, the species also consumes young rice plants. It is the main cause of the increase in the costs of agriculture and water management. Another vision on the impact of red crayfish on rice field is that digging behaviour can also cause erosion of agricultural land and increase water turbidity [45], [50]. In addition to that the density of rice plants can be reduced by 100%, Feeding trials showthat crayfish prefer rice seedlings [51], [52].

Regarding agricultural economic impacts specifically, crayfish infestation has seriously damaged drainage systems because of its feeding and burrowing activities, causing important losses of rice yield [53], [54].This Infestations can decrease rice grain production [54]. In northern Italy, *Procambarus clarkii* caused a 6% decrease in rice production [55].

IV. Conclusion

The Gharb area contains one of the most important agricultural potential in Morocco. It produces most of the

Moroccan rice. The presence of crayfish in the Gharb area represents a real threat, especially to rice cultivation. The population of *Procambarus clarkii* increases year by year, the disturbances that crayfish cause in rice cultivation are considered significant. The transport and commercialization of *Procambarus clarkii* in its living state favoured its rapid spread in the Gharb area.

Understanding of the invasion process of *Procambarus clarkii* in the Gharb area and the evolution of the spread can help managers to recognize the potential threats that this species poses to newly invaded ecosystems and to support management and impact mitigation efforts.

Conflict of Interest

The authors declare no potential conflict of interest.

Author Contributions

MEAEM conceived and supervised this study, SS wrote the main manuscript text, prepared figures and tables, analysed and interpreted the data, MEAEM and AS participated in discussions and provided suggestions. All the authors reviewed and approved the final manuscript.

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