Current state of knowledge on Louisiana crawfish (*Procambarus clarkii* Girard, 1852) in Morocco

[1]Yahya Ben Yahkoub, [2]Mohamed Fekhaoui, [1]Ikram El Qoraychy, [1]Ahmed Yahyaoui

[1] Laboratory of Biodiversity, Ecology and Genome, Faculty of Sciences, Mohammed V University, Rabat, Morocco; [2] Scientific Institute, Mohammed V University, Rabat, Morocco. Corresponding author: Y. Ben Yahkoub, benyahkoubyahya@gmail.com

Abstract. In Morocco, the Louisiana crawfish (*Procambarus clarkii*) was illegally introduced in the late 90s / early 2000s by the willful release of young specimens into the Nador Canal in the Gharb region and in the Low Loukkos Marshes in the Larache region. This introduction has been carried out in both regions by an owner of an eel farm in the small town of Mehdia. Currently, *P. clarkii* is present in almost every body of water in these regions and constitutes a stock estimated at respectively 60.39 tons in the Gharb and 30.33 tons in the Low Loukkos Marshes. These populations are between 80 and 110 mm in length with an average weight of 32.12 grams in the Gharb region, and between 60 and 100 mm in size with an average weight of 14.3 grams in the Low Loukkos Marshes. The comparison with a previous study in 2015 showed no significant change in the distribution of size and weight classes of the Gharb population relative to the present 2017 study.

Key Words: Louisiana crawfish, *Procambarus clarkii,* density, introduction in Morroco, distribution.

Introduction. The transfer of crawfish from an aquatic environment to another, as well as its introduction goes back to the prehistoric ages (Spitzy 1979). In the end of the 19th century, the American crawfish transfers multiply to repopulate the environments where the autochthonous crawfishes were decimated by the "crawfish plague", a disease caused by *Aphanomyces astaci* (Laurent 1997). Unlike the repopulation with autochthonous crawfish, the introduction of American species appears to be very efficient. The first experiences concern *Oroconect limosus* in Germany, and then *Pacifastacus leniuculus* in Sweden (Laurent 1997). Currently, the red crawfish from the marshes of Louisiana, *Procambarus clarkii*, is the most widespread in the world (Henttonen & Huner 1999). This is due to high fecundity (Ackefors 1999) added to the fact that it can inhabit a wide variety of freshwater habitats, indeed *P. clarkii* is very tolerant and adapts to a wide range of aquatic conditions including moderate salinity, low oxygen levels, extreme temperatures and pollution (Cruz & Rebelo 2007).

In Morocco, the presence of *P. clarkii* is known, however, our current knowledge about the species in Morocco is in its initial stages and the only studies published is by El Qoraychy et al (2015). Moreover, it has been shown the proliferation of *P. clarkii* goes with negative impacts on the environment (Angeler et al 2001; Correia et al 2008; Yamamoto 2010) and hydraulic structures (Gherardi et al 2000; Yue et al 2010).

For these reasons it is important to work on a situational analysis on the evolution of the populations of *P. clarkii*, in order to shed light on the way this species was introduced to Morocco. It is also important to determine what areas are currently affected, the stock estimation and to examine the characteristics of the populations in order to facilitate later implementation of management/exploitation tools.

Material and Method

Description of the study sites. This study was conducted in two areas localized in north-west Morocco (Figure 1): the Gharb Plaine and Low Loukkos marsh. For the first,

the sampling has been at the level of Nador canal in part along Ould mesbah town to coordinates 34°48'48.8"N and 6°17'54.7"W (Figure 2). Nador canal drains Gharb Plaine closed depressions, and it leads to Merja Zerga south part.

Concerning the second area, sampling has been between Ain Chouk town and DHIRIA to coordinates 35°08'12.2"N and 6°06'30.5"W (Figure 3). The area concerned is a part of wet area complexe belonging to the largest wet area for Ain Chouk, Baggara and Boucharene.

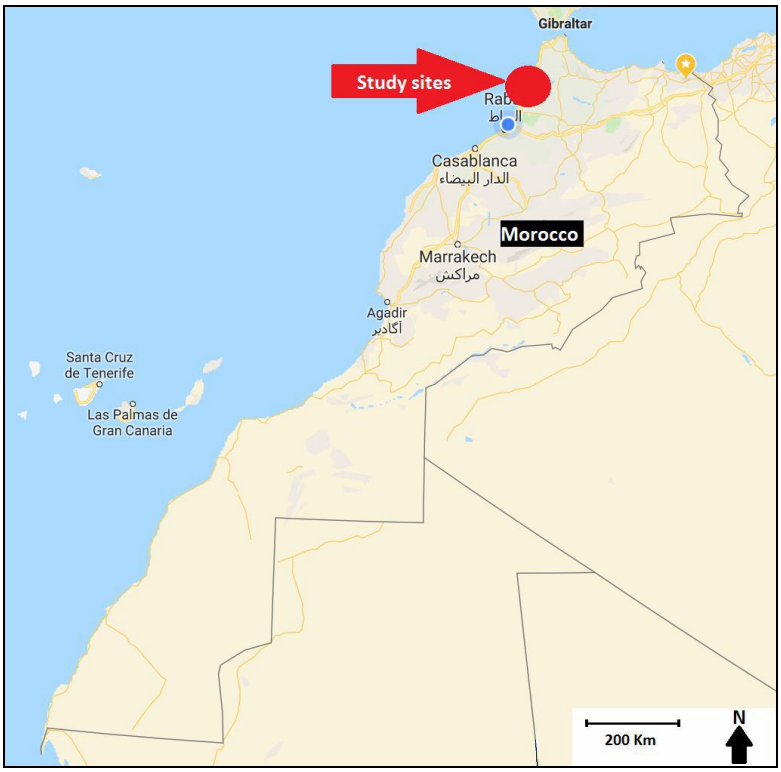

Figure 1. Study sites localization in Morocco (Google maps 2019).

Figure 2. Sampling area localization in Gharb Plain (Google maps 2019).

Figure 3. Sampling area localization in Low Loukkos marsh (Google maps 2019).

Crayfish catching and characterization methodology. Crayfish capture is carried out using a cage 80 cm in length and 25 cm both in hight and width, in grid to 5 mm mesh. The inlet corresponds to a cone 15 cm long and 6 cm in diameter at the smallest side (Figure 4); as bait, local fish or sardines (depending on availability) were used in each trap.

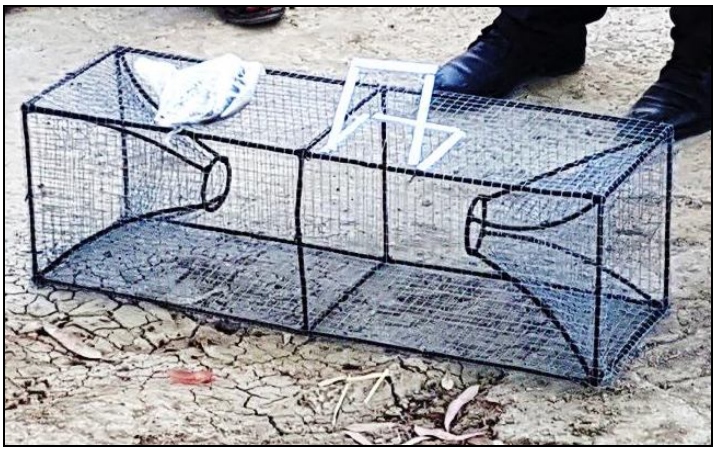
Figure 4. Cage used for trapping crayfish.

For Louisiana crayfish population's characterization, the point was put on the biometric parameters (weight and total length measured from the rostrum to the telson) and the sex identification for the sites of the Nador canal and Low Lukkos marsh. Then collected data have been transformed in histograms for analysis.

Stock estimation methodology. As there is no standard method to estimate *P. clarkii* stock, we tried the catch-tag-recatch method, applied to stock estimation of fish. This method turned out to be inefficient for crawfish. Indeed, none of the thirty tagged crawfish got recaptured, due to their wandering, fearful and burrower behaviour.

We took these behavioural parameters into account to set up a new stock estimation method based on the principle that the most important catch in a 3-month series is the maximum number of individuals that can be captured relative to the trap surface. Estimation of the influential perimeter of the trap takes into account the crawfish feeding behaviour and the recommendations by Paillisson et al (2011): 1) on the trapping time, which was fixed at 24 hours to avoid crawfish loss in the net and to have a less biased idea on the structure of the sampled population; 2) on the trapping effort,

which was fixed at 10 linear meters, due to the recommendation of putting a trap every 10 meters to have a reliable estimation of the catch per effort unit (CPUE). The total sampled surface is then 100 m^2.

Thus, for a given area (or stratum) (i), biomass stock (number and/or weight) can be estimated with the following formula:

$$B = Ni \times Ai/ai \times 1/Xe$$

where: Bi = stock biomass (number and/or weight);
Ni = abundance index (number and/or weight);
Ai = total surface of the area or stratum;
ai = sampling surface (square surface by area).
Xe = escapement factor of the species.

For *P. clarkii* the escapement factor concerns the individuals whose size is lower than the mesh, and those which do not have the feeding behaviour that is appropriate to the trapping method. This type of individuals is the non-exploitable stock and is a minority, taking into account the species ecology.

Considering the aim of the study, the escapement factor will not be used, in order to estimate only the exploitable stock (prone to be caught). Thus, the formula becomes:

$$Bi = Ni \times Ai/ai$$

The abundance indexes are calculated in number and weight, by unit surface (m^2), on every prospected area. To estimate the total abundance and biomass, we extrapolated the average abundance index or the average density on the whole concerned surface. It is worth noting that the total surface estimation was based on the Google Earth Pro application.

Results and Discussion

History of the introduction of P. clarkii in Morocco. The Louisiana crawfish *P. clarkii* is the most widespread American crawfish in the world (Henttonen & Huner 1999), characterised by its high production, fast growth and high fecundity (Ackefors 1999), which have fostered its propagation. Initially introduced for breeding only in Europe, it escaped and adapted perfectly by colonizing lakes and water streams (Laurent 1997).

At a regional scale, Spain was the first country which introduced the species in 1973 for commercial purpose (Laurent 1997). In Morocco, no breeding installation or introduction operation of *P. clarkii* has been authorised or realised by the competent organisms. So how did *P. clarkii* arrive in Morocco? What is sure is that some specimens of *P. clarkii* were described to us by local fishermen in the early 2010s.

For further information, an investigation has been conducted with the local population around the Nador canal and more precisely around Douar Ouled Mesbah. It appeared that *P. clarkii* was introduced willfully and at the same time illegally. The owner of an eel farm in Kenitra, called by the local people “Mr PEPE”, helped by his assistant who used to collect the eels captured by the local fishermen, introduced the species into the area.

This way young specimens of *P. clarkii* were released in the Nador canal (Gharb region) and in the Loukkos marshes (Larache region). The local population described them as little shrimp of around 2 cm. Four months after this incident took place, Mr. PEPE and his assistant came to ask the local fishermen if they caught or noticed the presence of crawfish. The fishermen understood what happened only four years later when they began to see crawfish getting out of water or trapped in their nets.

According to the local fishermen, the introduction took place in the late 90s / early 2000s. The local fishermen indicate that since then, *P. clarkii* has become increasingly abundant with an exceptional population peak in 2010. Currently, *P. clarkii* is still abundant in the Gharb region. Concerning the Larache region, the situation has remained constant since the 2010 peak when the marshes were invaded by the red crawfish.

Characteristics of P. clarkii populations. In the areas of Nador canal and Low Loukkos marshes, characterisation of *P. clarkii* populations focuses on biometric parameters and sex identification. Thus, for each extraction, a sample of thirty crawfish

(or less if the total headcount is less than thirty) was caught in a random manner. Each individual then undergone sex identification and measuring which allows to establish the following characteristics of the present crawfish in each area:

- the population sex-ratio;
- the stock distribution among the different size classes;
- the stock distribution among the different weight classes.

The Table 1 below indicates the minimum and maximum length and weight in each area.

Table 1

Overview of maximum and minimum length and weight in each area

Area	*Max. weight (g)*	*Min. weight (g)*	*Max. length (mm)*	*Min. length (mm)*
Nador canal	50	1.89	117	47
Loukkos marshes	25	6	98	63

Sex-ratio of Louisiana crawfish populations. The identification of sexes in the two areas combined has revealed the ratio of 43% males and 57% females. The detailed analysis in each area has revealed the following percentages:

- 53% of males and 47% of females in the Nador canal;
- 33% of males and 67% of females in the Loukkos marshes.

The sex-ratio data globally indicate that the number of females is greater than the males with a sex ratio (males:females) of 0.75:1. The sex-ratio detailed by area is:

- 1.13:1 in the Nador canal;
- 0.5:1 in the Low Loukkos marshes.

The sex-ratio imbalance and the disparity between the 2 areas is linked to the reproduction behaviour of *P. clarkii* and the abiotic and biotic characteristics of the areas studied.

The evolution of sex-ratio depends on the catch period and generally on the season (Blatter 2013). Dörr et al (2006) observed that in South Tuscany, the sex-ratio of a *P. clarkii* population is extremely variable and depends on geography and season, as reported by other authors (Penn 1943; Huner & Barr 1991).

It is established that during the eggs maturation period, females stay underground and avoid going out, which explains their absence in the extractions (Bravo et al 1994; Frutiger et al 1999). The sex-ratio bias may also result from the sampling method: the nets concentrate the individuals in a confined space and limit the attraction of females, being less inclined to confront other individuals (Blatter 2013).

According to previous studies in central Italy, a stable population of *P. clarkii* has a 1:1 sex-ratio (Scalici & Gherardi 2007). In Morocco, the population sex-ratio of *P. clarkii* at Merja Zerga is 1.35:1 (El Qoraychy et al 2015).

Distribution of stock among size classes. Length measurements have been gathered in classes and the head-counts have been converted into percentages for each area studied. A stacked bar chart has been created in order to analyse the distribution of the species among the classes. Size classes analysis shows unimodal distribution of body length in the two areas (Nador canal and Loukkos marshes). Size classes analysis by area shows that the most common size is 90-100 mm in the Nador canal (Figure 5) and 80-90 mm in the Loukkos marshes (Figure 6). The Nador canal sample displays more size classes, compared to the Loukkos marshes sample. Compared to 2015 the Nador Canal population still displays the same size distribution profile (El Qoraychy et al 2015).

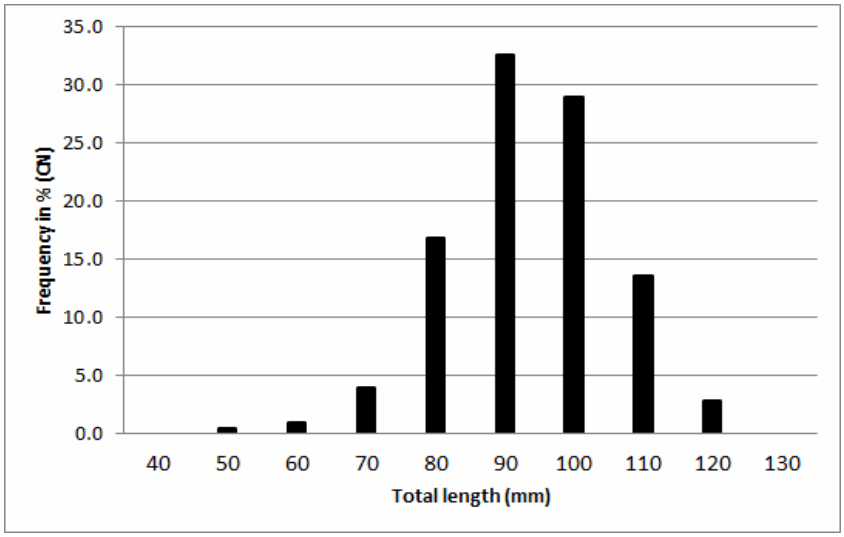

Figure 5. Total length (TL mm) frequency bar chart of *P. clarkii* (Nador canal).

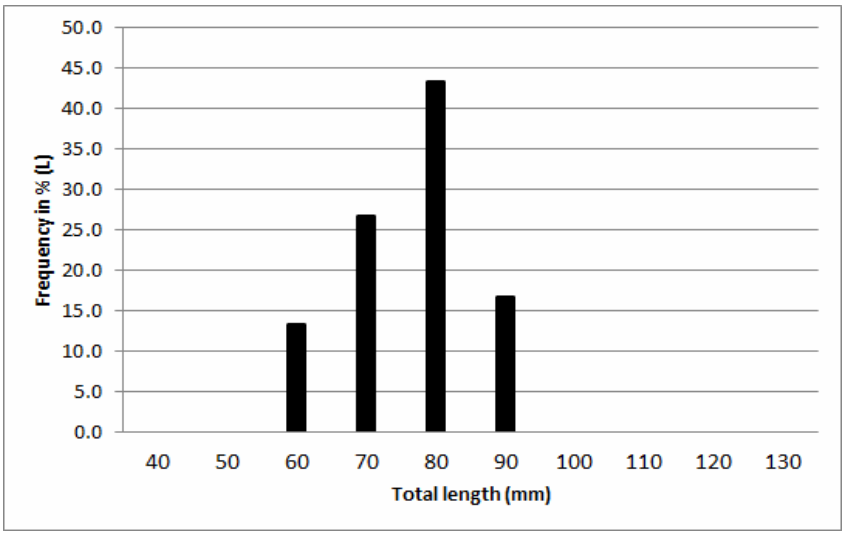

Figure 6. Total length (TL mm) frequency bar chart of *P. clarkii* (Loukkos marshes).

The distribution of size classes in the studied areas shows that the most common size class is 80-90 mm, followed by 90-100 mm and 100-110 mm, which constitute the majority of the population. All size classes are represented in Figure 7.

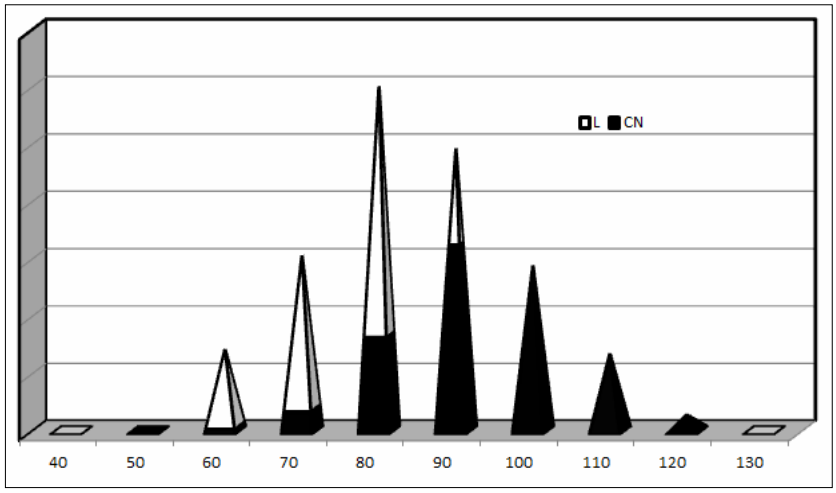

Figure 7. Size classes stacked bar chart in the Gharb (CN) and the Low Loukkos (L).

Distribution of stock among weight classes. Weight measures have been gathered in classes and the head-counts have been converted into percentages for each studied area. A stacked bar chart has been created in order to analyse the distribution of the species among classes.

Like the length analysis, the analysis of weight classes according to the total weight shows unimodal distribution of weight in both areas (Nador canal and Loukkos marshes). Weight classes analysis by area shows a wide dispersion of weight in the Nador canal, since all weight classes from 0 to 80 grams are represented (Figure 8). On the opposite, only 3 weight classes, from 0 to 30 grams, are represented in the Loukkos marshes (Figure 9). The respective average weights of *P. clarkii* crawfish by area are the following:

- 32.12 g in the Nador canal;
- 14.3 g in the Low Loukkos marshes.

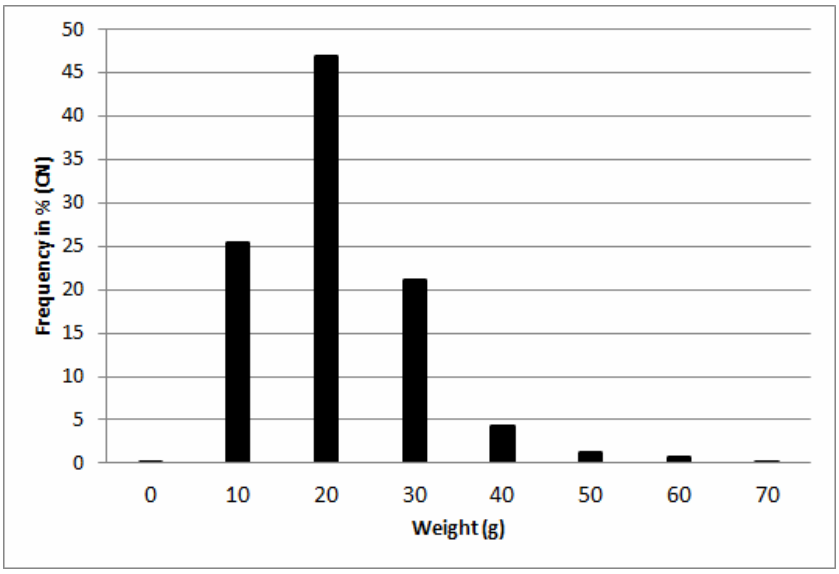

Figure 8. Weight (g) frequency bar chart of *P. clarkii* (Nador canal).

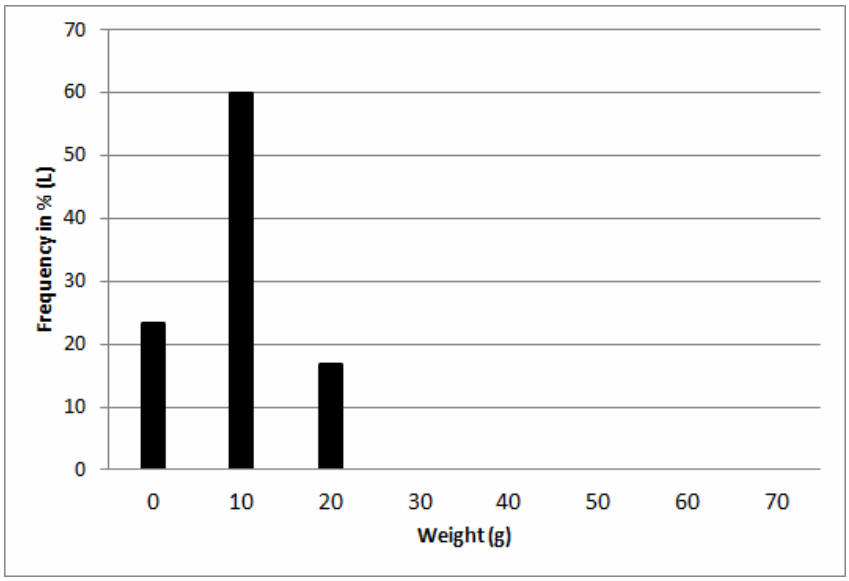

Figure 9. Weight (g) frequency bar chart of *P. clarkii* (Low Loukkos marshes).

Like size distribution of *P. clarkii*, the comparison of weight distribution with 2015 data (El Qoraychy et al 2015) concerning Meja Zerga and the Nador canal (Figure 10) shows no variation, with almost the same profile in the Nador canal.

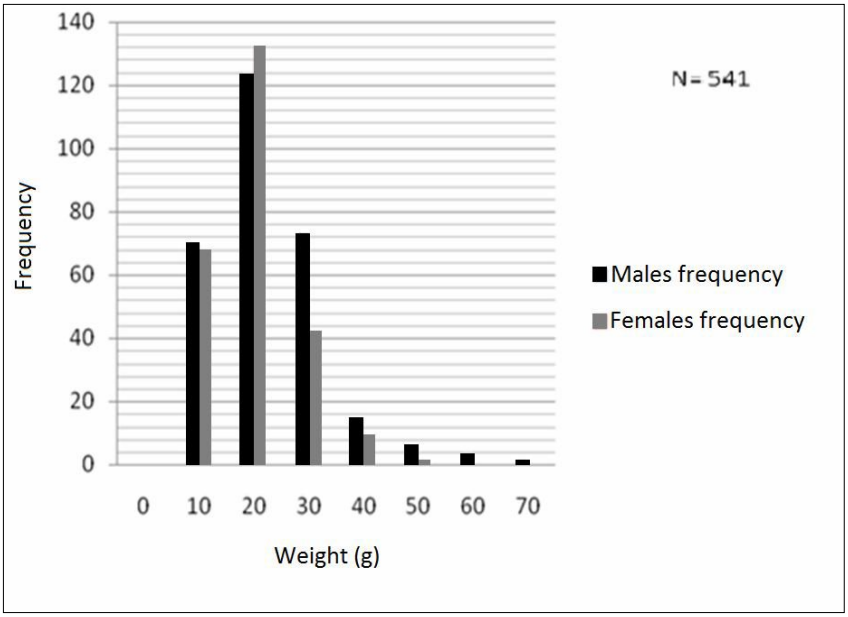

Figure 10. Weight (g) frequency bar chart of male and female *P. clarkii* (Nador canal) (El Qoraychy et al 2015).

Weight classes stacked bar chart shows that the weight of the population studied ranges between 10 and 30 g (Figure 11).

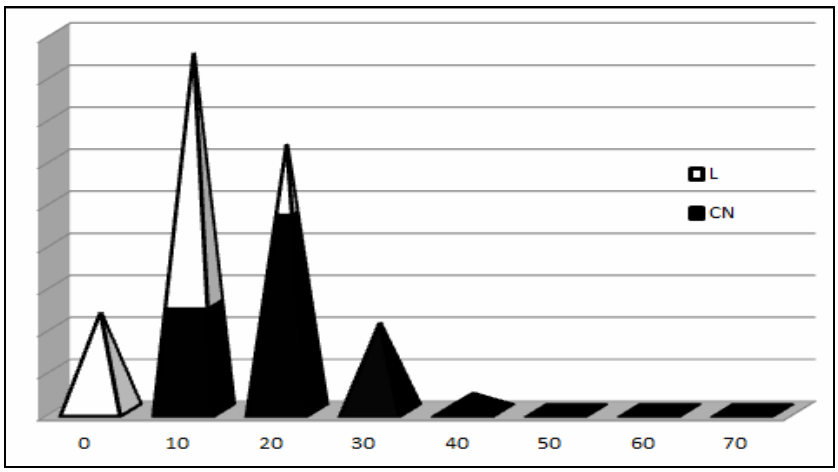

Figure 11. Weight classes stacked bar chart in the Gharb (CN) and the Low Loukkos (L).

Gharb plain. This area concerns the rice fields of the Allal Tazi region and the Merja Zerga represented by the Nador canal which drains the rice fields around the Gharb plain. The results of biomass estimation are summarised in the Table 2.

Table 2

Biomass estimation (Bi) in number and weight on the Gharb plain

Biomass estimation parameters	*Area*	
	Nador Canal	*Rice fields*
Ni (Number / trap)	37	30
Ni (Weight / trap)	856 g	696 g
Ai (Total surface of the area)	550 000 m^2	8 000 000 m^2
ai (Sampled surface)	100 m^2	100 m^2
Bi (Biomass number)	203 500	2 400 000
Bi (Biomass weight)	4.71 t	55.68 t

Low Loukkos. This area is composed of marshes and rice fields, situated in the Low Loukkos wet zone. The results of Low Loukkos biomass estimation are summarized in the Table 3.

Table 3

Biomass estimation (Bi) on the wet zones of Low Loukkos

Biomass estimation parameters	*Low Loukkos wet zone*
Ni (Number / trap)	30
Ni (Weight / trap)	429 g
Ai (Total surface of the area)	7 070 000 m^2
ai (Sampled surface)	100 m^2
Bi (Biomass number)	2 121 000
Bi (Biomass weight)	30.33 t

Distribution. The current distribution of *P. clarkii* established in this study, is located at:

- Larache region: complex of wet zones and rice fields in Larache (Figure 12);
- Gharb region:
  - between Merja Zerga and Souk Larbaa in the North,
  - Dar Guedarj and Allal Tazi in the East,
  - right-bank of Sedou in the South,
  - Atlantic Ocean in the West.

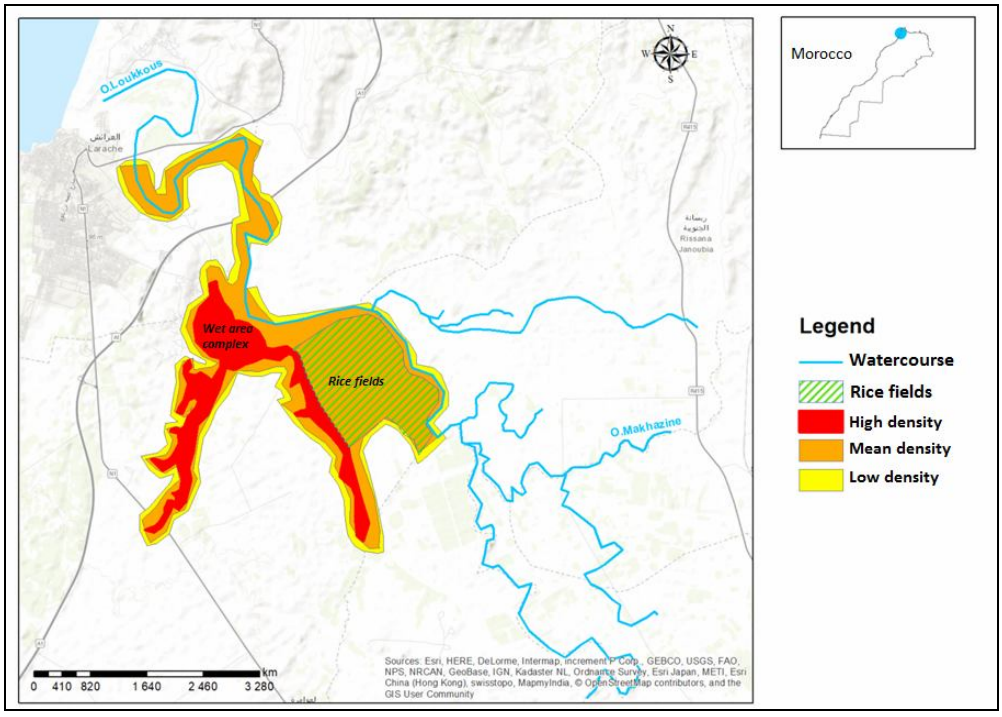

Figure 12. Density of *P. clarkii* in the wet zones and rice fields of Low Loukkos.

In this area the species occupies all categories of waterbody: lagoons, irrigation and draining canals, temporary Merjas, rice fields (Figure 13).

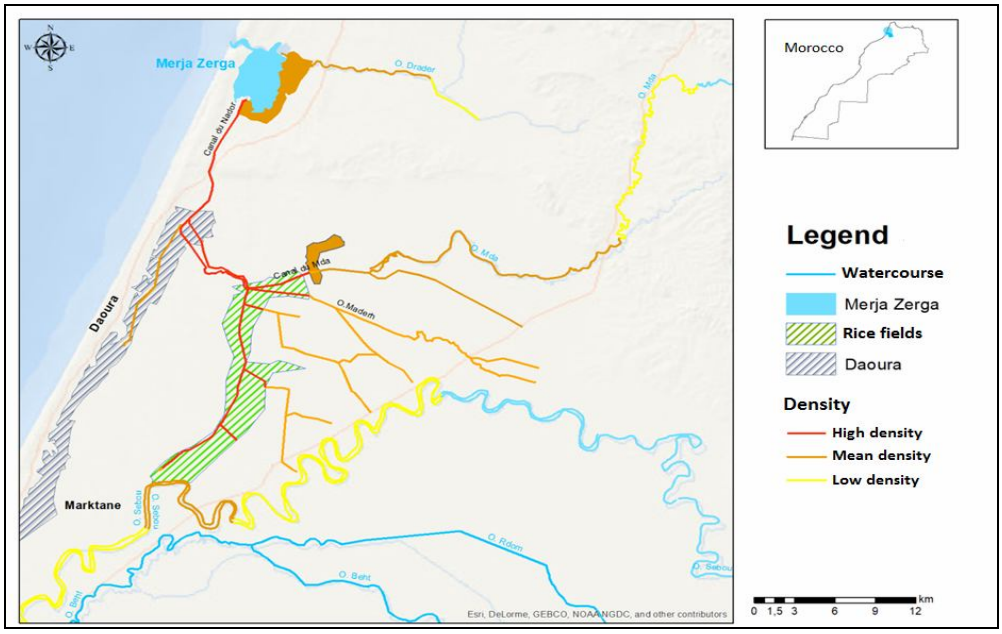

Figure 13. Density of *P. clarkii* in the Gharb region.

Conclusions. Morocco has 103 animal and vegetal invasive species according to 'The Global Invasive Species Database' managed by 'The Invasive Species Specialist Group ISSG' from the 'Species Survival Commission' of the IUCN. In the near future Louisiana crawfish *P. clarkii* will be added to this list as a result of its wilful and illegal introduction.

Due to their high adaptation capacity, *P. clarkii* populations have colonised almost every body of water in the Gharb Plain and the Low Loukkos marshes, with a stock estimated at respectively 2 603 500 individuals (equivalent to 60.39 tons) in the Gharb and 2 121 000 individuals (equivalent to 30.33 tons) in the Low Loukkos marshes. The stock is mainly composed of individuals of 80 to 110 mm in size with an average weight of 32.12 grams in the Gharb region, and of individuals of 60 to 100 mm in size with an average weight of 14.3 grams in the Low Loukkos marshes.

The experience of the introduction of invasive species has showed that acclimatisation and proliferation of populations are irreversible. Generally, the population control is expensive but, nevertheless, *P. clarkii* can be economically interesting if it is correctly exploited by developing commercial chains and by updating the current regulations. Thus, *P. clarkii* populations can be controlled at lower cost in order to reduce the potential impact on the environment and the ecosystems.

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Authors:
Yahya Benyahkoub, Mohammed V University, Faculty of Science, Laboratory of Biodiversity, Ecology and Genome, Morocco, Rabat, Ibn Battouta Avenue, B.P. 1014, e-mail: benyahkoubyahya@gmail.com
Mohamed Fekhaoui, Mohammed V University, Scientific Institute, Morocco, Rabat, 10106, Ibn Batouta Avenue, B.P. 703, e-mail: uhe_isr@yahoo.fr
Ikram El Qoraychy, Mohammed V University, Faculty of Science, Laboratory of Biodiversity, Ecology and Genome, Morocco, Rabat, Ibn Battouta Avenue, B.P. 1014, e-mail: ikramelqoraychy@gmail.com
Ahmed Yahyaoui, Mohammed V University, Faculty of Science, Laboratory of Biodiversity, Ecology and Genome, Morocco, Rabat, Ibn Battouta Avenue, B.P. 1014, e-mail: yahyaoui.ahmed@gmail.com

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