MINISTERE DE L'ENSEIGNEMENT SUPERIEUR

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Graduation Project

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Developed by :

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BLACK RAT ERADICATION IN INSULAR ECOSYSTEM :
CASE OF KURIAT ISLANDS, MONASTIR TUNISIA

Realized within

Notre Grand Bleu

Supervised by

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Dedication

To the first hero of my life, to the one who thought me how to walk, how to talk and how to see the world differently. To his memory, to his soul, to him where Ever he is today, to the one who's not here any more but he is with me where ever I am and where never I will be, in my heart, in my thoughts and in my soul. To the one who thought me how to love, how to care and specially how to live. And weirdly the one who thought me how to live in this world without him...

To my mother, my guardian angel, the one that always was there for me even though she is hundreds of miles away, to the reason of my being, to my source of power and the source of my inner peace... To the one who knows what's going on with me just by hearing my voice even though I try to hide my tiredness and weaknesses but she knows it, she just feel it... To her so that I tell her that I can do it never mind I wouldn't give up this is just the beginning... the rest is coming up... I will always keep trying... trying even harder and harder...

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Abreviations list

APAL	L’agence de Protection et d’Aménagement du Littoral
BP	Before Present
CEPF	Critical Ecosystems Partnership Fund
FFEM	Fonds Français pour l’Environnement Mondial
ISSG	Invasive Species Specialist Group
IUCN	International Union for Conservation of Nature
NGB	Notre Grand Bleu
NGO	Non Gouvernemental Organisme
RAC/SPA	Centre d’activité régional d’aire marine spécialement protégées

Presentation of the Association

I Notre Grand Bleu

'Notre Grand Bleu' is a non-governmental association created in 2012. Its vision is the preservation of marine and coastal life in the Mediterranean and the human activities that depend on it and ensure a sustainable future for the littoral area.

Among its objectives, awareness-raising for the conservation of biodiversity and the preservation of the marine, coastal and insular environment, awareness-raising among young schoolchildren and high school students on the importance of safeguarding the coastline and the sea and their resources natural, with a focus on the conservation of marine and coastal biodiversity, including the protection of species that have a great interest in the ecosystem or endangered species such as the sea turtle *Caretta caretta* and Posidonia seagrass etc. .). There is also interest in the impacts of human activities on biodiversity, pressure on natural resources, pollution of the marine environment, contribution to the protection of fragile ecosystems and participation in the realization and management of protected coastal and marine areas.

II. Project: Contribution to the conservation of the Kuriat Islands and the Monastir Bay through the involvement of civil society and the private sector

This project integrates and complements the activities and work carried out on the Kuriat Islands site by the various actors.

The project is funded by the CEPF or Critical Ecosystems Partnership Fund, a joint initiative of the French Development Agency, the Conservatoire du Littoral Français and the French Global Environment Facility (FFEM), the Government of Japan , The John D. and Catherine T. MacArthur Foundation, and the World Bank.

The project was organized in three main areas:

- Strengthening the capacities of the association ‘Notre Gran Bleu’ and its partners in integrated coastal zone management, marine ecology and isular biodiversity.
- Eradication of the Black Rat of the Kuriat Islands.
- Influence of tourism and fishing user units in favor of practices adapted to nature

Introduction

Kuriat Islands are home to many notable species such as *Caretta caretta, Pinna nobilis, Posidonia Oceanica.* Kuriat is also the main sea turtle nesting site in Tunisia and western Mediterranean, nurseries for several species of vertebrates and invertebrates in barrier reef meadow of Posidonia and home to many species of migratory birds. However, it is under various pressures such as illegal fishing, pollution and invasive species which threaten the stability of the ecosystem. The protection of such natural wealth is essential.

This study is interested by the main threatens, which is Black rat invasion. *Rattus rattus* is one of the most harmful alien species in the world. It is known by its impact on insular ecosystems, especially sea birds and sea turtles.

In 2013, a scientific team of monitoring sea turtle nesting on Kuriat islands, reported an increased presence of Black Rat and also some cases of baby turtle attacked by black rat while their emergence. It's presence in an insular ecosystem is considered very dangerous because of their generalist character feeding on wide sources of nutriment, including bird eggs, reptiles, insects and various species.

According to environmentalists, researchers, managers and non-governmental organizations, invasive species eradication campaigns such as the black rat in these vulnerable and isolated ecosystems are a very powerful nature conservation tool (Donlan *et al.*, 2003).

Falls within this context that a black rat eradication campaign started on the Kuriat Islands. This initiative was headed by the NGO 'Notre Grand Bleu'. This action is one of the main phases of the project 'Contribution to the conservation of Kuriat Islands and Bay of Monastir through the involvement of civil society and private sector', funded by the 'Critical Ecosystem Partnership Fund' (CEPF).

The aim of this study is monitoring the main phases of black rat eradication program on Kuriat Islands.

Bibliographical research

I. Insular biodiversity:

I.1. Importance of insular biodiversity:

Biological diversity is the resource upon which families, communities, nations and future generations depend. It is the link between all organisms on earth, binding an inter-dependant ecosystem, in which all species have a specific role; it is the web of life. The Earth's natural assets are made up of plants, animals, land, water, the atmosphere and humans; Together we all form part of the planet's ecosystems, which means if there is a biodiversity crisis, our health and livelihoods are at risk too.

Islands are isolated habitat, located at a considerable distance from the nearest similar habitat. They can be oceanic or continental island (crater lakes, mountain peaks, nature reserves, national parks). The 100,000 islands on Earth, covering only 3% of the Earth's surface, are exceptionally rich biodiversity reservoirs. Ecologically fragile and economically vulnerable, they shelter certain forms of life and certain ecosystems, which are considered to be the most exclusive of the planet (Challenge & Glispa, 2010).

Importance of these ecosystems becomes even greater when it is thought that more than 600 million people depend on these ecosystem services for food, water, housing, medicines and other natural. Insular ecosystems are visibly unbalanced and species are threatened with extinction, with obvious negative effects on humans. The main causes of species extinction on island are destruction of their habitat, biological invasions, tourism development, climate change, natural disasters, overexploitation, pollution and waste (Challenge & Glispa, 2010).

Many species are now threatened by extinction and some have already disappeared. These disappearances are irreversible and the consequences are unpredictable: the disappearance of predators (sharks) leads to the proliferation of prey (jellyfish), the decrease in the number of insects and pollinating animals (bees, bats ...). Leads to a decrease in the fertilization of plants (which produce fruits, vegetables, seeds, oils ...). The diversity of species also allows ecosystems to adapt better to changes in the environment (notably climate) and is thus a wealth for all living things. Finally, biodiversity provides services to humans: food supply, water filtration, oxygen production ... (Approach, 2016).

I.2. Biodiversity role

I.2.1. Socio-economic role

Although the socio-economic value of biodiversity is still unclear, its role remains unquestionable (Barker, 2007). From an agronomic point of view, Man has sought in the course of evolution to select the particular animal and vegetable species which possess a high yield in order to maximize their production, and consequently their profitability. But this choice is not without risk, because it leads to genetic uniformity and therefore greater vulnerability to epidemics and diseases (Brittany, 2014).

I.2.2. Nutritional Role

Man has been since the beginning of his existence, two million years ago, dependent on fauna and flora for food. It takes from natural environment the necessary food for its survival: plants, meat, fish, etc.

Since the beginning of agriculture, it has selected plant varieties and animal breeds best adapted to its needs from the beginning of agriculture, covering 90% of its diet with 14 domestic species and only four plant species - wheat, corn, rice, potatoes - covering half its energy needs (Chapin *et al.*, 2000). In parallel, many races and varieties disappear. Of some 6300 listed domestic breeds, 1350 are endangered or already extinct (Costanza *et al.*, 1997).

I.2.3. Pharmaceutical role

Biodiversity also plays a role in the pharmaceutical industry and therefore human health. Indeed, several molecules supplied by the plant or animal species are used for the manufacture of the drugs. It is estimated that almost half of the drugs used (40%) come from a natural active substance extracted from living creatures (in two thirds of the cases from a plant). The pharmaceutical industries have also understood the importance of biodiversity since they are very involved in its knowledge and maintenance (Barbault, 1993).

I.3. Threats

The concept of biodiversity is very recent, since it was conceived at the Earth Summit of ‘Rio de Janeiro’ in 1992. But it was in 1985 that Edward O. Wilson asked the question of accelerating the rhythm of species extinction (Jourdan & Vidal, nd). Currently, researchers estimate that extinction’s rate is 100 to 1000 times the natural rate.

In fact, the causes are known and Man is the first responsible. On the other hand, the gravity of this phenomenon is still poorly known (in terms of magnitude and speed). This lack of knowledge is mainly due to three main factors:

- Data are often fragmentary
- The phenomenon is still underway
- Extinguishing processes are complex

Threats can be classified into five categories:

- **Habitat Destruction and fragmentation**: Habitat destruction occurs whenever humans change a landscape and alter the ecosystem that resides there. It’s the main cause of biodiversity loss (Jourdan & Vidal, nd).

- **Biological invasion:** The main cause of species extinction in insular ecosystem, 3/4 of recent extinctions is related to invasive species. Biological invasion is the voluntary or involuntary introduction of species into places where they are not present naturally. Some particularly dynamic species (1/100) become invasive outside their natural context and influence native species [1].

- **Over-exploitation:** This is a sample exceeds the renewal capacity of the populations of certain species.

- **Pollution and bio-contamination:** There is a sort of toxic bioaccumulation (heavy metals, pesticides ...) due to pollution in the animal and plant bodies, which can cause physiological dysfunction or death by poisoning.

- **Global Climate Change:** 15-35% of species could be extinct by 2050 because of climate change (Thomas *et al.*, 2004).

II. Biological Invasion

II.1. Definition

Biological invasion occurs when an organism succeeds in breeding somewhere outside its initial range (Williamson & Fitter, 1996).

A biological invasion is therefore characterized by the long-term increase in the range of a taxon. This definition is implicitly based on consideration of taxonomic, geographic (range) and temporal criteria.

The impact of invasive species on the ecosystem can be defined simply as all the effects induced by its presence on the fauna, the flora, physical and chemical environment. This is a management term that refers to the ecological niche concept developed by Elton (1927). It encompasses all the relations that a species maintains with the flora, the fauna and the physicochemical environment that shelters it. However, it is wrong to speak of an empty ecological niche because a living being and, by extension, a species must, in order to survive, maintain relations with the living world as well as with the physical environment in which it lives. Any species, whether indigenous or non-indigenous, therefore has an impact on the host ecosystem.

The question, therefore, is not so much whether the allochthonous species affects its environment (it still affects), but rather assesses the nature and intensity of its impact.

It has often been proposed to restrict all biological invasions to those causing major disturbances. Thus, 'Invasive Species Specialist Group' (ISSG) of the International Union for Conservation of Nature (IUCN), describes invasive species that is being established in a new geographical area it becomes an agent Disturbance and biological diversity (Anonymous, 1999).

Finally, the term "invasive species" is inappropriate if it does not refer to a geographic entity because the species is by definition "non-invasive" within its initial range. In the absence of a reference to a geographical entity, it is therefore necessary to speak of an "invasive population" of a species rather than an "invasive species" (Pascal *et al.*, 2006).

III. Why should we be interested in biological invasions?

III.1. Biological invasion and economy

Some biological invasions have a strong economic impact. To illustrate this, two historical examples include: the introduction of the fungus of North America *Phytophthera infestans*, a pathogen of potato that caused Ireland between 1845 and 1847, one of the last European famines occurred in peacetime (McMichael & Bouma, 2000); and the introduction of Phylloxera, an aphid also of North American origin, which was first reported in France in the Gard in 1863 and contributed largely to dropping French wine production by 84 million hectares In 1889 (Desert, 1967).

More recently, and more generally, a survey conducted at the request of the US Congress (US Congress of Technology Assessment, 1993) estimated the annual cost of the impact of biological invasions of The US economy in 1993. The "ecological" or environmental cost was not taken into account in this estimate because of the difficulty in assessing the cost of certain major disturbances induced by biological invasions, of a species for example. Since this assessment has been refined and updated and the latest in fixed date that amount to more than US $ 100 billion per year (Pimentel *et al*, 2005).

III.2. Biological Invasion, Human Health, and Veterinary

Some biological invasions of pathogens or their reserves and vectors have a strong health impact. A lot of severe epidemics have originated from biological invasions. We can take the example of the appearance of the plague bacillus which, coupled with the development of the allochtonous populations of black rats and their fleas, considerably reduced the human population of Western Europe in the Middle Ages (Audouin Rouzeau & Vigne, 1997, Audoin Rouzeau, 2003). More recently, at the end of the 19th century, the introduction of the ‘Tsetse’ fly on ‘Principe’ Island off the coast of Africa, the vector of the parasite responsible for sleeping sickness, reduced practically to nil the human population of this island in less than twenty years (Lapeyssonnie, 1988).

At the beginning of the 20th century, following a shipwreck, the Norway rat disembarked and settled on the island of ‘Trielen’, in the ‘Molène archipelago’, at the tip of Brittany. In 1996, examination of virtually all individuals in the population of red rats, collected during an eradication operation, revealed that it contained nine species of endo-parasites. None of them were previously known to parasitize rodent, but they were known to infest various indigenous species of the island, including some marine species. New host-parasite couples were thus formed in less than a century on this island (Pisanu, 1999). What are the possible consequences of the emergence of a new parasitic reservoir on indigenous fauna, even on human or veterinary health? This question has no clear answer at the moment, deserves further research (Pascal *et al.*, 2006).

III.3. Biological Invasion and Biodiversity

Biological invasions are currently considered the main cause of biodiversity loss across the globe and as the main cause of the trivialization of fauna and flora (Diamond, 1989; Vitousek *et al.*, 1997; Hulme, 2003).

Some examples from around the world demonstrate the extent to which biological invasions can have a significant impact on biodiversity:

In Africa, between 1954 and 1957, the Nile perch *(Lates niloticus)* was introduced into Lake Victoria (68,000 km²) in order to develop fishing. By 1970, this species has eliminated 99% of the endemic species of the lake (Witte *et al.*, 1992 & 1995), are causing a drastic simplification of the food chain and a cascade of changes in the operation of the lake ecosystem (Lévêque, 1997).

In New Caledonia, the island that is among the ten "hot spots" (hot spots) Global biodiversity (Myers, 1988), the introduction of the rabbit and deer *Cervus timorensis* russa (Bouchet *et al.* 1995) resulted in the extinction recorded in 1995, *Pittosporum tanianum*, an endemic tree of the sclerophyllous forest.

III.4. Biological invasion and insularity

Insular species are particularly sensitive to biological invasions (Moors & Atkinson, 1984; Lever, 1994). Between 1600 and present, extinctions in insular environments accounted for 93% of amphibians and reptiles (Honnegger, 1981); 93% of birds (King, 1985) and 81% of mammals (Ceballos & Brown, 1995).

Insular ecosystems are undoubtedly the best indicators of the impact of biological invasions. The fauna and flora of islands are indeed little diversified, compared to those of the ecosystems of the nearby continents. Their trophic chains are simplified and host a significant number of endemic species (Nunn, 1994; Whittaker, 1998). These species have long evolved without undergoing selection pressures induced by continental species. In particular, they have gradually lost much of the morphological, chemical and behavioral defenses to allochthonous species (Brown 1997, Kress 1998, Billing 2000, Atkinson 2001).

In general, introductions have led to a very large number of plant and animal species disappearing in insular environments (Bell, 1978, Cox 1999, Bird Life International, 2000). Numerous plant and animal species have been introduced on the islands, but these are the introductions of mammals that are currently the best documented (Ebenhard, 1988; Atkinson, 1989; Feed 1994; Vitousek *et al.,* 1997). These islands and islets are devoid of native mammals except bats, two insectivores, the crocidure Zimmermann in Crete, *Crocidura zimmermani,* and crocidure Sicilian *Crocidura sicula,* currently in Sicily and Gozo (Vogel *et al .,* 2002) and a rodent, *Mus cypriacus,* Cyprus (Bonhomme *et al.*, 2004; Cucchi, 2005 Cucchi *et al*, 2006)..

Before Man colonized these oceanic islands, they harbored an indigenous terrestrial mammalian stand composed of endemic species. The mammals introduced by humans to the islands during their colonization were instrumental in removing these native species, causing a total renewal of wildlife (King, 1995; Gargominy *et al.,* 1996; Pascal, 1982.1983).

III.5. History of biological invasion in the world

Since prehistoric Man is the main responsible of voluntary and involuntary introduction of alien species. This introduction has been made in several ways:

- Introduction of non-native species directly. Also via the transport of goods and people.

- Changing the structure of ecosystems: especially in the old world where intensive agriculture has contributed to a trivialization early landscapes and food webs, while large predator stalking and hunting made them disappear. The introduction of dogs, rats, cat, sheep or cattle and goats in many islands has been a frequent cause of rapid decline in biodiversity.

Paleo-ecology shows that natural processes of colonization, took place at the end of ice ages, from areas of refuge. It was a matter of re-colonization of zones emptied of their species by the ice.

The current process of invasion by alien species populations, human-induced involves a sudden or subtle but lasting implementation of these invasive competition with species and communities that have for thousands of years consists of the ecological balance. This anthropogenic process began at the end of prehistory.

We take the following two cases as examples: in the United State of America, the number of introduced plants has increased from 100 in the eighteenth century to over 2000 in the twentieth century. In Europe, the number of insects introduced and identified as settled (breeding and having constituted significant or even significant populations) exceeds 1,000 species in 2005 and fishes more than 270 species (including one Thirds takes place in the years 60-70).

Among the long list of invasive species, we will focus on one of the most harmful invasive species in the world, *Rattus rattus,* or black rats. This mammal, rodent; is a focus of ecologists due to its direct and conspicuous effects on native fauna.

There are three species of rats that represent a threat everywhere and especially a danger for insular ecosystems. These three species are Pacific rat or *Rattus exulans,* Norwegian rat or *Rattus norvegicus* and the black rat *Rattus rattus.* These three commensals colonized at least 82% of the 123 major groups of islands (Atkinson, 1985).

The black rat had the most harmful impact of these three species (Lever, 1994). A well-known example of the impact of black rats on indigenous vertebrate communities is their introduction around 1964 on Big South Cape Island, New Zealand, where they caused the loss of three endemic birds, complete extinction of two other species of birds and a species of bat in less than two years (Courchamp *et al.,* 2003)

III.6. History of black rat introduction in Mediterranean:

The oceanic form of *Rattus rattus,* is origin of south of the Indian peninsula (Sri Lanka) were introduced to most of the islands of the three main oceans (Yosida 1980). Although a representative of the oceanic form dating back to 20000BP (Before Present) was identified in the Middle East (Chernov 1968), the black rat does not appear to have reached the Mediterranean before 8000BP (Palestine) or 3500BP for Mesopotamia (Erynck 2002). Then, during the Roman period, taking advantage of the rise of human and commercial exchanges, it would have been largely transported on the shores and islands of the whole Mediterranean basin, as well as in continental Europe, (Armitage, 1984, Audouin & Vigne, 1996), traveling by boats. The implantation of the black rat in Western Europe seems to have taken off since the eleventh century, when the most devastating events of the plague were raging (Audouin R., 1999). Its spread from Europe to the Atlantic and Indian oceans began sporadically at the end of the 15th century with the period of great discoveries, and then intensified, especially in the Pacific (Atkinson 1985; Martin *et al.,* 2010)

III.7. Why study invasions by rats?

Rat’s effects of on island fauna sometimes take on dramatic proportions, leading very quickly some endemic taxa to total extinction. One of the most striking examples is the case of Big South Cape Island in New Zealand. Accidentally in 1964, black rat caused the disappearance of more than 40% of the local avifauna and complete extinction of a species and a subspecies of bats in two years. Similarly, the invasion of Lord Howe Island in eastern Australia by black rat following the stranding of a steamer in 1918 resulted in local extinction of five species of forest birds in five years (Atkinson 1985). In 1943, two species of birds disappeared definitively from Midway Island, 18 months after the arrival of the black rat by military cargo (Martin et al., 2010).

IV Black Rat

IV.1 Description

Class	Mammalia
Order	Rodent
Family	Muridae
Kind	*Rattus*
Species	*rattus*

Figure 1 *Rattus rattus*

Rattus rattus is generally called black rat, roof rat or ship rat. In the past they used synonymously *Mus rattus* (Linnaeus, 1758);*Mus Alexandrines (Geoffroy,* 1803); *Musculus furgivorus* (Rafinesque, 1814); *Mus novaezelandiae* (Buller, 1870); And several other appointments (Innes 2005). In terms of evolution, the kind *Rattus* appeared there 2-3 million years (Aplin *et al.* 2003; Shiels *et al, 2014.).*

The ancestral form of the Asian rat houses, *Rattus tanezumi,* with 42 chromosomes, is native of Southeast Asia. This initial range is much more oriental than that of the black rat which comprises populations of 38 or more rarely 40 chromosomes, corresponding to a succession of one or two chromosomal fusions (Pascal *et al.,* 2006).

IV.2. Distinctive features

It exists several features that can be used to distinguish the black rat *Rattus rattus* from other invasive rodents (*R. exulans, R. norvegicus* and *Mus musculus)* such that the length of tail and ear. The tail of *R. rattus* is about 27 ± 2 mm (± 1% or 16%) longer than the rest of his body (Innes 2005, Shiels, 2010), while the three other rodents mentioned above if all Tails approximately equal to or less than the length of their bodies (Atkinson & Towns 2005). The length of the tail and the elegant shape of the body may be linked to their adaptation for arboreal activity, which is more common than other invasive rodents (Shiels 2010, Foster *et al.,* 2011, King *et al,* 2011). The length of the ear of the black rat (between 19 and 26 mm) is usually the largest of the four main invasive rodents, including *R. exulans* (15.5 to 20.5mm), *R. norvegicus* (from14 to 22mm) .*R. exulans* ears are like those of *R. rattus,* they cover the eye when pulled forward, and the hair purposes ears do not extend beyond the edges of the ears, which distinguish them those of *R. norvegicus* and *Mus musculus* (Shiels *et al.*, 2014).

IV.3. Ecology of *Rattus rattus* introduced on islands

On islands, black rats occupy very varied environments such as agricultural, forestry and coastal environments. *Rattus rattus* is considered the most generalist species in the selection of its habitat, with a preference for dry and temperate habitats. It is a very agile arboreal rodent but easily adopts a terrestrial way of life by nesting, sheltering and breeding in burrows or under bushes (Musser & Carlton 2005). In Mediterranean region, where the outside temperature remains soft during the year, it lives outside the habitations and has established strictly non-commensal populations (Faugier & Pascal 2006).

IV.4. Physiology and behavior

Physiological and behavioral adaptations of *R. rattus* have likely aided in its successful establishment in insular ecosystems. Black rat has a relatively high metabolic rate and keen sense of smell. They are agile, move beneath vegetation cover rather than in exposed areas, use aboveground habitat (trees) more than other introduced rodent species, and typically move food items upon collection but generally do not store them. An important point for rat control and eradication programs is that rats typically suffer from "neophobia," which is fear of new objects; it occurs when there is a change in an otherwise familiar situation (Barnett 1963, Clapperton 2006).

Rodents have large surface areas relative to their volume, which results in greater heat losses from their bodies when compared with larger mammals. Thus, to maintain their body temperatures, rodents have high metabolic rates. Some rodents must find and eat up to 70% of their body weight each day to support their metabolic requirements (Alderton 1996).

Black rats are smart, good climbers, excellent jumpers, and adept swimmers (Meehan 1984, Innes 2005, Foster et al. 2011, King et al. 2011). When *R. rattus* was compared with *R. norvegicus* in New Zealand, Foster et al. (2011) determined that *R.* rattus was moving faster and more agile, more easily overcame obstacles, was less dependent on footholds, was less likely to fall, and could more easily reach unsupported ends of small branches (Pitt et al. 2011). Black rats have been known to swim 300 – 750 m to colonize adjacent islands (Innes 2005). Determination of the home range of *R. rattus* helps elucidate the rat distribution and preferred habitats, and intervenes in the strategies against this rodent such as spacing traps and bait (Shiels et al., 2014).

IV.5. Reproduction and population dynamics

Rattus rattus density can vary widely between different sites and different islands. Resource availability, rainfall, plenty of predators and disease are factors that can potentially influence the population dynamics of *R. rattus.* Black rats reach sexual maturity between 2 and 5 months. Gestation lasts an average of 22 days. The average number of litters per year is 4-6, each containing an average of 6-8 young. Adults live on average 9-12 months The breeding season lasts from mid March to mid-November (Shiels *et al.*,2014).

V. Impact of black rats on invaded ecosystems

The period of great discoveries, which began in the late fifteenth century offered black rat as, later, to its congener the Norway rat, *Rattus norvegicus*, the opportunity to conquer in commensal of Man, America, Africa and Australia, but also many archipelagos, islands and islets from all regions of the world, including the sub-Antarctic zone, only the polar regions of the two hemispheres escaped this invasion. Thus roof rats and Norway rats, through the Europeans and the Pacific rat, *R.exulans* by the Polynesians, constitute the "infernal" trio which one or the other components, and in some cases three, have been introduced by humans, intentionally or not, in over 80% of the world's islands (Pascal *et al.*, 2006).

These introductions continue today, as evidenced by the constitution over the past decade of a black rat population on the isolated Clipperton Island, located in the Pacific over 1000 km from the nearest land, Mexico. Archeology and recent studies show the deep disturbances that all these invasions have created within insular ecosystems, which are particularly vulnerable to this kind of aggression. Rodents have caused or contributed to the disappearance of many indigenous or endemic taxa, including vertebrates, but also plants, terrestrial gastropods and insects. This list is certainly not limiting since many taxa have not yet been subjected to detailed studies (Pascal *et al.,* 2006).

Because of their opportunistic behavior, polyphagous regime and ubiquitous distribution, the three species of rats introduced have always exerted and continue to exert significant impacts on the indigenous fauna and flora communities of islands to which they were introduced. Rats are predators of a wide spectrum of species groups, such as invertebrates (Clout 1980 Ruffaut Gibbs & 2003; & Myer Shiels 2009), reptiles *(*Towns*1994;*. Towns *et al,* 2007), amphibians (Whitaker 1978), terrestrial birds (Penloup *et al.,* 1997; Innes *et al,* 1999) and marine (Jones *et al,* 2008), and flying mammals (Fellers *2000).* Their impacts on native island fauna are also manifested through competition processes for resources with small mammal (Harris 2009) and bird (Clark, 1981) communities, and the transmission of pathogens against which wildlife native is not suitable (Wyatt *et al.,* 2008).

V.1. Impact on native flora

Native flora of islands is affected by the herbivore behavior of rats (Clark, 1981), especially through the seed predation and impaired regeneration of seedlings (Allen *et al.,* 1994; Shaw *et al.,* 2005). The deleterious effects of rats on island communities can be promoted and enhanced by the presence of an alternative food resource that would allow rats to survive on islands when the primary indigenous prey is temporarily absent (rabbits introduced to Whale Island, new Zealand*:*. Imber *et al,* 2000; case of green turtle emergences on Surprise island, new Caledonia*.* Caut *et al,* 2008; Martin *et al, 2010).*

V.2. Impact on native wildlife

Effects of rats on island fauna sometimes take on dramatic proportions, leading very quickly some endemic taxa to total extinction. One of the most striking examples is the case of Big South Cape Island in New Zealand. Accidentally in 1964, the black rat caused the disappearance of more than 40% of the local avifauna in two years, as well as the complete extinction of a species and a subspecies of bats. Similarly, Lord Howe Island's invasion of eastern Australia by the black rat after the landing of a steamer in 1918 resulted in the local extinction of five species in one year, Forest birds (Atkinson 1985). In 1943, two species of birds disappeared definitively from the island of Midway, 18 months after the arrival of the black rat by military cargo. Rats have caused or contributed to the local disappearance of other animal taxa, including vertebrates. However, although the causal relationship between the arrival of the rat and the extinction of island species appears clear in the three examples cited, most cases of local extinctions attributed to rats remain circumstantial and based on the discovery subfossil remains and comparing past and present distribution patterns (Towns *et al.,* 2006; Ruffino & Vidal, 2010). In addition, invertebrate extinction rates that are partly or wholly associated with rat effects are undoubtedly underestimated due to poor knowledge of invertebrate fauna on some islands and lack of data on distribution patterns most invertebrate species (Martin *et al.,* 2010).

V.3. Impact on human and veterinary health

Black rat is known to be a vector and reservoir of many pathogens that can alter human and veterinary health. His role as major reservoir in the medieval epidemics of plague in Europe, a moment in question in the 1990s, is now widely supported again, not least by the recent removal of the chip Man, *Pulex irritans*, the list of potential vectors of the disease agent (Pascal *et al.,* 2006).

The possible impact of the pathogens carried by black rat on the indigenous fauna and largely unknown, the epidemiological work devolved to it has been confined to urban and peri-urban areas. The only recent work conducted in France in this area was carried out on the island of Ouessant, about 33 adults on a sample of 60 black rats, six tested positive for the bacterium *Leptospira interrogans* responsible for human leptospirosis , also known as disease sewer workers (Pascal *et al.,* 2006).

Overall, understanding the determinants of extinctions is complicated by the synergistic and cumulative effects of other risk factors; effects of other introduced predators or competitors, human impact, climate change (Martin et al., 2010**).**

VI. Eradication program

VI.1. Need for eradication

From the 15th century, invasive species have been partially or totally responsible for species extinction (Maggs *et al.,* 2015). Therefore, control programs of these species, especially eradication of mammals from islands have increased in recent decades (Courchamp *et al.*, 2003; Howald *et al.*, 2007). In insular ecosystems, invasive rodents colonize 90% of the islands and have become a major threat; due to their omnivorous behavior and the fact that they can adapt to different habitats.

Faced with this problem, and in order to protect insular biodiversity and slow down the rate of extinction, environmentalists, government officials, researchers, managers and NGOs have chosen eradication campaigns as powerful conservation tools (Donlan *et al.*, 2003).

Eradication is the complete removal of all the individuals of the population, down to the last potentially reproducing individual, or the reduction of their population density below sustainable levels (Courchamp, Chapuis, & Pascal, 2003). This is generally, although not always, the best strategy for islands, but it is often limited by its high cost, logistically as well as economically.

VI.2. History of rodent eradication

It was not until the late 19th century that naturalists in New Zealand and Australia are beginning to understand the impact of invasive species on native populations. Between the 1950s and 1960s ecologists began to pay more attention to these rodents and their impacts on islands.

VI.3. Strategies for the eradication of non-native rodents

The strategic choices relate to the technique (s) of eradication, how they are applied and the timing of their implementation. The most widely used techniques for combating allochthonous animal species are of two kinds: mechanical (physical) by trapping or chemical through the use of chemical bait based on anticoagulants molecules. There is also the integrated method that combines mechanical trapping and chemical bait. Eradication technique, application modalities and implementation schedule are modulated by the geography and climatology of the site, the local biology of target species, of native species, and the objectives pursued by the manager.

- **Chemical control:** Rodenticides, such as those containing the anticoagulants diphacinone or brodifacoum, have been used on many islands to control *R. rattus*; one benefit over trapping is that rodenticide bait can simultaneously affect many rats over longer periods than a single baited trap. Rodenticide baiting is also generally less labor-intensive than trapping. Anticoagulants became the toxicants of choice for controlling rats beginning in the 1950s and were applied by placing the poison in plastic baggies and tossing them into agricultural fields and surrounding habitat (Shiels, Pitt, Sugihara, & Witmer, 2014).

- **Trapping:** Eradicating a population of rodents in traps is possible but requires a massive, constant and rigorous trapping pressure for a month or more. This method has the advantage of being able to follow in real time the dynamics of the disappearance of the individuals of the target species. It also allows a very complete collection of geo-referenced information about the target population. The information collected to date on the use of this eradication technique relates to morphology, reproduction, diet, parasitology, bacteriology, genetic and social structure and even microevolution mechanisms, artwork. The use of this information is of interest to basic research and to the manager. The use of genetic information to determine the causes of an eradication failure (Abdelkrim *et al.*, 2007).

- **Integrated method:** These are mechanical trapping coupled to chemical control has been developed and used on the occasion of thirty Eradications of island populations of rodents and carnivores (Lorvelec & Pascal, 2005). On the environmental front, it has the advantage of reducing the risk of indirect poisoning of non-target species by more than 90%, trapping allowing the catch in 12 days and, consequently, the island's withdrawal, From 90 to 100% of the individuals of the target species.

VI.3.1. Anticoagulants and rodent control

Since effectiveness is directly linked to the consumption of the substance by rodents, the control strategy must guarantee the consumption of the bait. The most common commensal rodents, the black rat, the brown rat and the domestic mouse, are capable of developing food aversion. That is, they can associate the consumption of a new food source with symptoms of intoxication occurring shortly thereafter. Anticoagulants help to avoid food aversion, simply because of their delayed action: this allows the first individuals consuming the baits to put the colony in confidence to come and consume in the same place. Once a rat is accustomed to a food source, it will return to feed, baiting from anticoagulant active substances is based on this same principle. It is therefore necessary, and normal, for the success of the treatment to observe signs of efficacy only several days after the consumption of the baits (between 4 and 6 days on average).

VI.3.2. Anticoagulants action mode

Anticoagulant active substances used for raticide are exclusively substances whose target is the cycle of ‘K vitamin’. They act by inhibition of the recycling of K vitamin epoxy to K Vitamin directly in the cycle. The active substances bind to the enzymatic receptors 'Epoxide Reductase' or VKORC1 until saturated. These are therefore no longer available to recycle vitamin K epoxy to K Vitamin.

Epoxy vitamin K is eliminated naturally and the natural stock of K Vitamin is depleted little by little due to the absence of recycling. When the initial stock of K Vitamin is depleted, the cycle stops. Due to the absence of a component necessary for their synthesis, there is no longer any production of coagulation factors.

The organization draws on its reserves to meet its needs. The stock of coagulation factors present makes it possible to compensate for shortfalls for an average of 4 to 6 days. Subsequent signs of hypo-coagulation are rapidly observed. In the absence of treatment, the hypo-coagulability will lead to irreversible hemorrhage and the death of the rodent.

This action mode explains the delay of action, which is normal and intrinsic to all anticoagulant active substances. The anticoagulant rootstocks are therefore adapted to the control of rodents, because they make it possible, as a result of this delay, to bypass the phenomenon of food aversion (or neophobia).

VI.4. Consequences of eradication of allochthonous populations on indigenous fauna

An eradication operation is a political decision in the broad sense and represents an act of management. This action is therefore subject to the identification of clearly defined objectives. Deciding on its failure or on its success requires that we have the means to verify whether these objectives are achieved or not. Only the comparative approach makes it possible to answer this question (Pascal & Chapuis, 2000). It consists of comparing pre-eradication information's - qualitative ones, such as inventories of fauna and flora, and quantitative ones, such as numbers or abundance indices of various taxa, their spatial distribution, Success of reproduction, etc. With those obtained from post-eradication phase. The validity of the conclusions resulting from these comparisons is based on the relevance of data acquisition protocols and the rigor of their collection (Pascal *et al., 2006).*

In addition, before, during and after eradication, observations are made to identify and quantify possible perverse effects that may result, on the one hand from the implementation of eradication tools; on the other hand from the disappearance of the target species to date, no such effects have been reported.

VII. Kuriat Islands

VII.1. Islands Location

The two islands are located in Monastir Gulf, 19 km from the coast, the Great Kuriat (Kuria Kbira) is at the point of: N 35.7969 / E 11.033 and the Little Kuriat (Kuria Sgira)at: N 35.7675 / E 11.0083 (Figure 2).

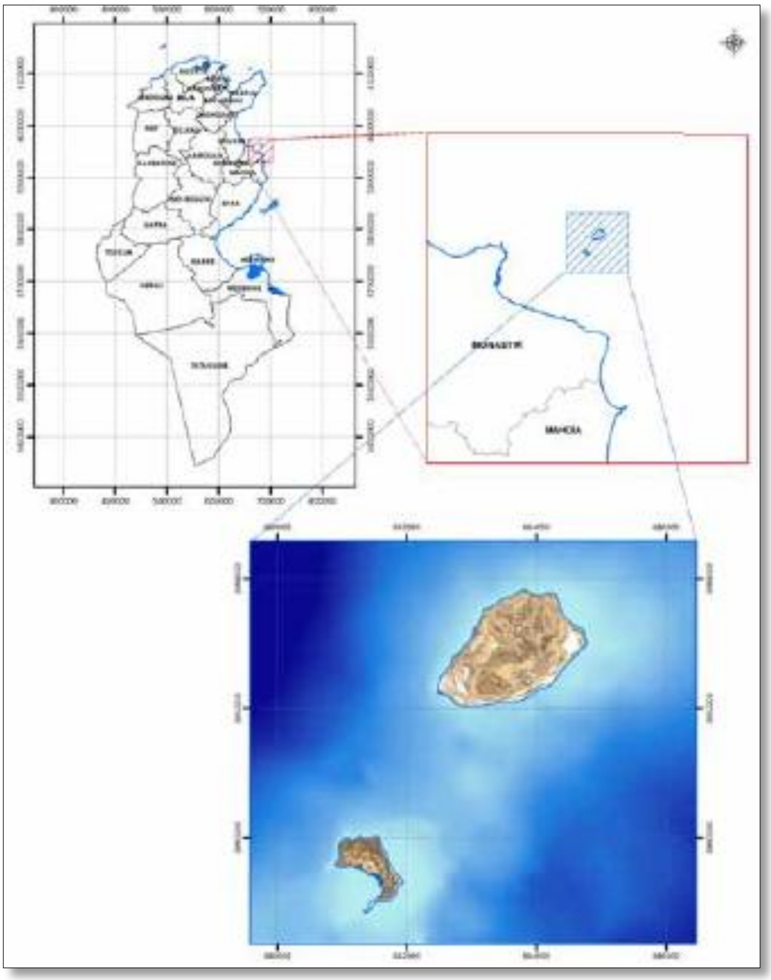

Figure 2 Location of the Kuriat Islands (RAC / SPA, 2015)

VII.1.1. Great Kuriat

Great Kuriat has an ovoid shape, covering 270 ha with a length of 3.5 km and a width of 2 km (Figure 3). The altitudes vary between -1 m and 5 m. There are three large ‘Sebkha’: one in the east, another in the south-west and west, a construction in the north of the island, in the highest region, a lighthouse dating from 1888, not very far from the latter, there is a ‘marabout’ "Sidi Sâad". This island is monitored by military, but that doesn’t stop summer visitors as well as fishermen to visit it.

Figure 3: Great Kuriat (Kuria Kbira)

VII.1.2. Little Kuriat

Little Kuriat has a quasi-triangular shape and covers 50 ha (Figure 4). It is also noted that it has low altitudes (Aguir, 2011). Thanks to its sandy beach which extends over 1000 meters long, the island is very frequented by tourists especially during the summer period, around 45,000 people per year (Riviere & Lo Cascio, 2014).

Figure 4: Little Kuriat

VII.2. Kuriat Island's Biodiversity

Kuriat Islands are characterized by their rich fauna and flora and a significant ecological potential. They possess a natural heritage endowed with a great richness floristic and faunistic which has undergone modifications due to human presence.

VII.2.1 Sea turtle Nesting

Three marine turtle species are observed in the Tunisian sea. The green turtle *Chelonia mydas* is rare, the leatherback turtle *Dermochelys coriacea* is regularly observed and the loggerhead *Caretta caretta* is common and reproduces on some beaches.

Kuriat Islands are considered the most important nesting site of sea turtles in Tunisia. Little Kuriat has a total of 800 m of sandy beach situated in the north-eastern part of the island; the rest of the coastline is rocky or marshy. Almost one third of the great Kuriat shoreline is rocky and large deposits of sea grass (*Posidonia oceanica*) detritus further restrict the accessible nesting sites particularly in the south and the south-western beaches. The principal nesting beach lies on the western coast and is almost 900 m in length. Great Kuriat is a military zone so it is forbidden to be there at night, while Little Kuriat is highly frequented by tourists and plays host to hundreds of day trippers.

Although most nesting of Mediterranean loggerhead turtles is localized in Greece, Cyprus, Turkey and Libya, 'minor' nesting sites exist in other countries and their protection is desirable because they can give an appreciable contribution, both in number and in genetic diversity. Researchers concluded that nesting numbers at Kuriat (Figure 5), although very small, are stable and increasing and, at least in the nesting sites, subject to high levels of protection (Casale P., 2010).

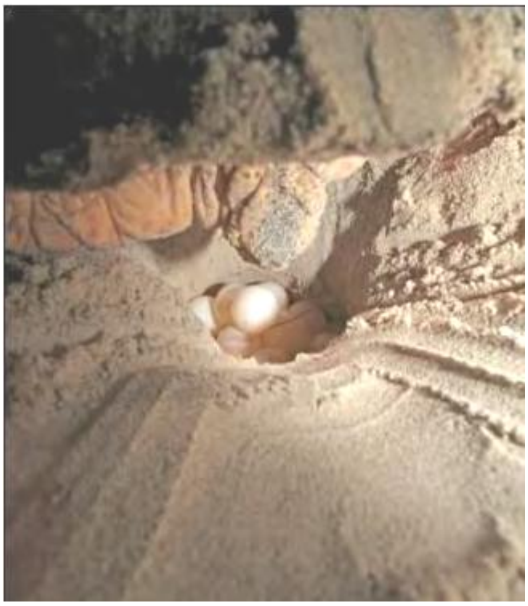

Figure 4 Depposting turtle's eggs in a nest, Kuriat Islands (CAR/ASP, 2015)

During baby turtles emergence (Figure 6), the scientific team of sea turtle monitoring on Little Kuriat have registered some cases of baby Caretta caretta attacked by black rat (Figure 7).

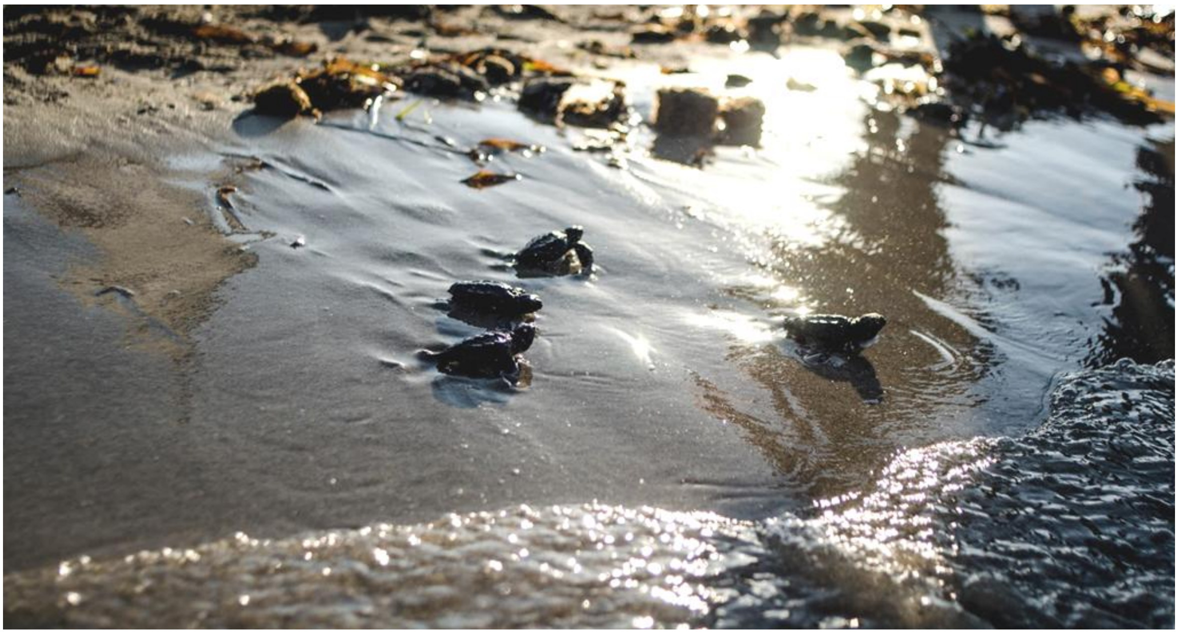

Figure 5 Caretta caretta babies emergence

Figure 6 Baby sea turtle attacked by black rat, Little Kuriat, 2013 (CAR/ASP, 2015)

VII.2.1. Vegetation

During 1994, a first naturalist mission was organized on Kuriat Islands to discover the biodiversity on this site, some of which was interested in vegetation. After 20 years, another naturalistic mission was organized for the census of plant biodiversity within the framework of the PIM initiative for Little Mediterranean islands. None of these studies was subject to scientific publication (Abid, 2016).

VII.2.2. Rabbits

Kuriat Islands are islands of the rabbits, hence the name of the Little Kuriat "Conigliera" which means "rabbit" (Sayadi, 1979). The indicators show the presence of rats and wild rabbits which, like the Great Kuriat, were introduced voluntarily (Riviere & Lo Cascio, 2014).

Figure 7: European rabbit on Kuriat Island

VII.2.3: Goats

A goat's herd (between 200 and 300) on Great Kuriat (Figure 8). Since the emergence of this herd about 10 years ago, the landscape has completely changed and a bio-ecological catastrophe is apparent for those who know very well this site, especially that these animals are completely free. For example one of impacts is the beginning of *Pancratium maritimum* disappearance from the sand dunes. This plant is known by its beautiful flowers and its characteristic smell. This plant is highly appreciated by goats which has caused its complete disappearance (CAR/ASP, 2015).

Figure 8 Goat's herd in Great Kuriat

VII.2.4. Herpetofauna

Several reptile species have been reported on the islands during the naturalistic mission of the Little Mediterranean Islands initiative on Kuriat Islands (Table 1).

Table 1: Reptiles Kuriat Islands (River & Lo Cascio, **2014)**

Cash	Great Kuriat	Little Kuriat
Hemidactylus turcicus	+	+
Tarentola fascicularis	+	-
Trachylepis vittata	+	+
Chalcides ocellatus	-	+
Mesalina olivieri	+	-
Malpolon insignitus	-	+
Caretta caretta	+	+

+: Presence -: Absence

VIII.3. Management / Conservation

Tunisia pays particular attention to coastal zones and their integrated management due to their economical and ecological importance, supported by commitments made by Tunisia under the Protocol to Barcelona Convention, the Rio De Janeiro Agreements, Agenda 21 of the Mediterranean Sea (1994) and Act No. 2009-49 of 20 July 2009, on marine and coastal protected areas, which describes these areas as "the areas designated by law for the protection of natural habitats, flora, Wildlife and marine and coastal ecosystems of particular interest from a natural, scientific, recreational, educational or economic point of view, which constitute a remarkable natural landscapes to be preserved". Tunisia has five protected marine area sites, two of which are already in existence: the Galite archipelago, Zembra and Zembretta, the others are being set up (Kerkannah, the coast between Cap Negro and Cap Serrat and Kuriat islands).

Kuriat Islands, Cap Negro and Kerakannah are very sensitive regions and very rich in terms of environmental richness. This contradiction is reflected in various pressures such as illegal fishing, pollution and invasive species emergence which threaten the stability of the ecosystem. For the protection, rehabilitation and enhancement of natural littoral areas, a national program for the protection and management of sensitive areas has been developed (RAC / SPA, 2014).

In this context, APAL and RAC/SPA have taken the lead in developing a management plan for these regions as part of the ‘MedMPAnet’ project illustrating the different objectives and reasons for safeguarding these areas. The reasons for the creation of MPAs are mainly to protect the natural and cultural heritage. Moreover, such protection makes it possible to control the management of the littoral zone. Once preserved, benthic communities will be repopulated (RAC / SPA, 2014).

Particular attention was paid to Kuriat Islands. These islands are a home to many notable species such as *Caretta caretta*, *Pinna nobilis*, *Posidonia Oceanica*. Kuriat play the role of a nesting site, a nursery seen the significant presence of posidonia barrier reefs around this archipelago and home to many species of migratory birds (RAC / SPA, 2014).

The protection of such natural wealth is essential. In order to do so, all possible sources of disturbance and destruction, such as illegal fishing, fishing gear, boat mooring, pollution, etc. must be eliminated immediately. And encourage artisanal fishing techniques while involving the different stakeholders in this strategy, thus ensuring the sustainable management of natural resources and the preservation of biological and economical heritage (RAC/SAP, 2014).

Material and methods

I. Black rat eradication strategy on Kuriat Islands

Rat eradication strategy on Kuriat Islands is based on our results from pre-eradication phase, each point being taken into account progressively to define the final strategy of eradication:

We showed an important impact of rats on the whole ecosystem, in particular on sea turtles (Figure. It was necessary to start eradication. Due to the short distance separating the two Kuriat (Figure 9), 2.5 Km, we decided to eradicate black rat from both islands to minimize the chances of re-invasion.

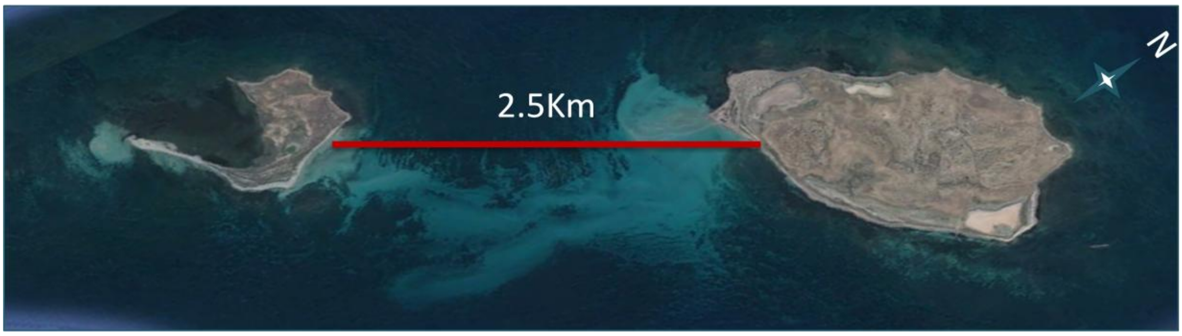

Figure 9 : Short distance separating the two Kuriats

Despite recently improved efficiency, especially concerning eradication of rodents from larger islands, trapping methods remain logistically difficult, and are costly in material, manpower, and time. Poisoning have a high cost efficiency on large and/or poorly accessible islands; its rapid effect is also advantageous. The need to distribute the lethal devices by hand and on foot over the whole island also influenced our choice towards poison baits over traps.

The common spacing between baits to eradicate ship rats from islands is around 25 m, based on their typical home range size (Taylor and Thomas 1993). Therefore the strategy of this eradication is based on devising the two islands on four different zones, each one is devised on parallel lines separated by 25 m (Figure 2), and the baits were distributed all over those lines distant also by the same common spacing.

Figure 10 : The layout of lines of the bait's stations

The total area of Kuriat islands is 340-ha, the Little island was considered as the yellow zone ‘J’, 70-ha. However the big island, 270-ha, was devised on three zones; the green zone ‘V’, the blue zone ‘B’ and the orange zone ‘K’.

Despite its advantages over trapping, poison often reaches non-target species. Numerous birds have been killed by either primary or secondary poisoning during field use of the poison all over the world. An ecosystem approach to eradication must provide a balance between efficacy and the risks to non-target species in the choice of poison (Zavaleta et al. 2001). Bromadiolone is lethal to both rats (Mathur 1997; Brown and Singleton 1998). The choice of 20-g poison cubes of bromadiolone involved minimal risk to other species because it is known to be less toxic to invertebrates and reptiles and is unattractive to marine birds.

The main baits used during this campaign of eradication, were Crack Rodent 20-g cubes based on Bromodiolone (Figure 11).

Figure 11 : Crack Rodent

Those baits were distributed attached to an iron wire which is attached to a PVC tube (Figure 12). This kind of tube has so many advantages such as:

- It allows us to follow up the disappearance of the rodent by following the state of consumption.
- Reduce the availability of baits to non-target species.
- Protect baits from bad weather.
- Recovery of unused baits at the end of this operation.

Figure 12 : Bait's station

I.1 Implementation of bait's station

This phase started the 16th of September 2015, by that time, they were more than 35 individuals distributed on the big Kuriat divided on 4 groups, three of them were responsible for distributing the stations all over the lines (Figure 13), trying to respect the required spacing (25m).

Figure 13 : Implantation of bait's stations

The first group was responsible for preparing the stations (Figure 14), food and taking care of the logistic requirements (boats, medicaments, shelter…).

Figure 14 : Logistics team

Each station placed was identified as the following picture:

Figure 15 : Reference code of the stations

'V' correspond to the zone, '29' is the number of the line and finally '6' the order of the station on that specific line (Figure 15).

I.2 Control missions

Just after the implantation phase, we started the phase of monitoring of this campaign, which consist basically on following up the rate of consumption of baits. All along the first 50 days, the monitoring was daily, which consist on registering the rate of consumption (25%, 50%, 75% or 100%) (Figure 16) of each bait controlled and replacing it by a new one.

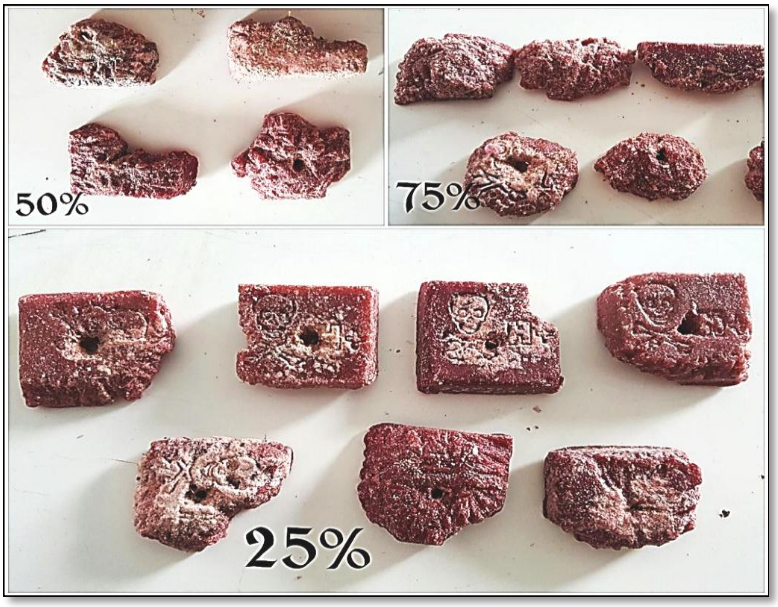

Figure 16 : Different rates of consumption of baits

This phase started from 22nd September until 15th of November, to achieve our goal we needed an average of four volunteers by zone (Figure 17). By mid November we reached a high percentage of zero consumption.

Figure 17 : Monitoring the consumption of baits

After this daily monitoring we moved to weekly and then monthly monitoring, which is based on the same rules, but this time we used some other techniques to reveal the presence or the absence of rats. One of those methods is based on mechanical traps (Figure 18).

Figure 18 : Preparing mechanical traps

The principle of their use is to capture individuals of black rat of there is still some of them on the islands but they are raised a behavioral resistance against the baits.

View the intelligence of our target species, we should pay more attention and try more techniques to make sure if we did eradicated or not yet at that phase. So we prepared two of the most attractive recipes, non poisoned baits. One of the recipes is made basically of honey and grains; the second one is made of cheese and sardine (Figure 19).

Figure 19 : Non poisoning baits

The purpose of those non poisoning baits is detecting the traces of incisors of black rat without killing it or capturing it.

II. Post eradication

In addition, long-term monitoring of post-eradication ecosystem is crucial to prevent reinvasion. It is crucial to be able to ascertain that the population has actually been eradicated, down to the very last individual (Morrison et al. 2007). Long-term monitoring would ideally benefit from comparison with nearby ecosystems in which the target alien species has never been present; in order to unambiguously associate the observed changes of the restored ecosystem to the removal of the aliens.

A post-eradication study will be conducted in the long term and its preliminary results published in a few years. The first step of this phase is to implement anti-re-invasion boxes (Figure 20) in their specific zones.

Figure 20 : Rats anti re-invasion box

In this case three to four baits will be attached by an iron wire and locked into this box. This type of bait's box has more advantageous than the other bait's stations used along the eradication phase:

- ✓ Provides more protection from weather conditions.
- ✓ Make the baits inaccessible for visitors.
- ✓ Only accessible for experts who have the box's special key
- ✓ Detect rodent in case of reinvasion.
- ✓ Prevent and decrease the chances of reinvasion

In our case of strategy of this post eradication phase is based on the previous phases, which gave us an idea on the preferable area for black rat. So we implanted those stations along the most frequented coast by all kind of boats (touristic and fishers) and around the most frequented areas by black rat.

The main goals of the anti-re-infestation stations are:

- Reduce the risk of re-introduction of rats and rodents to Kuriat Islands.
- Detect their presence as soon as possible if any rodent n case if they infest the Islands.

Those stations should be carefully implanted (Figure 21), away from sight of tourist and we should register its GPS coordinates so that we will easily check it later on.

Figure 21 : Implantation of black rat anti-invasion boxes (Great Kuriat)

Results and discussion

I-Rats Eradication Progress

Implementation of bait station all over Kuriat island lead to the result bellow:

Zone	Surface (ha)	Density Tubes/Surface (Tube/ha)	Nb. Of bait's stations	Frequence of control
Yellow 'J'	57	7	469	14
Green 'V'	39	21	820	7
Blue 'B'	63	16	991	8
Orange 'K'	128	17	216	8
Tota	288	-	444	-

Little Kuriat, represented by the yellow zone 'J' (57ha), covered by 469 bait's stations, each station was controlled at least 14 times.

Great Kuriat, divided on three zones:

Orange zone 'K' (127.7 ha), the largest zone, include contain 2160 bait's stations, each station was controlled at least 8 times.

Blue zone 'B' (62.86 ha), include 991 bait's stations; each one was controlled around 8 times. Green zone 'V' (39.23 ha), the smallest one, contain 820 bait's stations; each one was controlled at least 7 times.

Total surface covered is 288-ha from 340-ha (Total surface of Kuriat Islands), the 52-ha is represented by 'Sebkha' (four in Great Kuriat and two in Little Kuriat). A total of 4440 bait's stations were distributed all over the 288-ha.

Difference in controls frequency for each station may be related to the difference of surfaces between different zones, switch of volunteers, nature of plants and soil in each zone.

I.1 Daily monitoring

Daily monitoring for each station allow us to follow up bait's consumption, which reflect rat's death-rate (Figure 22).

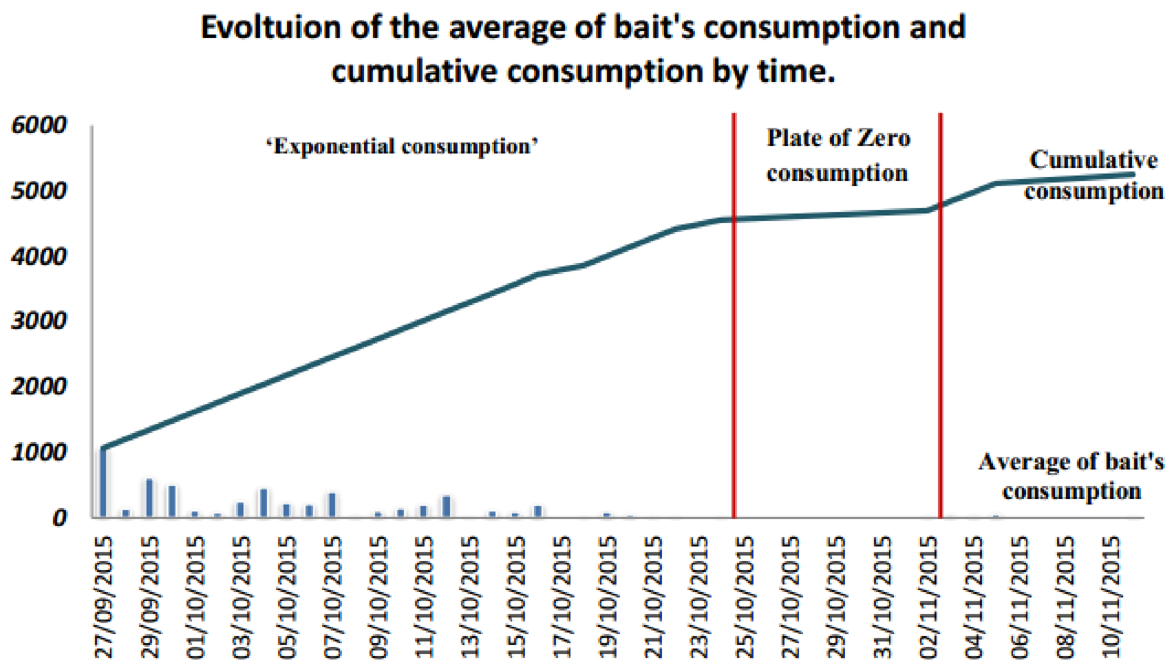

Figure 22 : Bait's consumption supervision

According to the data collected from the daily monitoring, first phase of rat eradication is divided on three different phases:

- Exponential consumption, average of bait's consumption between 100% and 25%, the cumulative consumption curve's slope is large, and keep decreasing by time
- Plate of Zero consumption, the slope is around zero; this could be explained by one of the two following hypothesis:
  - ✓ First sign of rat's successful eradication.
  - ✓ Rat population has gained a behavior resistant.
- Slight increase of bait's consumption; this increase happened during between the 2nd and the 10th of November, at that period Kuriat islands had an important pluviometry which favored conditions for snail, one of the main non-target species that consume our bait founded at that phase.

Registering numerous case of bait's consumption by snail in that third phase is a good argument in favor of the first hypothesis and the plate of Zero bait's consumption is the first sign of successful rat's eradication.

I.2 Indirect estimation of black rat's population in Kuriat islands

Based on data collected through bait's consumption's monitoring, we tried to estimate black rat's population in Kuriat islands.

We considered one rat eradicated only if it consume 5.6-g or more (lethal dose) of the bait. Along this campaign we used 20-g bait; if a rat consumed only 25% of it (5-g<5.6-g) which is less than the lethal dose, the same rat should pass twice 25% of the bait to reach the lethal dose. However, every case of 50%consumption and more are effectively lethal.

Thereby, in order to estimate the total number of rat eradicated from Kuriat islands, we developed the following equation:

$$R= (X*2) +Y+Z+W$$

- 'R': Number of rat eradicated
- X': Number of 25% consumption (Figure14)
- 'Y' : Number of 50% consumption (Figure14)
- 'Z' : Number of 75% consumption (Figure 14)
- 'W' : Number of 100% consumption (Figure 14)

Based on the previous equation we can estime that we eradicate 7049 rat from Great Kuriat and 4147 rat from Little Kuriat.

I.3 Density of black rat's population on Kuriat islands

By dividing those numbers on surface of each island we calculated the density of black rat on the Kuriat island. 59 rats per hectare in the Little island, 26 rats per hectare in the great Kuriat.

Difference between *Rattus rattus*'s population's densities between the two islands can be related to the invasion history; presence of black rat on the Little Island is much more ancient than the one on the Great Kuriat. It could be due to the high frequency of tourist, especially during summer, which offers more food resources for rats.

I.4 Maps of black rat distribution based on estimated densities

Based on the previous results we established the following maps:

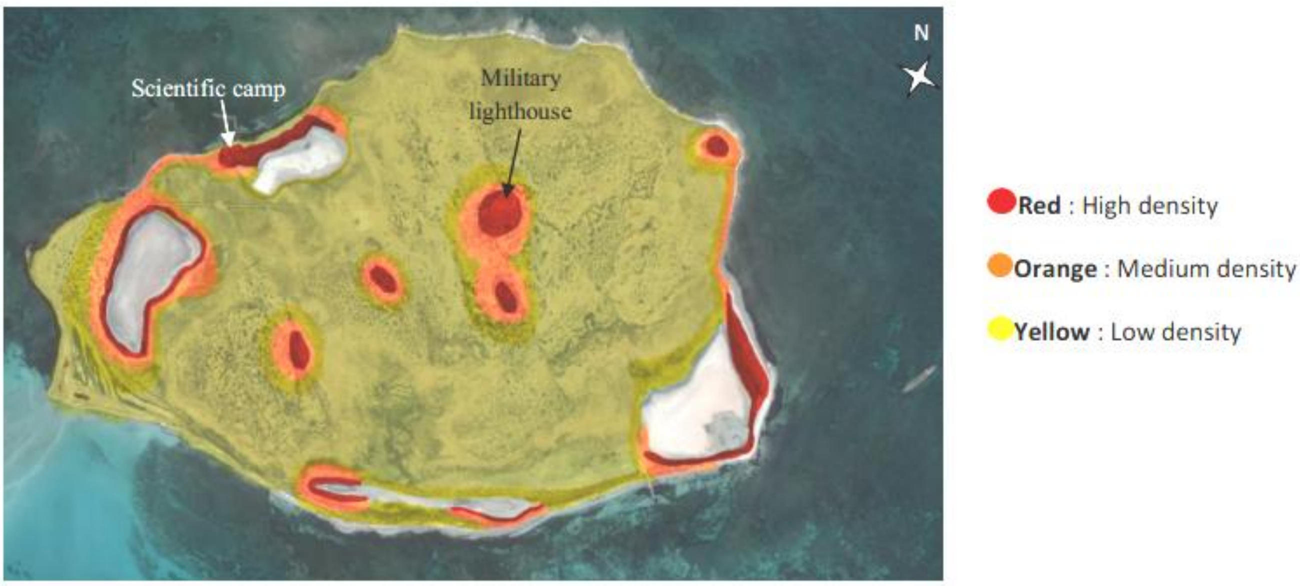

Figure 23: Black rat distribution according to their densities, Great Kuriat

This map represents the black rat distribution on the Great Kuriat Island according to their densities:

- ✓ All around Military lighthouse, one of the main food resources and good shelter for rats.
- ✓ Around the scientific camp attached to the coastal side of the zone 'V''s Sebkha, this one is also a good food resources for black rats on the Great Kuriat.
- ✓ Three other smaller zones dispatched around the other 'Sebkha' and near the coast.

Black rat population seems to prefer areas around 'Sebkha', especially between 'Sebkha' and sea. They are frequent in zones where they can find easily food and refuge (Military lighthouse and Scientific camp).

Based on distribution of vegetation's map on Great Kuriat (Figure24) and on our observation the other two zones are located in zones of high density of *Pistacia lentiscus*, this form represent a very good shelter to escape from raptors and a suitable feed source for rats.

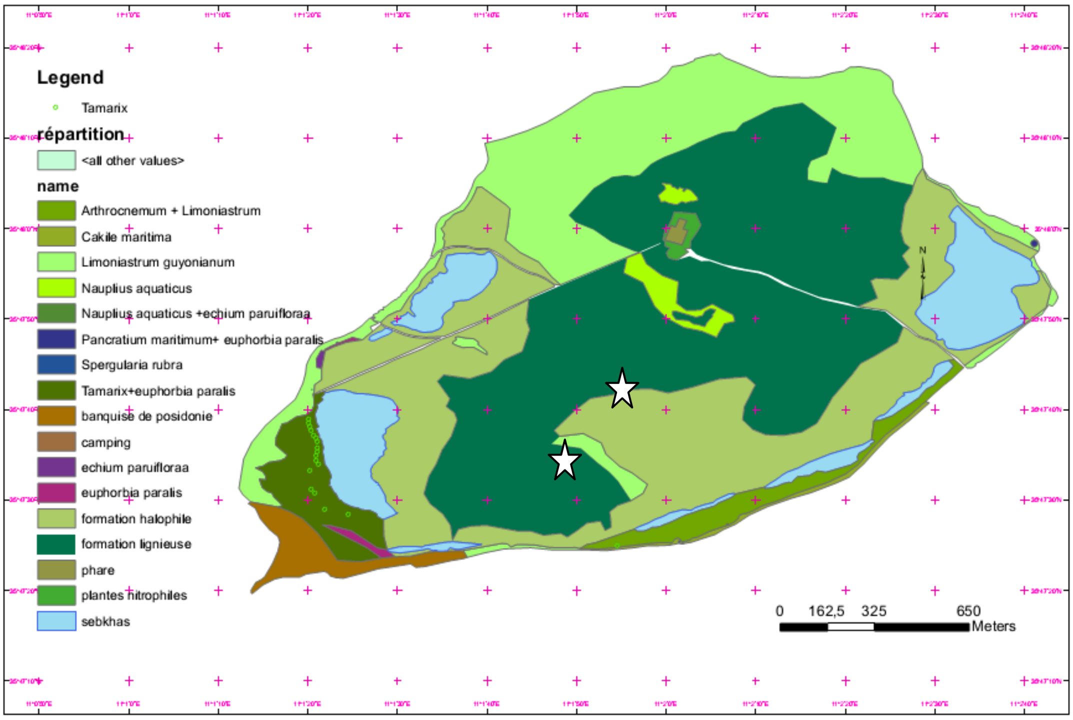

Figure 24 : Distribution of vegetation on Great Kuriat (Abid, 2016)

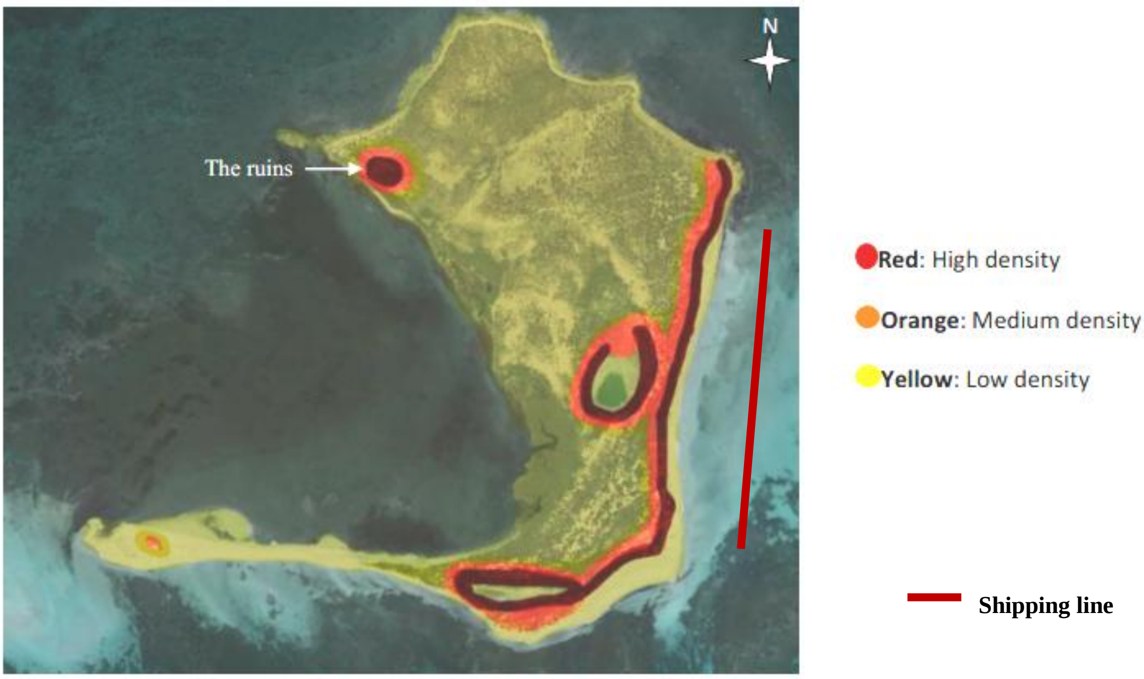

Figure 25 : Black rat distribution according to their density, Little Kuriat

According to the previous map, we noticed that black rat population on Little Kuriat prefer to settle in the coastal zone and also around 'Sebkha'. We found two main zones of high density:

- ✓ The coastal line. This coast is very frequented by tourist during summer.
- ✓ The ruins zone in north-west of the island, which represent a very good shelter for rats.

Little Kuriat is known by hosting tourist all summer and this has a huge impact on food resources abundance for rat population.

We noticed that rats' distribution in the two islands depend on three major factors:

- ✓ Food disponibilty
- ✓ Shelter
- ✓ Around 'Sebkha'

It's totally normal for any creature to search for food and shelter; although preferring the zones around 'Sebkha' is an unfamiliar behavior of rats, the only reason we could observe is the frequency of marine bird nest around 'Sebkha' which can be food resource for rats. We need more researches and deeper studies to understand this phenomenon.

Starting July 2016, Kuriat islands were declared free of rats and till the moment of writing this report no rats had been reported on the islands which we consider successful black rat eradication in Tunisia and in the Mediterranean.

II. Post eradication monitoring

II.1 Anti reinvasion plan

Long-term monitoring in post-eradication ecosystem is crucial to prevent rat reinvasion. It is crucial to be able to ascertain that the population has actually been eradicated, down to the very last individual (Morrison et al. 2007). It is also crucial to be able to detect rats in case of reinvasion. Strategy of post-eradication monitoring is based on anti reinvasion box (Figure 20).

Based on rat distribution according to their density’s map and boat’s shipping map (Figure 25) around Kuriat we proposed the following distribution map of anti reinvasion box’s (Figure 26, Figure 27).

Figure 26 : Anti re-invasion boxes's distribution map, Little Kuriat

Taking into consideration rat distribution according to their densities map we suggested to distribute the boxes among the touristic coast to the ruins.

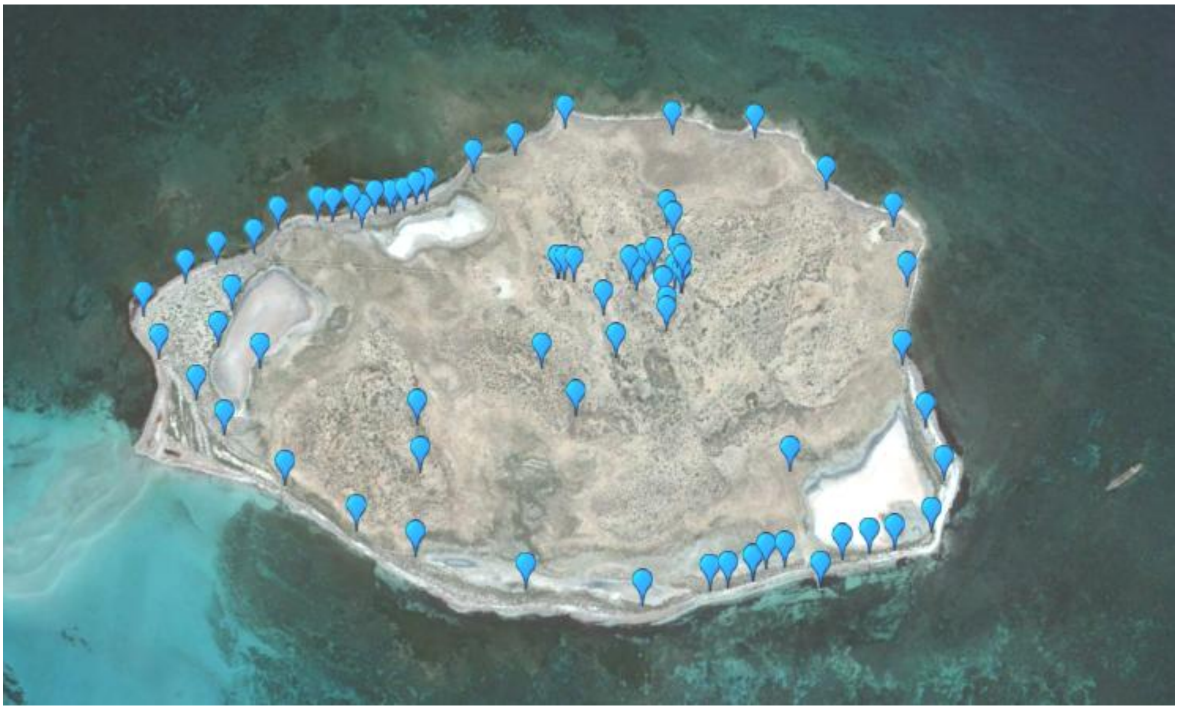

Figure 27 : Anti re-invasion boxes's distribution map, Great Kuriat

In Great Kuriat, there is no touristic visitors issues but we are dealing with two type of human presence, military and scientific staff. Besides protecting the coasts we tried to concentrate the boxes around the military light house and scientific camp.

II.2 First ecosystem response after black rat eradication

Measuring eradication programs success is the absence/ presence of the target species at the end of the control period. However, eradication success cannot be reduced to effective rat removal, because eradication of invasive rats should be viewed as a necessary, but not the only step towards ecological restoration (Atkinson, 2001). The real measure of success, in addition to the absence of the target species, is community's restoration by the recovery of some target populations of local plants or animals.

There are many reasons why restoration may not occur naturally following the removal of black rats; for example, native species may have been extinct or the habitat may have been deeply modified. The most studied of these undesired effects includes primary poisoning of non-target species (e.g., native rodents and granivorous birds). In Kuriat Island we observed many cases of non target species affected by eradication.

II.2.1 Rabbits

We register one case of rabbit mortality in Great Kuriat (Figure 28) during our mission to Great Kuriat the 29th and 30th of March 2016 we can't determine for sure the cause of death but poisoning by the baits is one of the hypothesis.

Figure 28 a rabbit cadaver found in Great Kuriat

II.2.2 Birds

Twelve cases of yellow legged gull mortality have been recorded on the islands. Death may be due to the effect of the anticoagulant (Figure 29).

Although population of yellow legged gull in Kuriat is estimated to 10000 individual and several mortality occur naturally.

Figure 29 : Yellow legged Gull mortality

A second case of bird mortality was recorded on October 16th during our 4th control mission on Great Kuriat (Figure 30). It is a female kestrel, a raptor, which feeds generally on mice, young rats, insects and sometimes frogs and worms. According to dissection, we found that the death occurred about two days. However, the blood still uncoagulated which is due to the anticoagulant molecule's effect.

Figure 30 : Female Kestrel's cadaver

In this case we are dealing with secondary poisoning of non-target predators and scavengers (e.g., raptors, insectivorous birds, etc) during rat eradication campaigns using poison baits.

However we registered some cases of consumption of baits by non target species such as ants, snails and beetles (Figure 31); and those cases didn't lead to the specie's death, but this bait's consumption lead to bio accumulation of the poison (anti-coagulant molecule: Bromiodialone) in the trophic chain.

Figure 31 : Beetles eating bait

The case of that Kestrel female my due to whether a young rat or some non target species whom consumed baits and received the lethal dose from the bioaccumulation in her prey.

II.3 Indicators of ecosystem recovery

Ecosystem responding to species removal, even alien invasive species, depend on many factors as the role of these species in the trophic network, how long this species was part of this ecosystem. Because of these interactions, any alteration to the species composition can have cascading effects throughout the ecosystem (Chapin et al. 2000). These unexpected and undesired effects based on chain reactions have been termed ‘‘surprise effects’’ or ‘‘Sisyphus effects’’ (Mack and Lonsdale 2002). They have been discussed in many different situations, and potentially concern all trophic levels.

Efficient ecosystem evaluation after rat eradication need several years. In the small amount of time that we had we tried to detect some signs of eradication impact.

II.3.1 chicken hatching in lighthouse

The first example is the success of nesting and hatching of chicken’s eggs near the Military light house (Figure 32) (one of the main zone of high density of black rat on Greta Kuriat Island). The military reported that before eradication all the chicks disappear and the hatching was rare.

Figure 32 : Hatching chicken success near the Military lighthouse

II.3.2 Hatching of yellow legged gull

The same observation was made with Gull, which is the most abundant species on the Kuriat Islands. Indeed, we took the GPS points of some nests belonging to certain zones of high density of rats, in order to follow it. It has been observed that each nest contains 3 eggs, and that the young gulls leave their nests only when they can fly, and that once they begin to walk, they always try to protect themselves by the vegetation near their nests (Figure 33).

Figure 33 : Hatching's success of Gull eggs

For most nests followed, the 3 young Gulls are in their nest or hidden in the neighboring vegetation. We have not recorded traces of stranded eggs, or attacked by rats. This could constitute evidence in favor of this eradication.

II.3.3 Hatching of Sternula albifrons

Another example of birds observed is *Sternula albifrons*, a migratory species, nesting in small colonies on beaches. Both parents dig a low depression in the soil, and the female sometimes garnishes the chosen place with large stones. The eggs are laid in May / June. The brood consists of 2 or 3 eggs dotted with dark points. The incubation lasts about 22 days, provided by both parents. Chicks fly after 4 weeks.

On the Kuriat Islands, the situation is a little different because of the nature of the beaches, rich in Posidonia, especially on the Great Kuriat. According to the turtle nesting monitoring team, in previous years, the dwarf tern is observed only at the end of August and early September and prepares its nest in depressions caused by Traces of feet in ‘Sebkha’. This year, we detected their presence from the beginning of June during our 12th mission where we found over thirty nests near the scientific camp, one of the areas of the highest density (Figure 34).

Figure 34 : Nests of dwarf tern near the scientific camp in Great Kuriat

The area near the scientific camp is one of the areas with the highest density of the black rat on the Great Kuriat, which means that the dwarf tern was threatened by the black rat before eradication. Thus, the significant presence of dwarf tern nests near the scientific camp is another sign in favor of eradication program.

III. Guidelines based on our experience with black rat eradication from Kuriat islands

III.1 Importance of eradication studies

Control programs of invading alien species, including the eradication of mammals from islands, have been increasing in numbers in the last few decades (Courchamp, Chapuis, & Pascal, 2003). In parallel, it has become more evident to both managers and researchers that eradication programs are powerful conservation tools (Donlan et al. 2003).

However, eradication studies, especially those discussing conservation strategies toward the management of invasive species, evaluating the conservation benefits of their control or reporting research on eradication techniques, are still greatly underrepresented in the literature (Donlan et al. 2003; Lavoie et al. 2007; Simberloff 2001). More coordination between science and management has been advocated before, and studies based on eradication strategies or programs incorporating research should be a high priority (Donlan et al. 2003).

Many authors have insisted on investing time in optimising the strategy used to reduce or eradicate an alien species from an island. In particular, to ensure the best chances of success, an investigation of the historical, ecological, social and economic situation of the island must be completed (Courchamp et al., 2003). Moreover, the aim of the program must be clearly defined in order to identify the available options and their respective likelihood of success.

Applying methods that were successful elsewhere, even if the same alien species is concerned or other aspects seem identical, is not necessarily a guarantee of success. Each case must be thoroughly studied independently, with careful planning of the protocol and how to institute it. Many authors have given rather precise guidelines based on their experience with certain species. There are, however, a number of basic points that can be cited as important for the success of a program. To be successful a control program requires (but is not guaranteed by) : (1) good planning (on all aspects, from logistics to ecology); (2) a good pre-control study of the situation (see below) ; (3) careful choice of the selected method or suite of methods (including good timing) ; (4) sufficient and lasting financial and political support to complete eradication (even if it takes time) ; (5) public support (e.g. Veitch & Clout, 2001).

Referring to the following diagram (Figure 35) we will summarize the main guidelines based on our experience with black rat eradication from Kuriat islands.

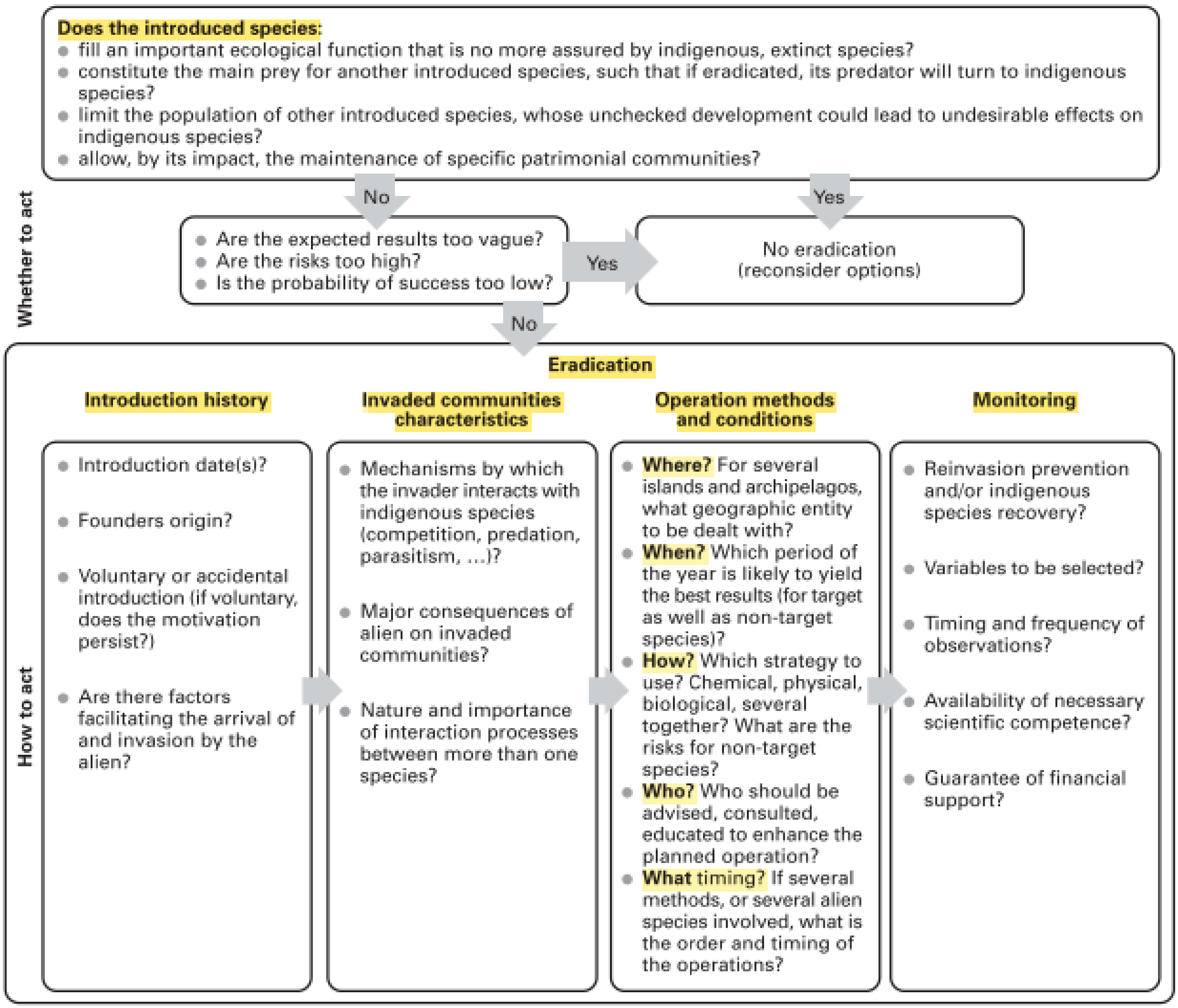

Figure 35 Decision diagram for the eradication of mammal species from islands (Courchamp et al., 2003)

III.2 Pre-eradication phase

This phase will give us the answers for the following sections: ‘Does the introduced species’,

‘Introduction history’ and ‘Invaded communities characteristics’.

Obviously, not all eradication programs can afford to spend years on pre-eradication studies, especially if they are management based. From a purely research perspective, one can also make the point that the pre-eradication study was neither sufficiently long, nor wide enough, in terms of species covered or details acquired. A more thorough assessment of rat impact would have been interesting, but it would have required a logistically (and financially) more constraining study, which would also have to have been carried out for longer. Although there is a clear need to formally define the impact of alien species on invaded communities (Parker et al. 1999), this is balanced by a delicate trade-off between the necessity to better understand the focal ecosystem and an obligation to act fast (Simberloff 2003). In our case, the trade-off imposed by the recently observed predation on sea turtle hatchlings. Although this trade-off will almost always be present, it is important to keep in mind that a minimal study of the trophic relationship of the focal invasive alien species with the invaded ecosystem is crucial in order to design the most suitable control strategy, avoid possible surprise effects, and ensure conservation success on all fronts.

III.3 Eradication phase

The following part concern the ‘Operation methods and conditions’ and ‘Monitoring’ until the

eradication of the last individual of the invasive species. In our case of study :

Where :

✓ View the short distance separating the two Kuriat islands (2.5Km) we decided to eradicate *Rattus rattus* from both islands to minimize the risk of reinvasion.

✓ View the large surface of Kuriat (340ha) we divided it in four zones, but it wasn’t an equal devising (in term of surface) which automatically lead to unequal monitoring (in term of time spacing).

Conclusion and perspectives

Invasive species impact on ecosystem can be defined simply as all effects induced by its presence/introduction on the ecosystem (fauna, flora, physical and chemical characteristics).

In our study, black rat invasion on Kuriat Islands seem to be a great chance for us to study rat invasion in insular ecosystem that offer many perspective for studying this animal interaction. First, danger on sea turtle was clear and the scientific team for monitoring of sea turtle nesting have registered some cases of baby turtle attacked by this invasive species. And since rats become a major threat; due to their omnivorous behavior and the fact that they can adapt to different habitats. Second important perspective for studying black rat's eradication was the difference of invasion historic between the two islands. Old invasion in the Little island with more than 20 years of rats presence and recent invasion of rats in great Kuriat with only 3 years of rats presence.

Black rat's eradication on Kuriat Island took place from 16 September 2015 to 23 July 2016. During this period, 5700 baiting station was installed and monitored. Eradication's strategy and daily monitoring allowed us to follow bait's consumption which reflect black rat mortality's rate. In total we estimated that 4147 rats eradicated from Little Kuriat and 7049 from Great Kuriat.

Based on collected data, main rat high densities zones was always near human activities, in the scientific camp and the lighthouse of great Kuriat. Along the touristic beach in the Little island.

The real measure of success, in addition to the absence of the target species; which is declared on July 2016, is community's restoration by the recovery of some target populations of local plants or animals. Efficient ecosystem evaluation after rat eradication need several years. In the small amount of time that we had we tried to detect some signs of ecosystem's recovery which appear mostly in hatching success of some birds (yellow legged gull, dwarf tern and chicken).

A long term post-eradication monitoring is essential to study further the impact of this invasive species eradication from Kuriat ecosystem and may help us to understand biological invasion in insular ecosystem for better management and conservation plan.

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Black rat eradication in insular ecosystem :
Case of Kuriat Islands, Monastir Tunisia

Graduation’s internship’s repport

RESUME

Les îles Kuriat représentent le seul site stable de nidification des tortues marines en Tunisie. En 2013, la présence accrue du rat noir sur les îles Kuriat a dangereusement affecté la survie des bébés tortues marines en les attaquant pendant leurs émergences. Selon les chercheurs et les ONG, les campagnes d’éradication sont un outil très puissant pour la conservation de la nature. L’éradication du rat noir sur les îles Kuriat a donc eu lieu du 16 septembre 2015 au 23 juillet 2016 ; dirigé par l’ONG ‘Notre Grand Bleu’. Au total, nous avons estimé qu’environs 11150 rats ont été éradiqué., En plus de l’absence d’espèce cible qui était déclaré en juillet 2016, le succès de cette campagne c’est reflété par la restauration de l’écosystème. Durant la période restreinte de cette étude nous avons essayé de détecter certains signes de restauration de l'écosystème, qui se traduisent principalement par le succès de l'éclosion de certains oiseaux (goéland leucophée, sterne naine et poulets). Un suivi post-éradication à long terme serait essentiel pour approfondir l'étude d’impact de cette action d’éradication et pourra ainsi nous aider à comprendre le phénomène de l'invasion biologique dans un 'écosystème insulaire dans le but d’instaurer un meilleur plan de gestion et de conservation des îles

Mots clés : Iles Kuriat, Rat noir, éradication, écosystème insulaire, restauration d’écosystème. .

SUMMARY

Kuriat is the main sea turtle nesting site in Tunisia and western Mediterranean, nurseries for several species in barrier reef meadow of Posidonia and home to many species of migratory birds. In 2013, an increased presence of Black Rat and some cases of baby turtle attacked by this invasive species while their emergence. According to researchers and NGOs, eradication campaigns are a very powerful nature conservation tool. Black rat’s eradication on Kuriat Island took place from 16 September 2015 to 23 July 2016; headed by the NGO ‘Notre Grand Bleu’. In total we estimated that around 11150 rats were eradicated. The real measure of success, in addition to the absence of the target species; which is declared on July 2016, is community’s restoration by the recovery of some target populations, and this need several years. In the small amount of time that we had we tried to detect some signs of ecosystem’s recovery which appear mostly in hatching success of some birds (yellow legged gull, dwarf tern and chicken). A long term post-eradication monitoring is essential to study further the impact of this invasive species eradication from Kuriat ecosystem and may help us to understand biological invasion in insular ecosystem for better management and conservation plan

Key words: Kuriat islands, black rat, eradication, biological invasion, insular ecosystem, restoration