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Current challenges faced by endemic Malagasy mayflies (*Cheirogenesia*, Demoulin 1952, *Proboscidoplocia*, Demoulin 1966, *Madecassorythus*, Elouard & Oliarinony, 1997, and *Spinirythus*, Oliarinony & Elouard, 1998) toward climate change, damaged habitat, and pollution

Abstract

Climate change and pollution are common problems all around the world. Madagascar is also affected. Habitat destruction is caused by the direct intake of natural resources as is the case in the majority of developing countries. These threats are very rapid; however the knowledge of the eco biology and area distribution of the endemic taxa is very limited. Based on a literature survey lasting a dozen years, and on our own experience, we present some data about endemic genera, such as *Proboscidoplocia* (Euthyplociidae), *Madecassorythus* and *Spinirythus* (Tricorythidae) and *Cheirogenesia* (Palingeniidae). The comparison between forested and disturbed areas indicates that not only the distribution, but also the life cycle, the abundance and the biomass, as well as the secondary production are highly affected by these changes. Conservation perspectives of these genera depend on the monitoring and the protection of their localized sites.

Keywords: endemic ephemeroptera, *Cheirogenesia*, *Proboscidoplocia*, *Madecassorythus, Spinirythus*, current knowledge, climate change, damaged habitat, pollution, Madagascar

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Introduction

Ecological concerns about environmental degradation are of great concern to human society today. Air and water pollution due to industrial growth and population growth, and rain forests deforestation threaten ecosystems. Yet, rainforests host most of the biodiversity in the world.[1] Climate change is a phenomenon that is among the challenges for most societies. These three aforementioned factors are mainly the sources of the change in balance of the terrestrial and aquatic ecosystems. Forest-water ecosystems are a key- preoccupation of the world internationally, including the Aichi Targets of the Convention on Biological Diversity, the United Nations Framework Convention on Climate Change, and the Ramsar Convention on Wetlands,[2] which reflects their considerable recognition in the socio-political sphere. Water is a natural resource that must be managed. To care about water quality means to take into consideration aquatic organisms and aquatic ecosystems. It is in this perspective that this research was conducted. The objectives were to:

i. Provide thorough knowledge on the distribution of the endemic species of Madagascar, particularly the species of *Cheirogenesia,* species of *Madecassorythus*, species of *Spinirythus* and species of *Proboscidoplocia*. These species belong to the order Ephemeroptera.

ii. Examine the impact of deforestation on the abundance, density, biomass, secondary production, and life cycle of *Madecassorythus ramanankasinae*, *Spinirythus hertui*, and *Proboscidoplocia vayssierei.*

Materials and methods

The present work was based on a literature review, the identification of all available collection materials from a project dating from 1993 to 1999,[3] and our sampling from 2012 to2015. The biological material of this study focused on a few species of the Ephemeroptera. For species of the genus *Cheirogenesia*, a distribution map was drawn up based on sampling and data from the literature. Distribution maps of species of Tricorythidae and species of Euthyploccidae were given, also taking into account sampling and data from the literature. A one-year study (June 2001 to June 2002) analyzed the development time and type of development cycle of *Madecassorythus ramanankasinae, Spinirythus martini* and *Proboscidoplocia vayssierei.* A sampling campaign carried out in June, September and November 2001, provided data on abundance, density, biomass, and secondary production of these species. Three stations located in the tropical rainforest and three stations located in the degraded environment were sampled. For the study of the developmental cycle, five stations in the rainforest of the National Park of the Eastern Coast of Madagascar (Andasibe) and five stations in the surrounding degraded environment of this region were selected.

The developmental cycle includes the larval period, the emergence and the flight period of the adult insects. There are three main types of developmental cycles:

i. The first type is the univoltine cycle which has a duration of one year for the development of a generation. This type of cycle can be divided into two subgroups:

a. The winter univoltine cycle during which the insects hibernate as larvae during the winter

b. The summer univoltine cycle during which larval development and hatching take place during the summer, and in winter, there is hibernation in the form of eggs.

ii. The second type of cycle is the multivoltine cycle; it includes the bivoltine cycle, if we have two generations per year, and the cycle is polyvoltine if we have at least three generations per year.

iii. The last type of cycle is the partivoltine cycle also called semivoltine cycle, with a developmental cycle of more than one year, generally around two years.

Density is the number of individuals caught per square meter of surface. Biomass and secondary production were calculated from the formula of[4] for species of Tricorythidae. Details of the methodology are described in the previous work.[5]

Results

The results concerned, first, the presentation of distribution maps of *Cheirogenesia, Madecassorythus, Spinirytus* and *Proboscidoplocia* species. Secondly, there was the comparison between the forest population and the population living in the degraded environment with respect to relative abundance, density, biomass, secondary production and development cycle length of some species of *Madecassorythus* (*Madecassorythus ramanankasinae*), *Spinirythus* (*Spinirythus martini*) and *Proboscidoplocia* (*Proboscidoplocia vayssierei*).

The distribution of the three *Cheirogenesia* species was highly localized in the highlands and eastern part of Madagascar (Figure 1). *Cheirogenesia decaryi* was found in only one basin, the Betsiboka basin. The same is true for *Cheirogenesia edmundsi,* which was found in the Mangoro basin, and *Cheirogenesia laurencae,* found only in the Rianila basin. It should be mentioned that during our ecological monitoring of the fauna of the Ikopa River in 2015, no species of *Cheirogenesia decaryi was* collected.

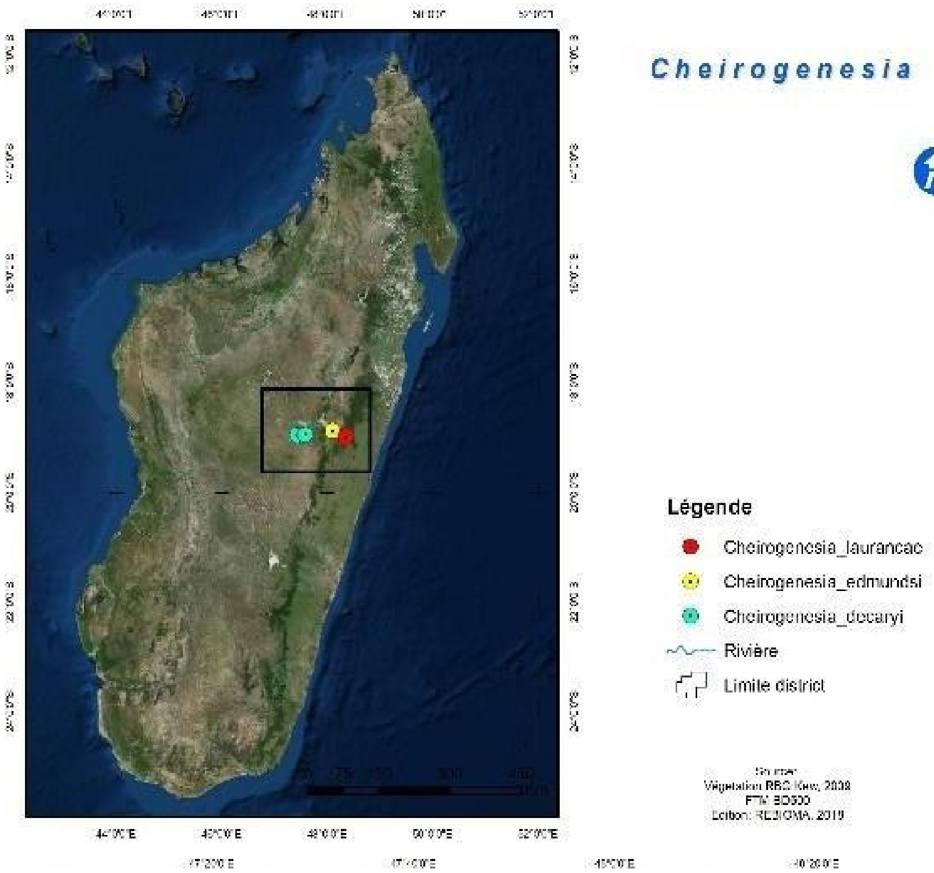

Figure 1 *Cheirogenesia* species distribution map.

Despite the wide distribution of some species of the genus *Madecassorythus,* the majority of the species are microendemic (Figure 2). *Madecassorythus linae* is restricted to the National Park which is a protected area of Andasibe - Mantadia. *Madecassorythus hertui* is located only in the Betsiboka basin. *Madecassorythus ramanankasinae* is found both in the Highlands and the Eastern part of Madagascar, but it is never met either in the North, in the West or in the South of Madagascar.

All the species are distributed only in the Highlands and in the Eastern part of Madagascar. Another genus of the family Tricorythidae, which is *Spinirythus*, seemingly having more *Spinirythus* species, was characterized by a wide distribution compared to *Madecassorythus* species (Figure 3). However, these species do not occur in the Northwest, Southwest and West of Madagascar. All the species namely *Spinirythus colasi, Spinirythus rosae* and *Spinirythus martini* were confined to the eastern coast, the Northeast, the Southeast and the highlands of Madagascar.

For the distribution of the two species of *Proboscidoplocia* (Figure 4), these species prefer the humid tropical forest zone and the surrounding forest environment. They are distributed in the Northeast,

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East and Southeast of Madagascar. *Proboscidoplocia vayssierei* had a wide distribution compared to *Proboscidoplocia billi* which lives only in Andringitra, in the Manampatrana basin in the Highlands. The larvae of *Probscidoplocia* sp. were distributed in the highlands and in the eastern part of Madagascar.

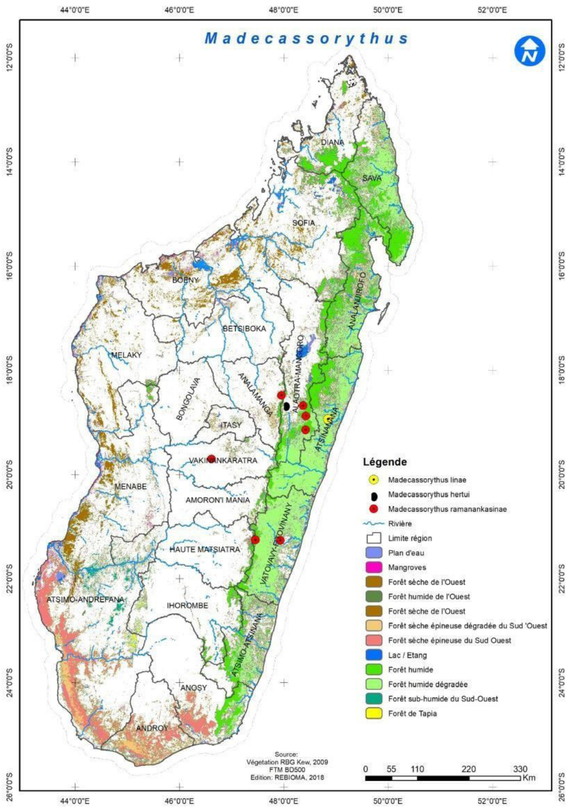

Figure 2 *Madecassorytus* species distribution map.

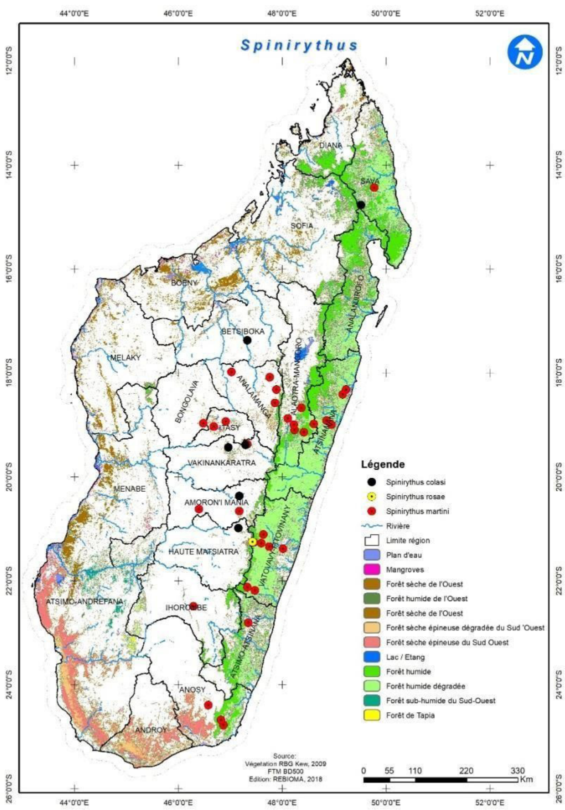

Figure 3 *Spinirytus* species distribution map.

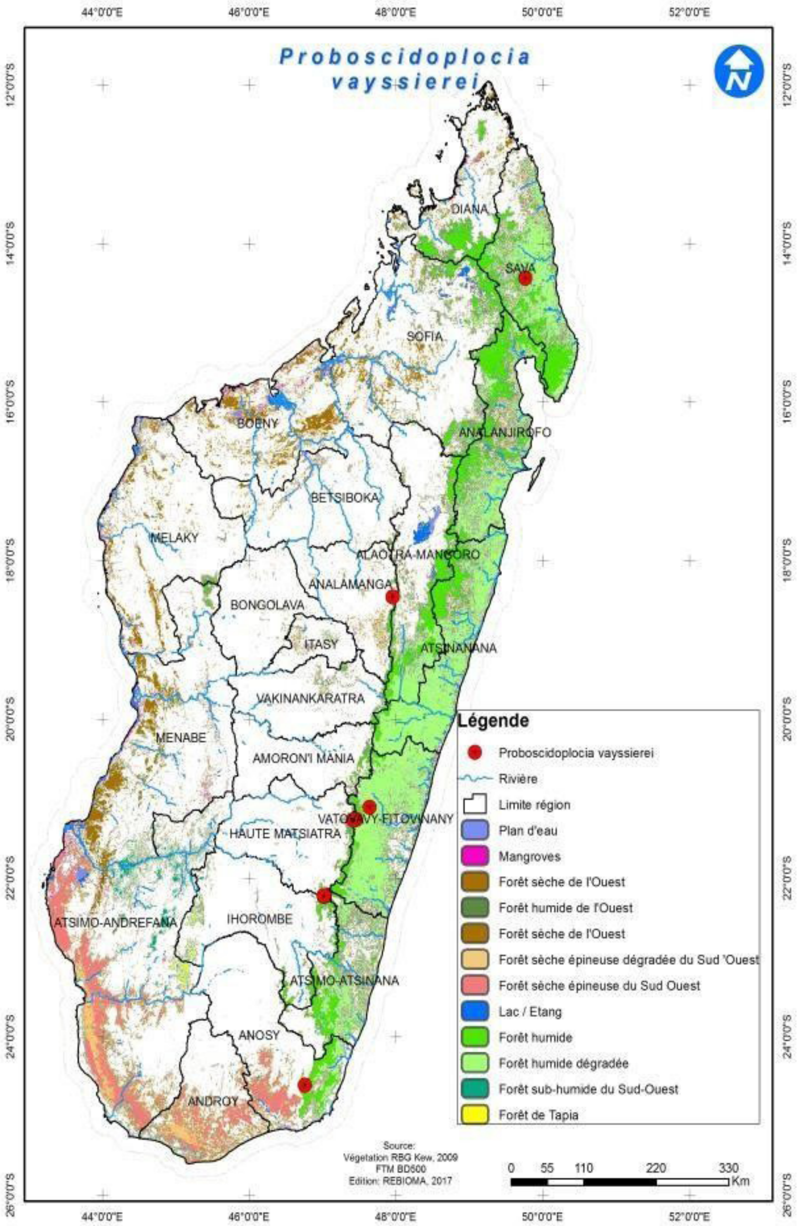

Figure 4 *Proboscidoplocia vayssierei* & *Proboscidoplocia billi* species distribution map.

The following tables Table 1 & 2 show the difference in relative abundance, density, biomass, secondary production and life cycle of the forest population compared to the population living in the degraded environment. Data on the forest population of *Proboscidoplocia* were not considered because of the low number of individuals captured in the forest. It seems to us that the preferred habitat of this species is the open canopy environment but moderately deforested.

Table 1 Summary of relative abundance, density, biomass, secondary production, and developmental cycle data

Forest sites					
	Abr (%)	**D**	**B**	**Pmean**	**CPI (days)**
Madecassorythus ramananakasinae	76	6,48±0,27	9,16±0,48	103,20±5,27	149
Spinirythus martini	56,25	13,33±4,82	12,65±4,41	151,165±27,58	131

B, biomass (mg.m-2); D, density (ind.m-2); P, production; (mg. m-2. yar-1) moy, mean; CPI, cohort production Interval (larval development stage) (days)

Table 2 Summary of developmental cycle, biomass, and secondary production data for *proboscidoplocia vayssierei*

Degraded sites					
	Abr (%)	**D**	**B**	**Pmean**	**CPI (days)**
Madecassorythus ramananakasinae	24	2,04±0,07	3,63±0,28	50,15±3,28	101
Spinirythus martini	43,75	10,37±0,29	9,41±0,40	127,125±4,20	111
Proboscidoplocia vayssierei	87	24,26±2,26	67,79±4,00	264, 27±18,59	465

B, biomass (mg.m-2); D, density (ind.m-2); P, production; (mg. m-2. yar-1) moy, mean; CPI, cohort production Interval (larval development stage) (days)

The abundance of species of the family Tricorythidae *Madecassorythus ramananakasinae,* and *Spinirythus martini* was higher (76 and 56, 25) in the forest compared to the degraded environment (24 and 43.75). Similarly, the values of the density (6.48±0.27, 13.33±4.82) and 9.16±0.48, 12.65±4.41) and the biomass of the forest population were higher compared to those of the degraded environment (2.04±0.07 and 3.63±0.28, 10.37±0.29 and 9.41±0.40). Regarding *Madecassorythus ramanankasinae,* these values were three times higher for the forest population, but for *Spinirythus,* the difference in density and biomass of the forest population was relatively small.

In terms of secondary production, forests favored secondary production, it was doubled for *Madecassorythus* (103.20±5.27 versus 50.15±3.28). For *Spinirythus,* although the secondary production in the degraded environment was lower (127.125±4.20) than in the forest (151.165±27.58), the difference was relatively small compared to *Madecassorythus.*

For *Proboscidoplocia vayssierei* of the family Euthyplociidae*,* density, biomass and secondary production were higher compared to those of the two species of the family Tricorythidae. The length of the developmental cycle was short for the degraded population (in *Madecassorythus*: 101d; in *Spinirythus*: 111d) compared to that of the forest population. The life cycle of the forest population continued for 149 d and 131 d respectively. For *Proboscidoplocia vayssierei, the life* cycle duration was more than one year (465d).

Discussions and conclusion

Most of the endemic species of Madagascar are located in the forest zone of the eastern rainforest or in rivers in the highlands but with their sources in the forest (Oliarinony et al. unpublished). The species of the genus *Cheirogenesia* are marked by microendemicity. This can be explained by the loss of the ability to fly of the adults. It is impossible for them to move from one basin to another.[6] This loss of the ability to fly is related to a change in the physiological phenomenon of *Cheirogenesia* species*,* by the use of energy reserves: carbohydrates instead of lipids as observed with other insects.[7] *Cheirogenesia decaryi* is known from only one basin, the Betsiboka basin of the Ikopa River located in the suburbs of the capital Antananarivo. From 1995 to 1996, this species was collected in several stations along the Ikopa River.[6] During our ecological monitoring of the Ikopa River fauna in 2015, no individuals of *Cheirogenesia decaryi* were collected in its natural habitat. Its habitat is being destroyed by human activities, among others, the damming of the river banks and the massive and intense extraction of sand from the river bottom (Figure 5).

In addition, this river is well exposed to various pollutions since it is easily accessible to the riparian populations. The specificity of *Cheirogenesia* larvae is manifested by the digging of horizontal holes[6] on the banks where there is silt and mud. (Figure 5) shows the deterioration of the banks of the Ikopa River and indeed the alteration of water quality through the disturbance of the river substrate. It is very likely that these phenomena have induced the insufficiency or lack of food for the larvae. *Cheirogenesia laurencae* lives in the primary rainforest.[6]

Figure 5 Destruction of the banks of the Ikopa River and sample of the sand extracted from this river for the construction of houses.

The rainforest of eastern Madagascar is being deforested for a variety of reasons,[8,9] including fuel wood and mining, but fire has long been a problem due to the practice of slash-and-burn cultivation by the inhabitants of Madagascar's eastern coast. Yet, deforestation affects not only the terrestrial ecosystem but also aquatic animals[10] since woody debris falling from forest trees into streams not only provides a source of organic matter, but also a habitat for aquatic fauna.[11] The composition of the riparian vegetation affects the abundance of aquatic insects.[12] Among the species of Tricorythidae, differences in abundance, density, biomass and secondary production are significantly higher in the species with a restricted distribution, *Madecassorythus ramanankasinae.* For *Spinirythus martini* with a wide distribution, these differences are small compared to those of *Madecassorythus ramanankasinae.*

Riparian vegetation modified by deforestation presents an impact on macro invertebrates and on submerged woody debris.[13] Detritus retention is an important factor in maintaining greater aquatic insect abundance,[10] meaning that aquatic insects living in forested rivers are abundant. Our results point out that forest destruction causes the decrease in abundance, density, biomass and secondary production of species of Tricorythidae (*Madecassorythus ramanankasinae* and

Spinirythus martini). Deforestation reduces the amount of detritus in a stream.[14] This affects the amount of organic matter along the river, and leads to reductions in the abundance, density, biomass, and secondary production of aquatic insects (*Madecassorythus ramanankasinae* and *Spinirythus martini*) in the disturbed environment. *Proboscidoplocia vayssierei,* which is larger and wider, is more abundant; its biomass, density and secondary production are higher in the degraded environment. This can be explained by the fact that deforestation leads to an increase in water temperature, this increase in water temperature has led to an increase in metabolism and an increase in the size of the larvae of Baetis (Ephemeroptera), especially in summer;[15] this is also the case for the species of *Proboscidoplocia* (Ephemeroptera). It should be mentioned that the interpretation of the development cycle is based on the interpretation of the duration of the larval state (Cohort Production Interval: CPI).

Deforestation leads to a shortening of the development cycle, for *Madecassorythus ramanankasinae,* the larvae living in the degraded environment mature 48 days before those in the forest environment. For *Spinirythus martini, the* length of the development cycle of the population in the degraded environment is shorter compared to that of the forest population, the difference in development cycle is 20 days.

Taking into account the type of development cycle, the forest population of *Madecassorythus ramanankasinae* has two generations per year, while that of the degraded environment has four generations per year. For *Spinirythus,* its development cycle is polyvoltine, this species produces three generations per year. The type of cycle development of the species of *Proboscidoplocia* is semivoltine. The development of this species lasts between one and one and a half years. Compared to the results observed more than 20 years ago, *Proboscidoplocia vayssierei* has a univoltine winter cycle.[16] Deforestation combined with climate change may be the main factors for this change in development cycle type. In conclusion, the endemic species of mayflies are sensitive to environmental changes through habitat destruction, climate change and pollution. The reactions of these aquatic insects are reflected by the absence of the species in their natural habitat, either by the modification of the abundance of the species, the density, the biomass, the secondary production or the duration of the development and the type of development cycle. The more micro endemic or narrowly distributed the species, the greater the difference between the forest population and the degraded environment population in terms of abundance, density, biomass, secondary production, developmental cycle length and type. Given that the response to the effect of climate change and ecological stress (deforestation and anthropogenic activities) would be different for each species of aquatic insect, it is recommended to continue the identification of species of other families of aquatic insects in Madagascar in order to adopt an appropriate biotic index for this country. Currently, an easy identification method, the DNA barcode technique, is being developed. Madagascar must resort to the use of this method to advance research in the practice of using bio indicators for river monitoring. The conservation prospects of these genera depend on monitoring and protection of their localized sites. To this end, freshwater aquatic fauna mapping and database development for aquatic insects and even macro invertebrates are useful for establishing collaboration between researchers and riparian populations to communicate through technology for monitoring the ecological health of rivers and aquatic fauna habitats. In the face of inhibiting factors, such as the presence of pandemic or epidemic diseases like the current Covid information and communication technology for both riparian forest managers and researchers and managers could be one of many solutions for aquatic wildlife and ecosystem conservation.

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Conflicts of interest

The author declare that they have no known competing interests.

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