THREE YEARS (2021-2023) MONITORING OF SEEDLING RECRUITMENT AND PLANT COVER BEFORE AND AFTER RAT ERADICATION ON MOTU AHUROA, TETI'AROA ATOLL (SOCIETY ISLANDS)

by

Jean-Yves Hiro MEYER (Dr.)*

*Délégation à la Recherche, Gouvernement de la Polynésie française
B.P. 20981 Papeete, Tahiti, Polynésie française
Email : jean-yves.meyer@recherche.gov.pf

in collaboration with the Tetiaroa Society

August 2023

Background and objectives

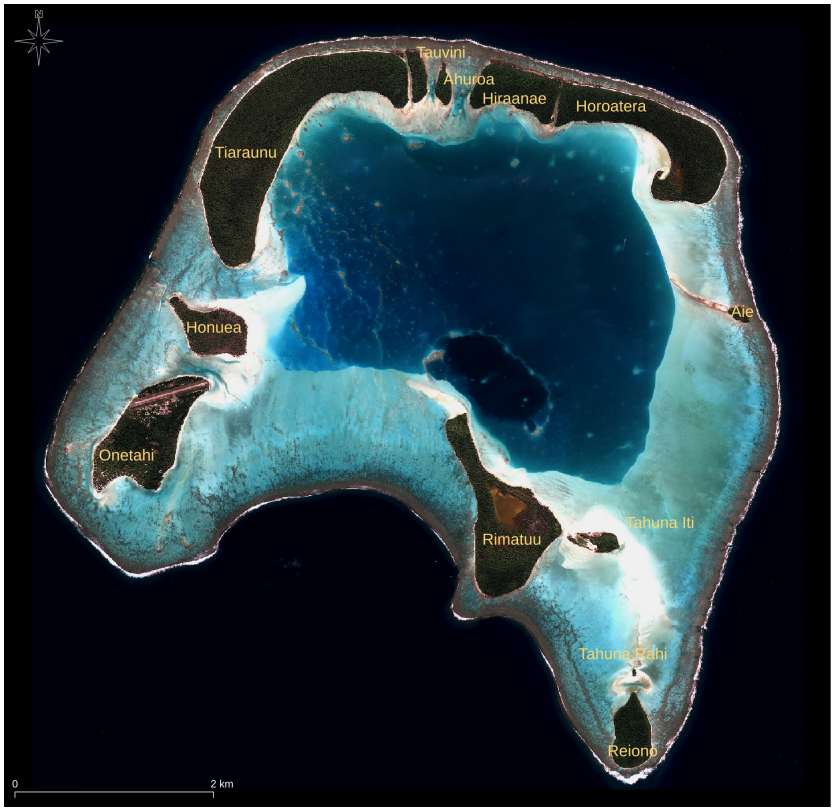
This study is part of the « Tetiaroa Atoll Restoration Program », and consists of a multi-years monitoring of plant recruitment (seedlings of woody native species and plant cover for herbaceous native and alien species) conducted in two « motus » (sandy islets) of the atoll of Teti'aroa (Society Islands, French Polynesia), Reiono and Ahuroa, before and after a rat eradication project, in order to better understand vegetation dynamics, and to try predict the forest ecosystem successional trajectories. This long-term monitoring provided also an opportunity to assess changes in plant recruitment and cover after natural disturbances (especially tree falls caused by strong winds, and high swells) that occured during our field surveys.

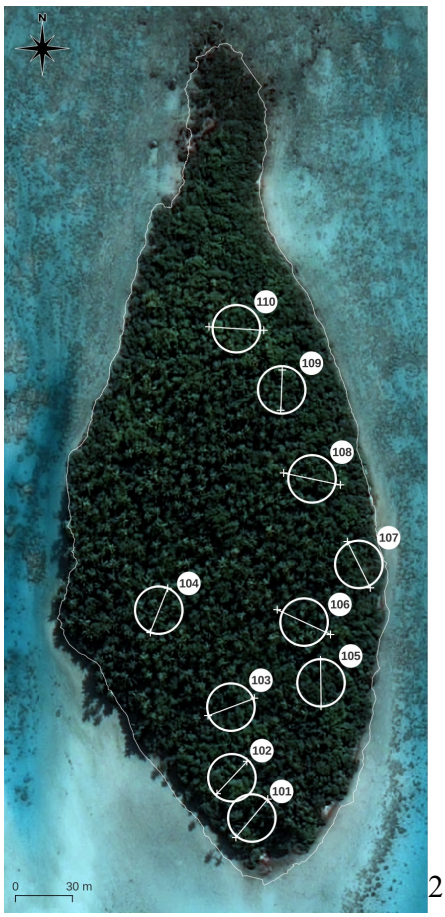
Material and method

Study site

Motu Ahuroa or Auroa (mispelled Ahurea on some maps), one of the smallest of the 12 motus of Teti'aroa with 4.6 hectare of land area (B. STOLL, pers. comm.), is located on the north of the island, at the opposite side of Motu Reiono with a surface of 23.7 ha (**Fig. 1**).

Figure 1. Satellite images of Teti'aroa atoll with the 12 motus (left) and closer view of Motu Ahuroa (right) (Pléiades, © CNES 2022, 2023, Distribution AIRBUS DS, tous droits réservés) **showing the location of the 10 permanent plots based on GPS coordinates** (courtesy of Benoît STOLL, Université de la Polynésie française, Laboratoire GePaSud).





Permanent transects, quadrats, and circular plots

We used the same experimental protocol conducted on Motu Reiono since 2018 (MEYER 2022), and inspired by a similar study (WOLF *et al.* 2018) done in the atoll of Palmyra in the Northern Line Islands (North Pacific): ten 25 m long x 2 m large transects (*i.e.* a total area of 500 m²) were set up in the interior of the Motu Ahuroa in different forest types, marked on the median line and at both ends by iron posts, tagged with color flags indicating the transect number (TR101 to TR110). Each transect was divided into fifty 1 x 1 m quadrats located on both side (right and left) of the median line. The « start post » and « end post » were georeferenced with a GPS (Garmin GPSMAP® 78).

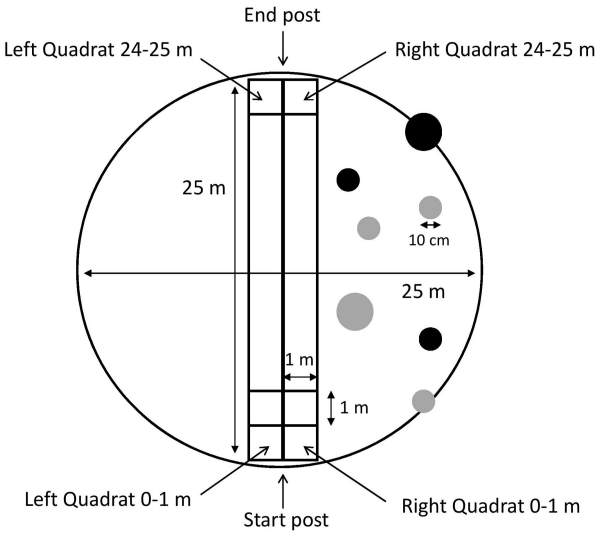
In each of the 50 quadrats, the total number of seedlings (< 30 cm in height) was counted for each woody plant species, as well as coconut « seedlings » (*i.e.* germinating coconuts with 1 to 6 small leaves). Resprouts (*i.e.* small stems with leaves) from roots were not counted, as well as coconuts without any leaves (*i.e.* young and full of water, or opened and empty, or dried and dead). A visual assessment of plant species cover (in %) found in the herbaceous strata (< 1 m in height) was added to this seedling recruitment protocol in order to monitor the changes in abundance of all native and alien plants which are present on the motu and might be also eaten by rats.

In order to better characterize the different plant habitats/forest types on the motu, we have set up 25 m diameter circular plots (CR101 to CR110) centered around the transects, representing an area of about 490 m² (**Fig. 2**). The number of standing trees and their number of trunks and stems with a diameter at breast height (DBH, taken at 1,30 m from the ground) above 10 cm were counted and their diameter (or circonference) measured. The total basal area (BA in cm²/m² or m²/ha) for each species based on the surface (s) of all its individuals (i), and for all species were calculated as followed:

$$s = \frac{\pi \times DBH^2}{4} \qquad BA = \frac{\sum_i s_i}{490}$$

The percentage of basal area for each species (%BA) was assessed to identify the dominant species in relation to their cover.

Figure 2. Diagram showing the circular plots (CP) centered in the middle of the permanent transect (TR).



Monitoring dates and period of survey

Our monitoring study started in July 2021, one year before the rat eradication campaign of June 2022, and representing a three years time period. Pre- and post-eradication surveys were conducted in July during the « dry and cool season » in the Society Islands in order to avoid seasonal variability in seed germination and seedling recruitment caused by heavy rains between November and March.

Results

A total of 547 trees (641 trunks and stems) were counted in the ten circular plots, representing a total basal area of about 411 cm²/m². The density reaches 1116 trees/ha in the sampled area of 0,49 ha representing 10.6% of Motu Ahuroa (**Tab. 1**). The two most common trees, according to their trunk or stem number, are *Pandanus tectorius* (« fara ») and *Pisonia grandis* (« pu'atea »), followed by *Guettarda speciosa* (« tafano ») and *Cocos nucifera* with few *Heliotropium foertherianum* (« tahinu »).

By comparison they were only 323 trees (representing 417 trunks and stems) counted in the ten circular plots of Motu Reiono (i.e. a lower density of 660 trees/ha) but with a higher total basal area of 662 cm²/m² because of the very large *Pisonia* trees (MEYER, 2022).

Table 1. Forest structure in the circular plots (490 m²) according to the number of trees and stems (DBH > 10 cm). Piso.= *Pisonia grandis*; Coco. = *Cocos nucifera*; Pand. = *Pandanus tectorius*; Guet. = *Guettarda speciosa*; Helio. = *Heliotropium foertherianum*.

Circular plot	Number of trees	Number of stems	Piso. stems	Coco. stems	Pand. stems	Guet. stems	Helio. stems
CP101	49	50	5	13	31	1	0
CP102	30	43	10	1	18	13	1
CP103	48	61	30	1	19	11	0
CP104	61	68	18	7	34	9	0
CP105	57	66	16	2	40	5	3
CP106	81	92	27	13	40	12	0
CP107	54	71	43	3	18	6	1
CP108	54	62	28	4	30	0	0
CP109	62	70	16	3	41	7	3
CP110	51	58	19	4	32	3	0
Total	**547**	**641**	**212**	**51**	**303**	**67**	**8**

Table 2. Woody species cover in the circular plots according to their Basal Area (cm²/m² or m²/ha).

Circular plot	Total Basal Area	BA Piso.	BA Coco.	BA Pand.	BA Guet.	BA Helio.
CP101	19.72	6.81	1.15	11.42	0.34	0
CP102	28.77	12.62	3.27	5.07	7.60	0.21
CP103	45.77	30.56	1.82	5.55	7.83	0
CP104	52.26	24.06	13.14	9.44	5.62	0
CP105	34.62	15.93	2.70	9.53	1.74	4.72
CP106	57.25	18.01	25.01	7.85	6.38	0
CP107	54.23	37.15	5.94	6.68	3.81	0.64
CP108	46.78	30.05	7.32	0	9.41	0
CP109	63.07	37.30	5.66	13.48	4.80	1.83
CP110	43.53	22.13	7.44	11.43	2.53	0
Total	**411.38**	**234.62**	**73.45**	**80.45**	**50.06**	**7.40**

Our results (**Tab. 3**) and forest classification (**Tab. 4.**) indicate that the most common forest type (found in 8 studied plots) is « mixed *Pisonia* forest », with slightly different species composition and tree cover, with one « *Pandanus-Pisonia* dense forest » (TR101) and one « *Cocos-Pisonia* dense forest » (TR106) (**Tab. 5**).

Table 3. Percentage of woody species cover in the circular plots according to their Basal Area (cm²/m² or m²/ha).

Circular plot	%BA Piso.	%BA Coco.	%BA Pand.	%BA Guet.	%BA Helio.	% BA Total
CP101	34.54	5.81	57.91	1.74	-	100
CP102	43.85	11.38	17.63	26.41	-	100
CP103	66.77	3.99	12.13	17.11	-	100
CP104	46.04	25.14	18.06	10.76	-	100
CP105	46.02	7.79	27.53	5.03	13.64	100
CP106	31.46	43.68	13.72	11.14	-	100
CP107	68.5	10.96	12.32	7.03	1.19	100
CP108	64.25	15.64	20.11	-	-	100
CP109	59.14	8.98	21.37	7.61	2.90	100
CP110	50.84	17.09	26.26	5.81	-	100

Table 4. Forest classication according to the %BA of each taxa with main types (MEYER, 2022).

Forest type	%BA of taxa
Forest dominated by X (« *X dense forest* »)	X>75%
Forest codominated by X and Y (« *X-Y dense forest* »)	30%<X<75% and 30%<Y<75% and X-Y<10%
Mixed forest dominated by X (« *Mixed X forest* »)	30%<X<75% and X> all other taxa
Mixed forest dominated by X with Y (« *Mixed X forest with Y* »)	Y>25% and X-Y>10%
With Z uncommon	10%<Z<25%
With V rare	5%<V<10%
With W very rare	W < 5%

Table 5. Description of the different habitat/forest types based on forest classification.

Plot/Transect	Habitat/forest type
CP101/TR101	*Pandanus-Pisonia* dense forest with uncommon *Cocos* and very rare *Guettarda*
CP102/TR102	Mixed *Pisonia* forest with *Guettarda* and uncommon *Pandanus*, *Cocos*
CP103/TR103	Mixed *Pisonia* forest with uncommon *Guettarda, Pandanus* and rare *Cocos*
CP104/TR104	Mixed *Pisonia* forest with uncommon *Guettarda, Pandanus*, *Cocos*
CP105/TR105	Mixed *Pisonia* forest with *Pandanus* and uncommon *Heliotropium* and rare *Cocos*,*Guettarda*
CP106/TR106	*Cocos-Pisonia* dense forest with uncommon *Pandanus*, *Guettarda*
CP107/TR107	Mixed *Pisonia* forest with rare *Guettarda, Pandanus, Cocos* and very rare *Heliotropium*
CP108/TR108	Mixed *Pisonia* forest with uncommon *Pandanus*, *Cocos*
CP109/TR109	Mixed *Pisonia* forest with *Pandanus* and rare *Cocos*, *Guettarda* and very rare *Heliotropium*
CP110/TR110	Mixed *Pisonia* forest with *Pandanus* and rare *Guettarda*

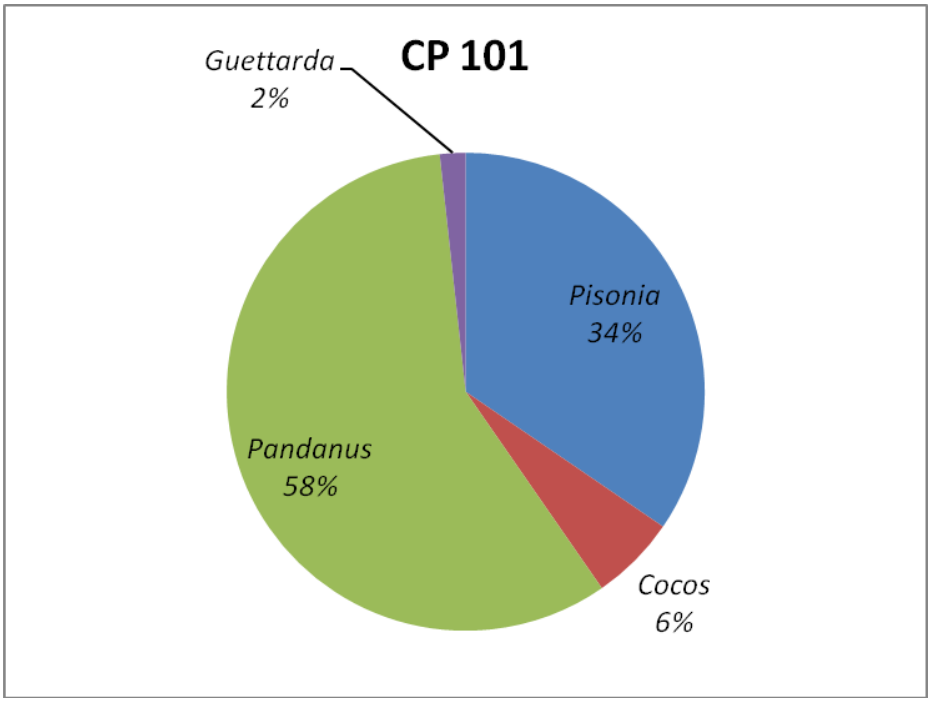
During our study period (July2021-July 2023), seedlings of four woody species were recorded in the quadrats and transects: the native trees *Pisonia grandis*, *Pandanus tectorius*, *Guettarda speciosa* and the introduced *Cocos nucifera*. No seedling of the native tree *Heliotropium foertherianum* was observed in the ten transects even in presence of reproductive trees. The herbaceous plants include the native creeping herb *Boerhavia tetrandra*, the native ferns *Asplenium nidus* and *Microsorum grossum* and the non-native (or introduced) succulent herb *Portulaca oleracea* (**Fig. 3-12**).

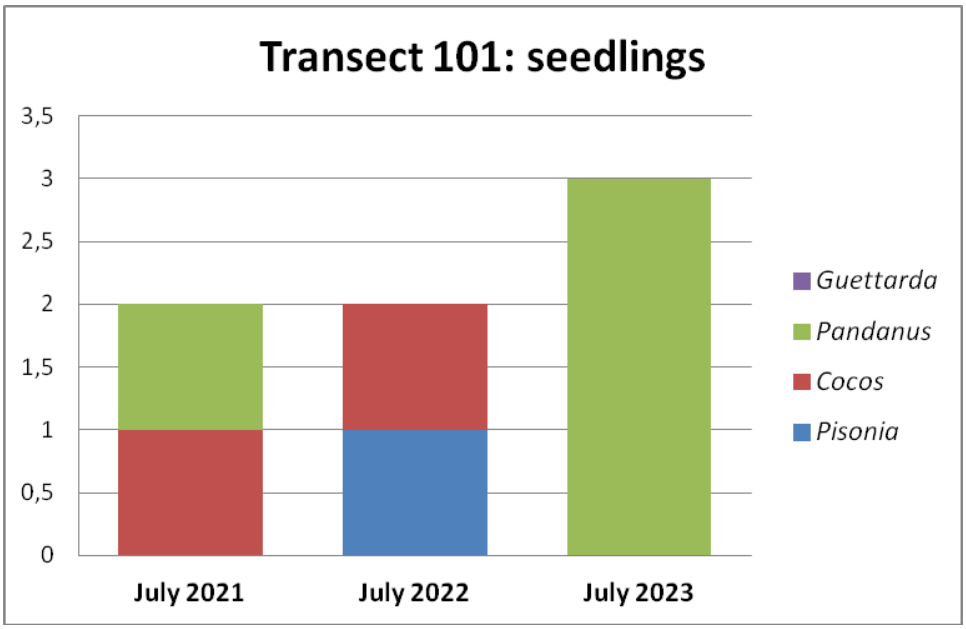
As expected, seedling recruitment differs according to the different forest types, with more *Pisonia* seedlings found in dense or mixed *Pisonia* forest (TR102, 103, 104, 107, 108, 110), and *Pandanus* seedlings in *Pandanus-Pisonia* dense forest and *Pisonia* mixed forest with *Pandanus* (TR105, 109, 110) in July 2021 before rat eradication. Surprisingly there were relatively few *Cocos* seedlings found in the *Pisonia-Cocos* dense forest (TR106).

An increase of *Pisonia* seedlings was observed in *Pisonia* dense forest and some mixed *Pisonia* forests just after rat eradication in July 2022 (TR101, 107, 109) (**Photo 1** in **APPENDIX**), but their number decreased one year after rat eradication whereas *Pandanus* seedlings increase in all forest types (**Photo 2**) as well as *Guettarda* seedlings (**Photo 3**) in most of the mixed *Pisonia* forest with *Guettarda* (TR103,104, 105, 106, 108, 109, 110). No increase of coconut seedlings was observed one year after rat eradication.

An increase of the native ferns *Asplenium nidus* (**Photo 4**) and *Microsorum grossum* (**Photo 5**) as well as the introduced (non-native) *Portulaca oleracea* (**Photo 6**) was observed after rat eradication, but not *Boerhavia tetrandra* (TR 102, 107).

Figure 3. Forest composition and woody species cover (%BA) in circular plot CP101, and evolution of the seedlings number in permanent transect TR101 between 2021 and 2023.




Transect 101: seedlings
3,5
3
2,5
2
1,5
1
0,5
0
July 2021
July 2022
July 2023
Guettarda
Pandanus
Cocos
Pisonia

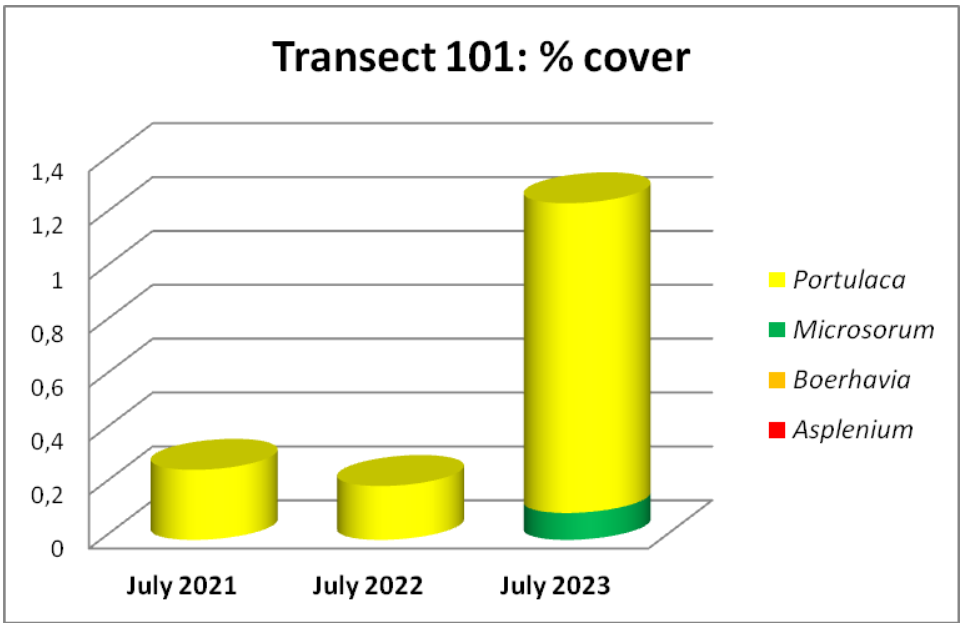
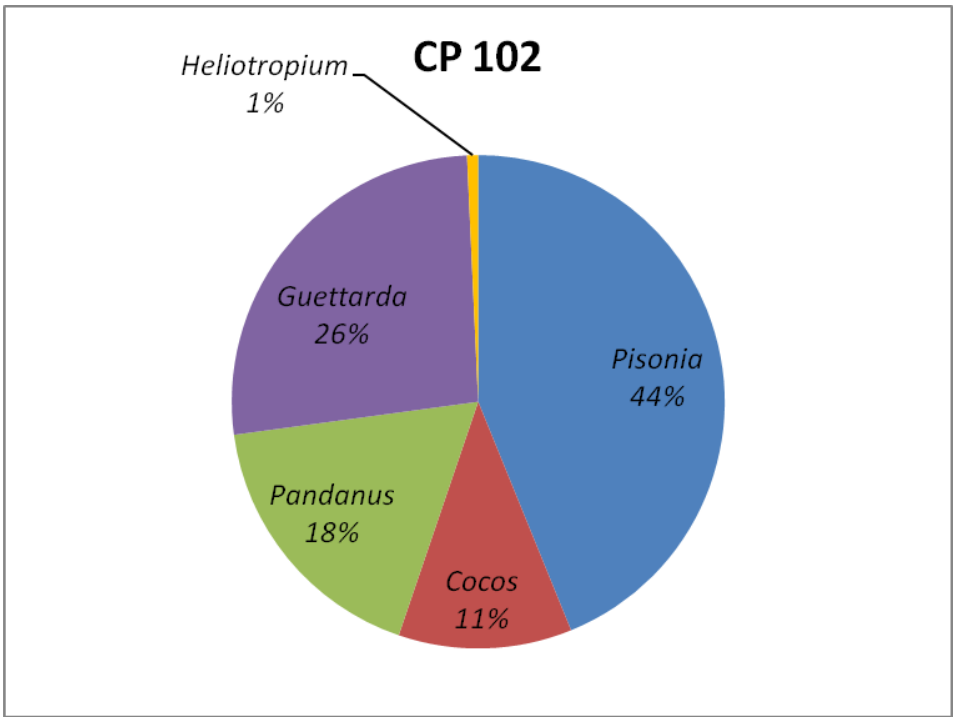
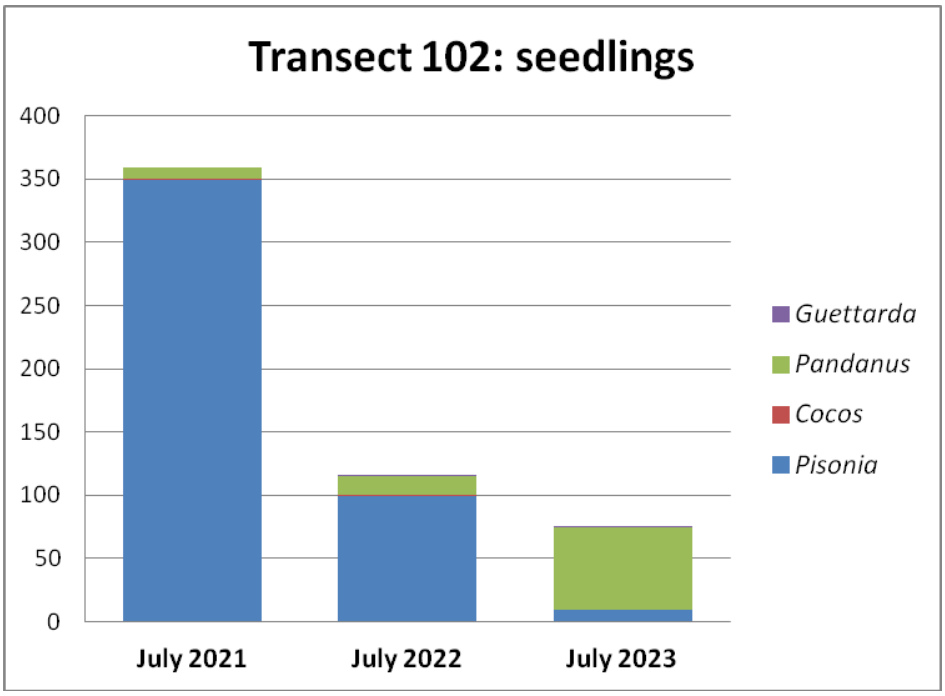

Transect 101: % cover
1,4
1,2
1
0,8
0,6
0,4
0,2
0
July 2021
July 2022
July 2023
Portulaca
Microsorum
Boerhavia
Asplenium

Figure 4. **Forest composition and woody species cover (%BA) in circular plot CP102 (near the shore, east side), and evolution of the seedlings number in the permanent transect TR102 between 2021 and 2023.**





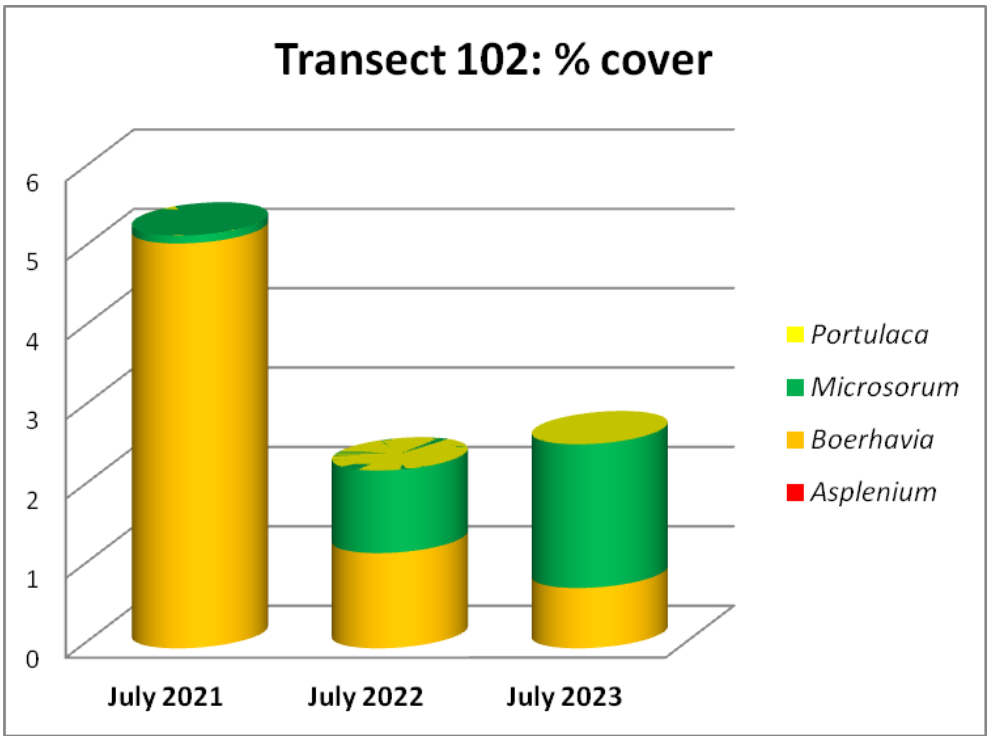
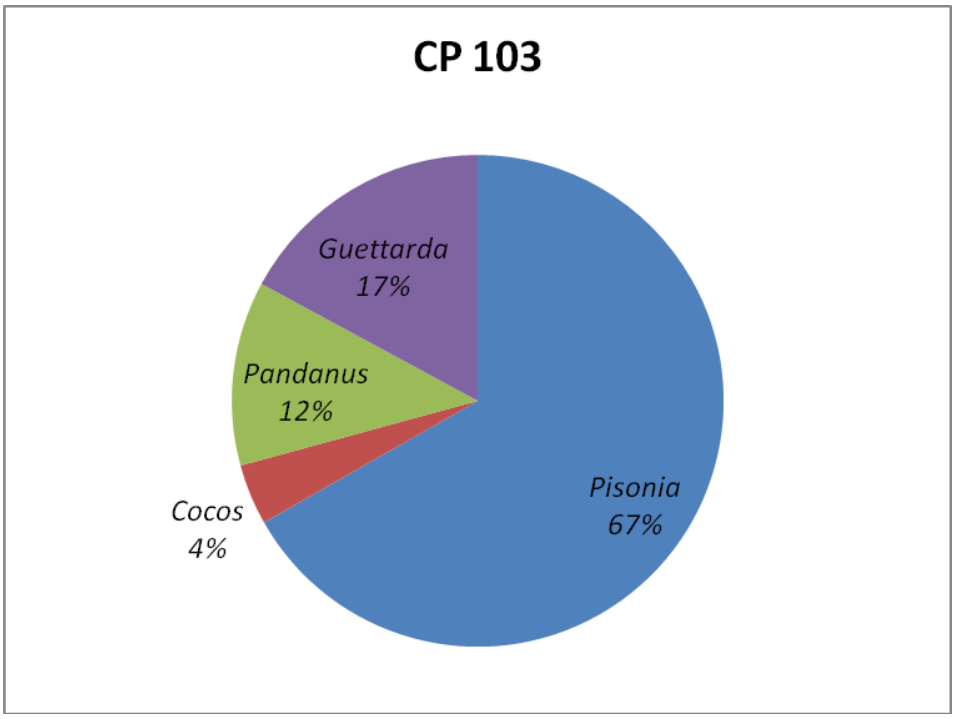


Figure 5. **Forest composition and woody species cover (%BA) in circular plot CP103, and evolution of the seedlings number in the permanent transect TR103 between 2021 and 2023.**



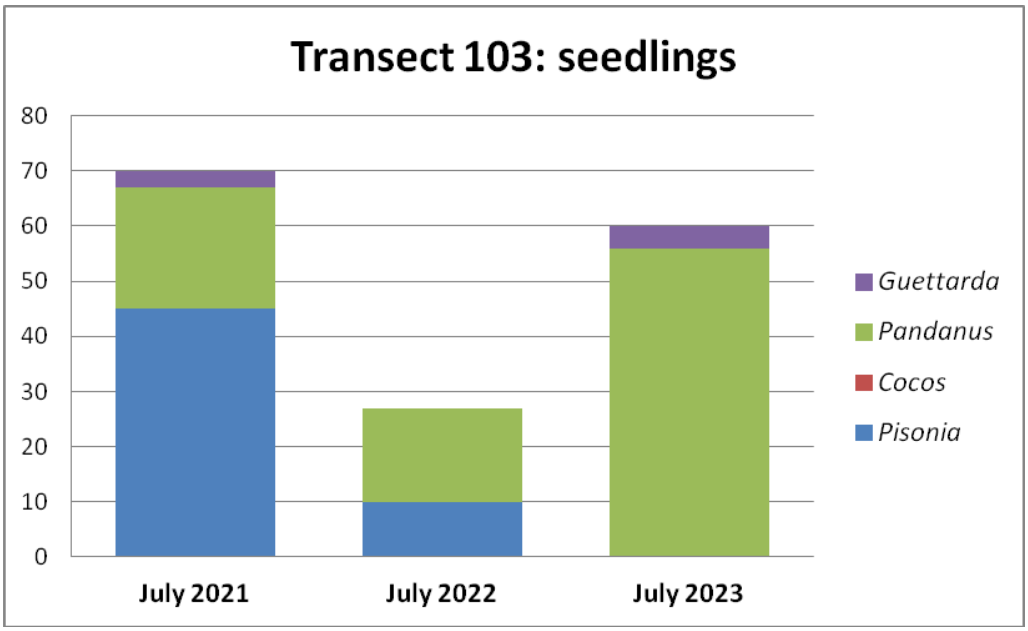
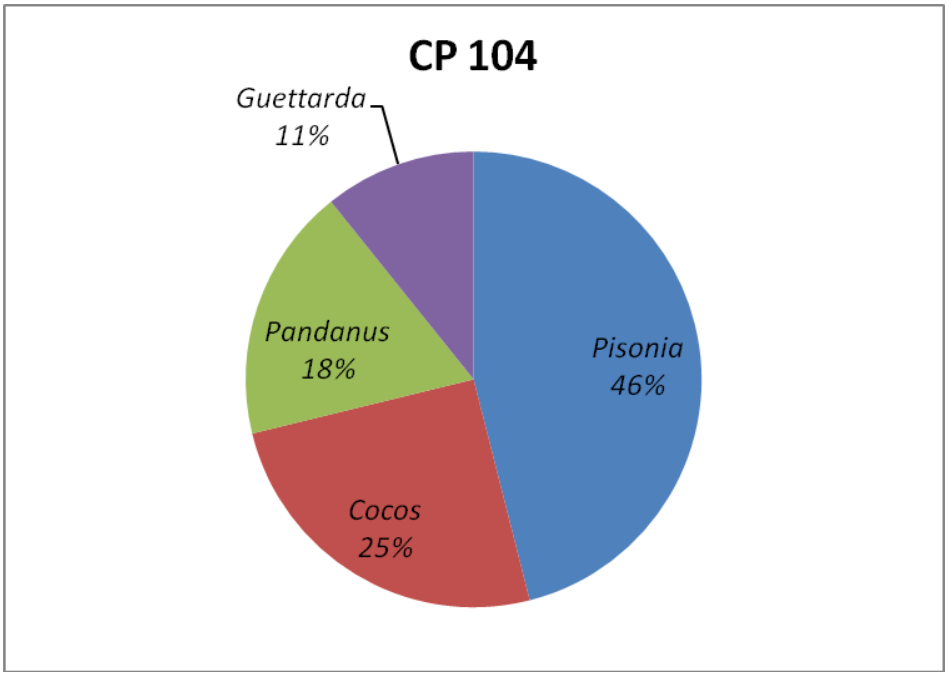
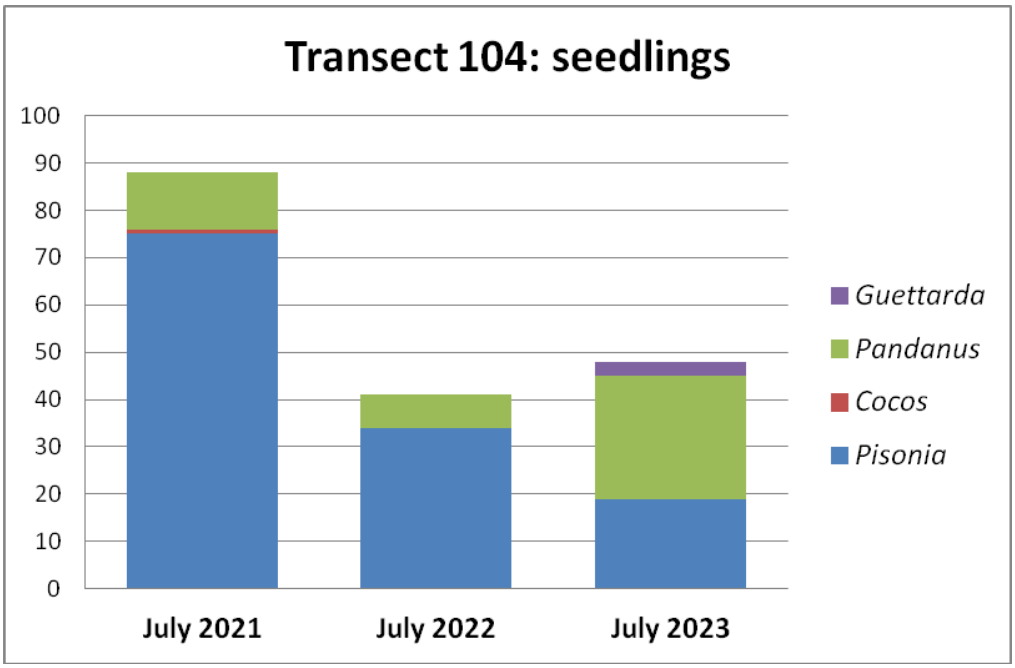


Figure 6. **Forest composition and woody species cover (%BA) in circular plot CP104, and evolution of the seedlings number in the permanent transect TR104 between 2021 and 2023.**




Transect 104: seedlings
100
90
80
70
60
50
40
30
20
10
0
July 2021
July 2022
July 2023
Guettarda
Pandanus
Cocos
Pisonia

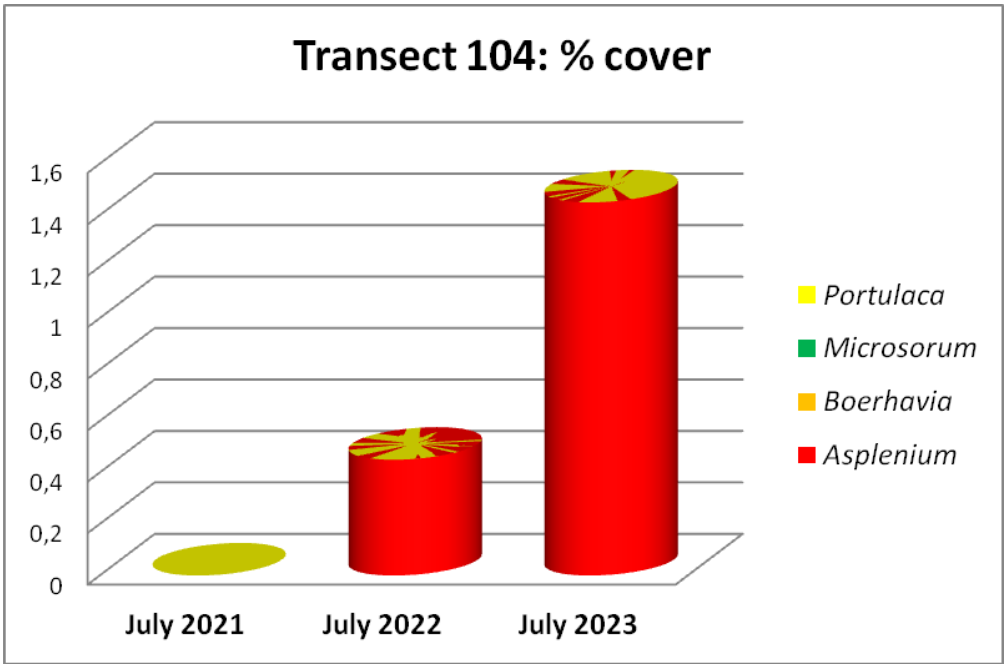
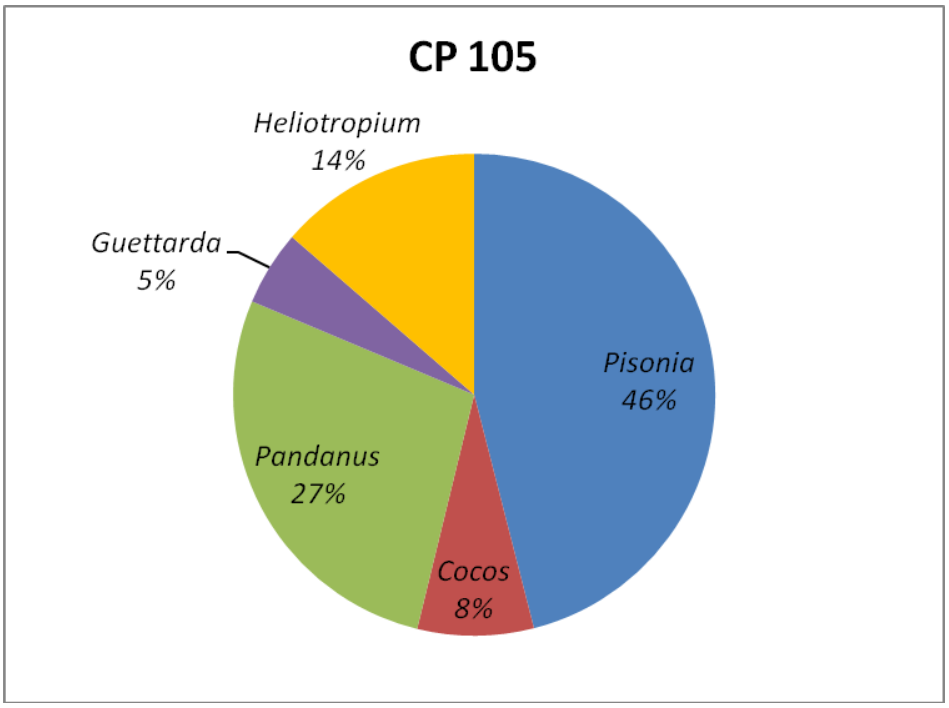
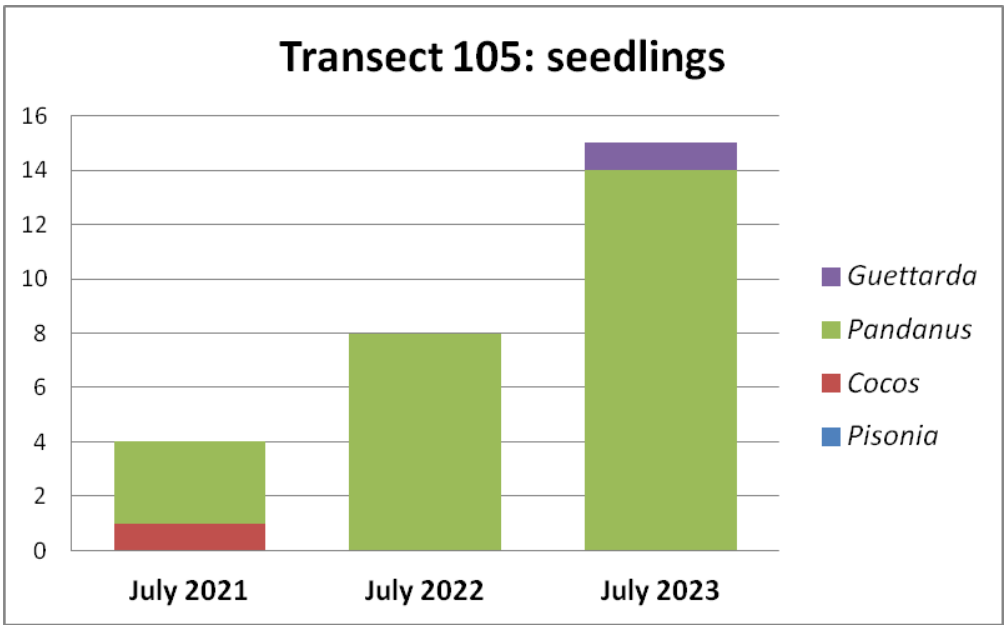

Transect 104: % cover
1,6
1,4
1,2
1
0,8
0,6
0,4
0,2
0
July 2021
July 2022
July 2023
Portulaca
Microsorum
Boerhavia
Asplenium

Figure 7. **Forest composition and woody species cover (%BA) in circular plot CP105 (near the shore, south side), and evolution of the seedlings number in the permanent transect TR105 between 2021 and 2023.**





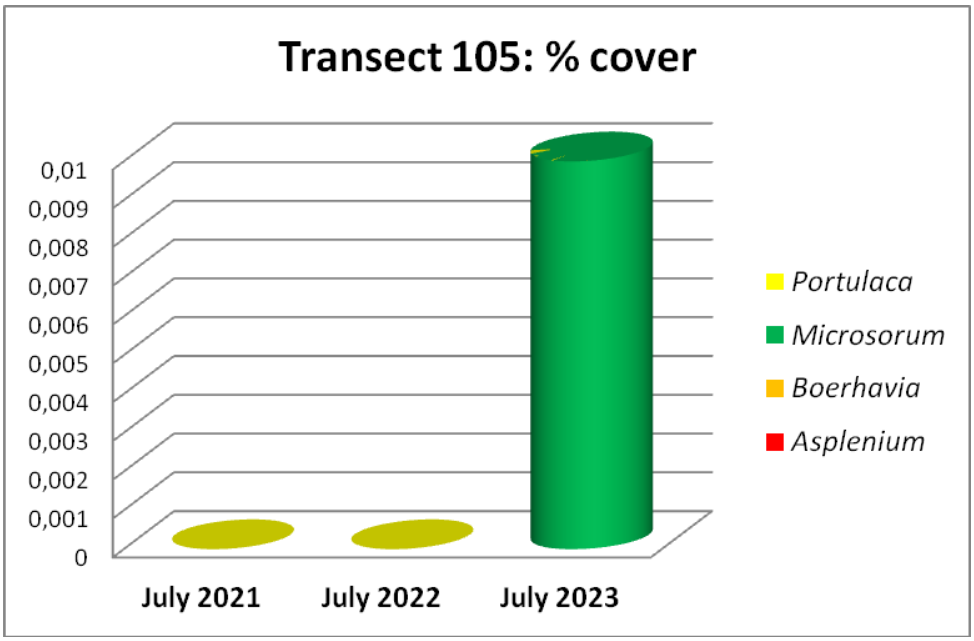
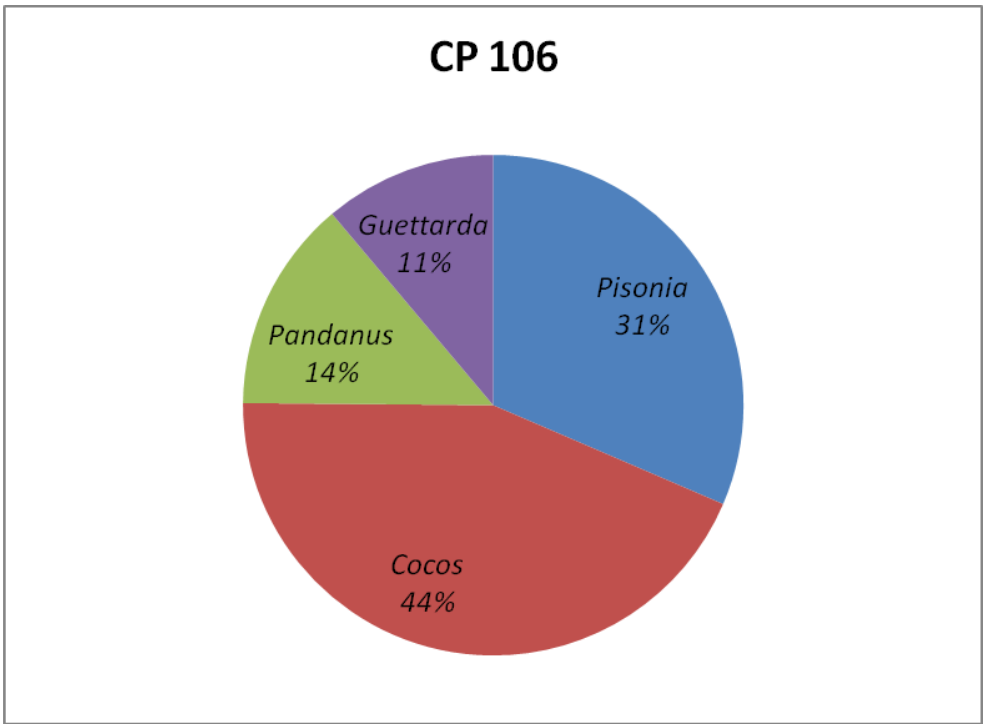


Figure 8. **Forest composition and woody species cover (%BA) in circular plot CP106 (near the shore, west side), and evolution of the seedlings number in the permanent transect TR106 between 2021 and 2023.**



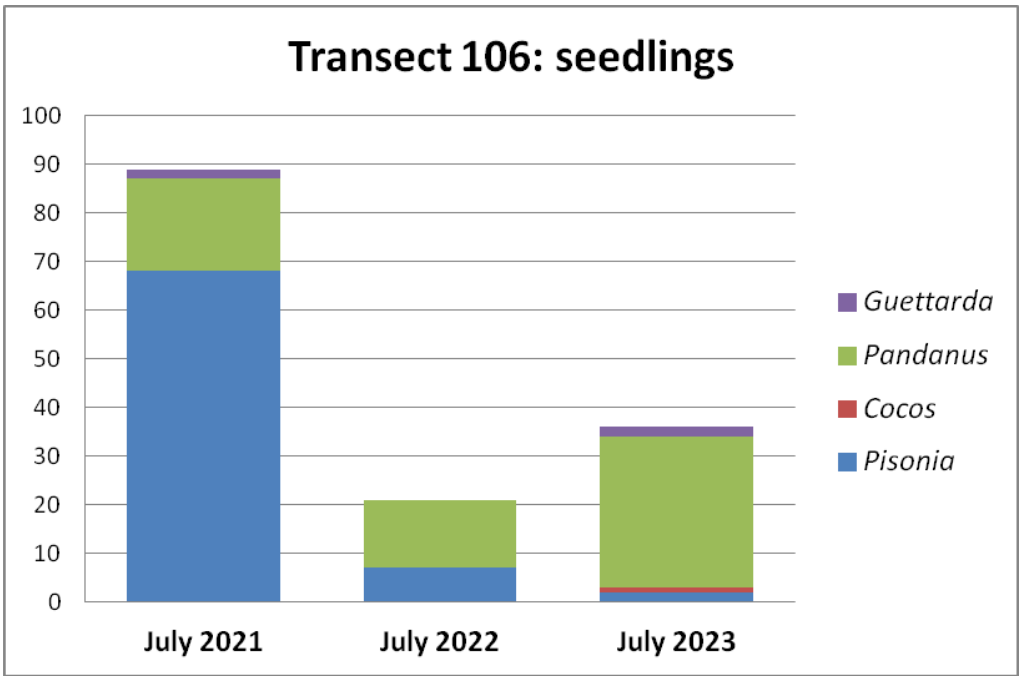
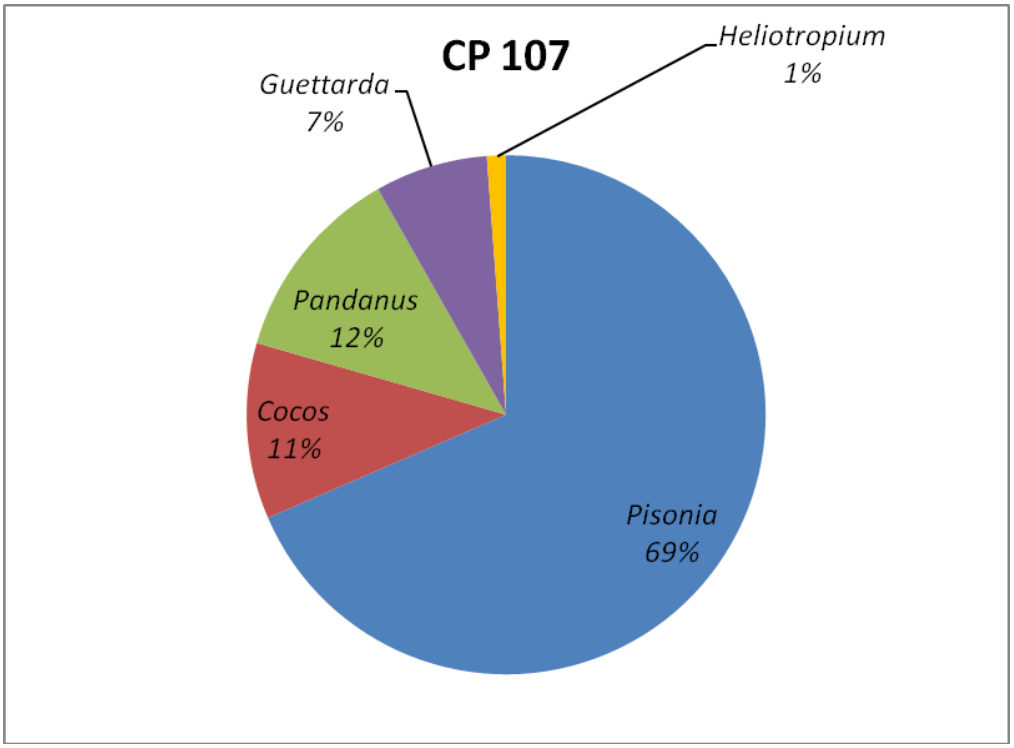
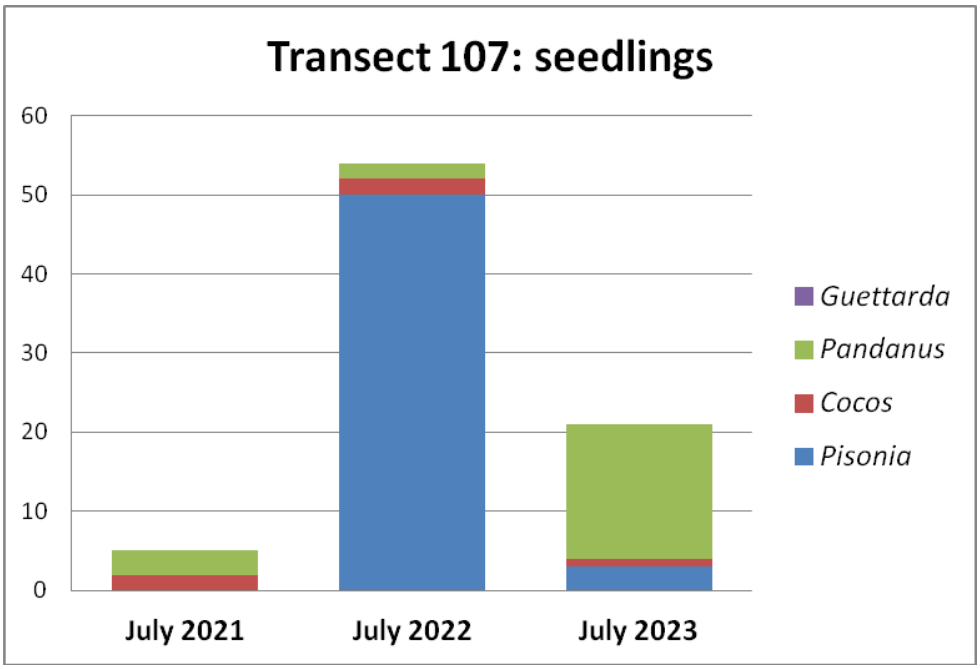


Figure 9. **Forest composition and woody species cover (%BA) in circular plot CP107, and evolution of the seedlings number in the permanent transect TR107 between 2021 and 2023.**




Transect 107: seedlings
60
50
40
30
20
10
0
July 2021
July 2022
July 2023
Guettarda
Pandanus
Cocos
Pisonia

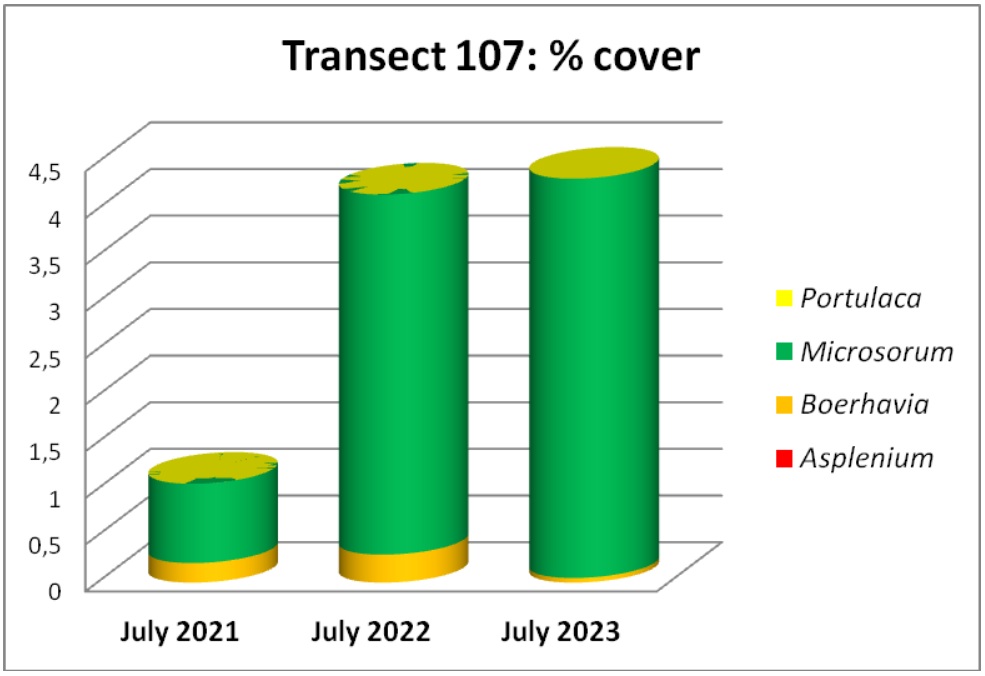
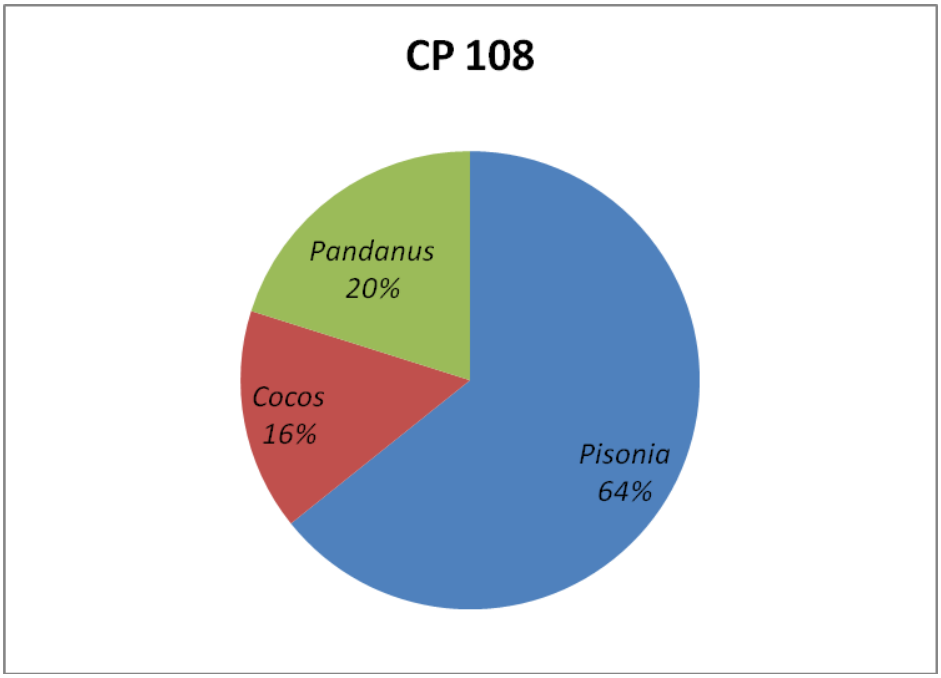
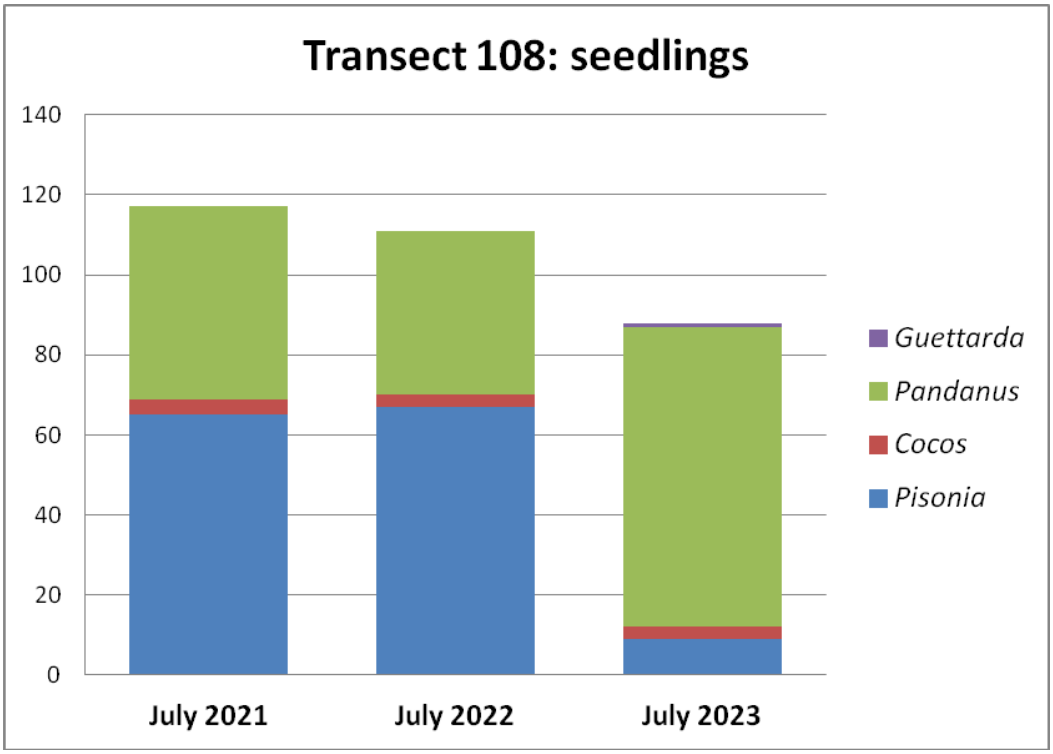

Transect 107: % cover
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0
July 2021
July 2022
July 2023
Portulaca
Microsorum
Boerhavia
Asplenium

Figure 10. Forest composition and woody species cover (%BA) in circular plot CP108, and evolution of the seedlings number in the permanent transect TR108 between 2018 and 2022.





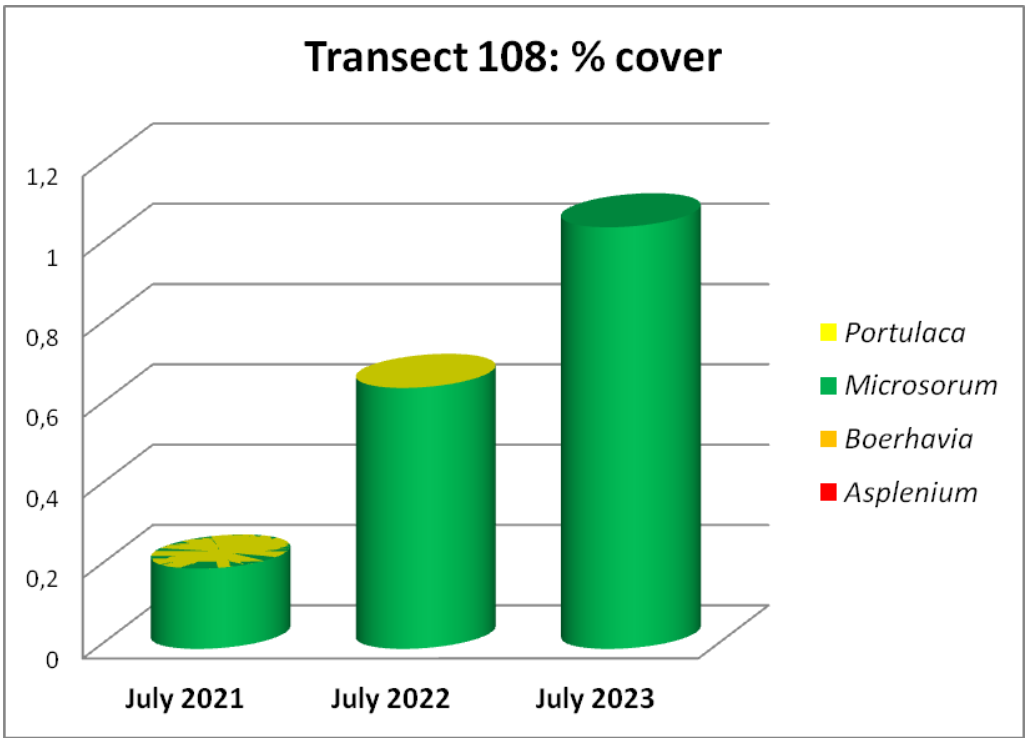
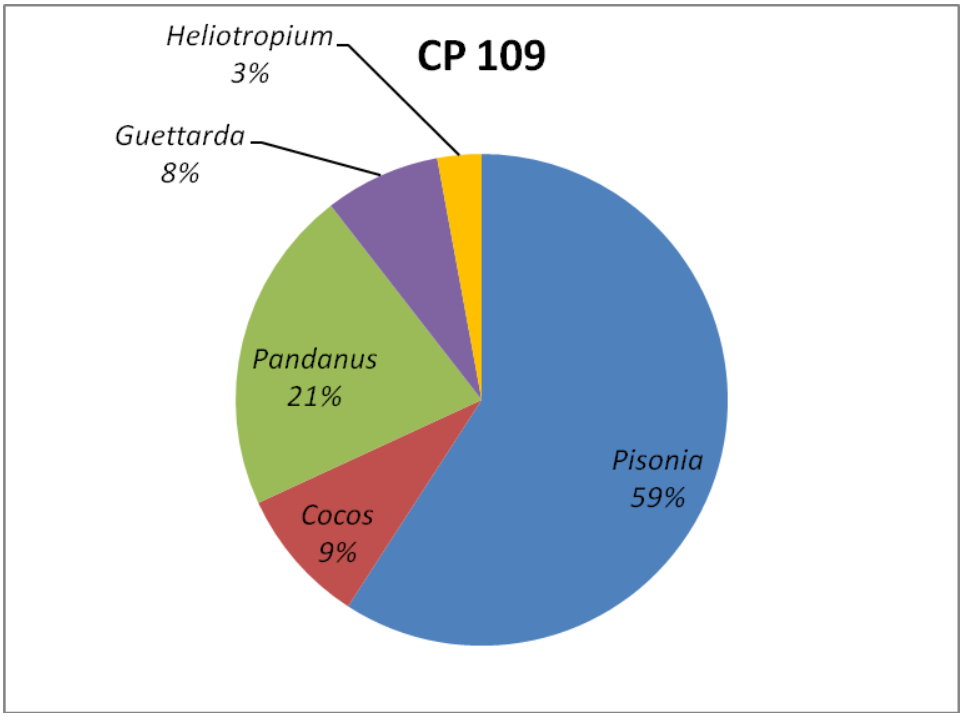
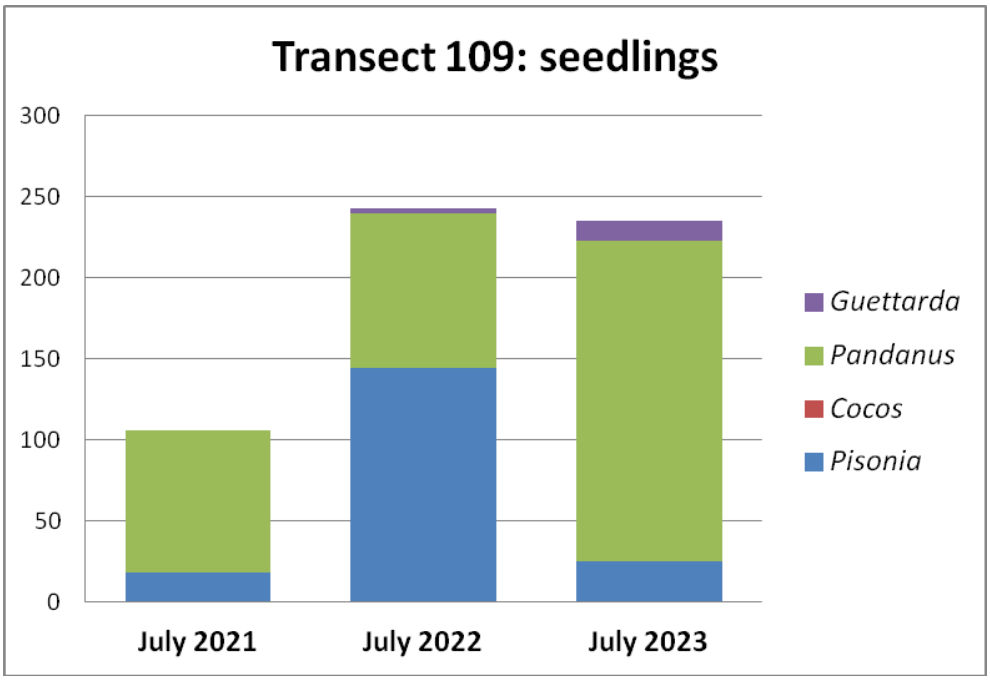


Figure 11. Forest composition and woody species cover (%BA) in circular plot CP109, and evolution of the seedlings number in the permanent transect TR109 between 2021 and 2023.




Transect 109: seedlings
300
250
200
150
100
50
0
July 2021
July 2022
July 2023
Guettarda
Pandanus
Cocos
Pisonia

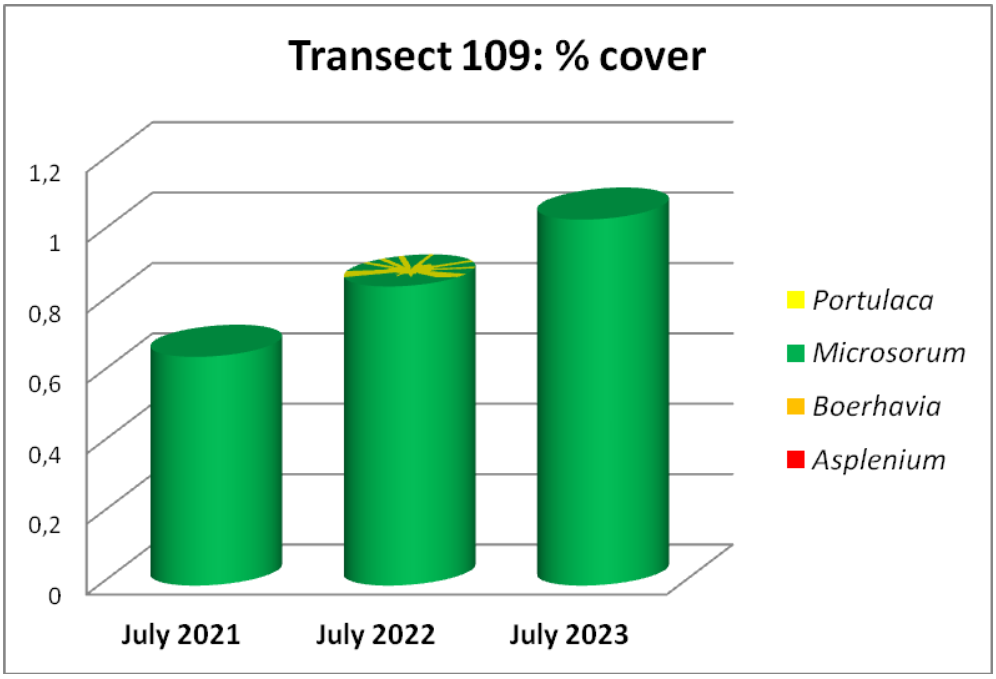
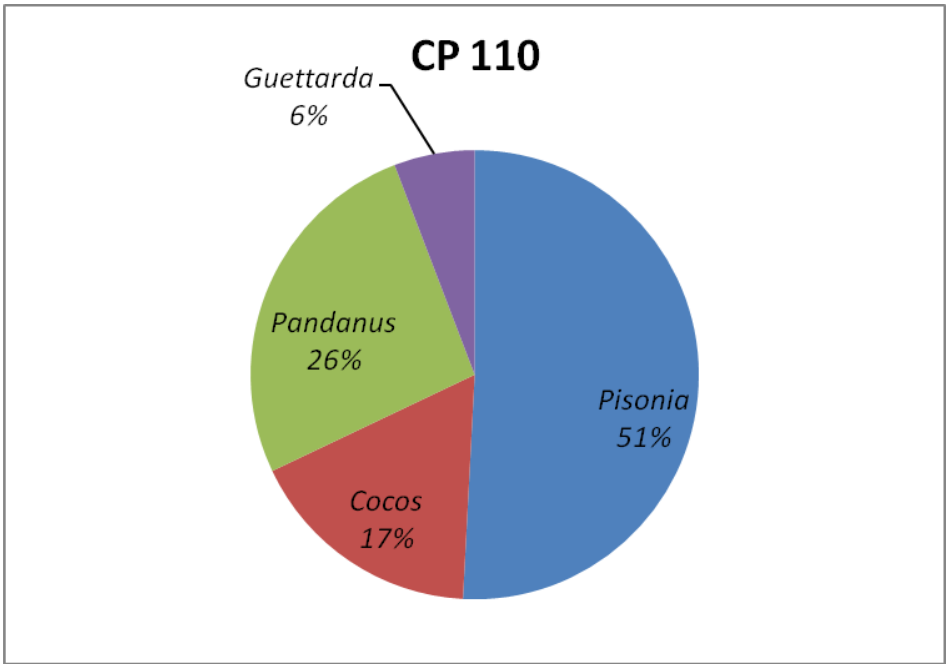
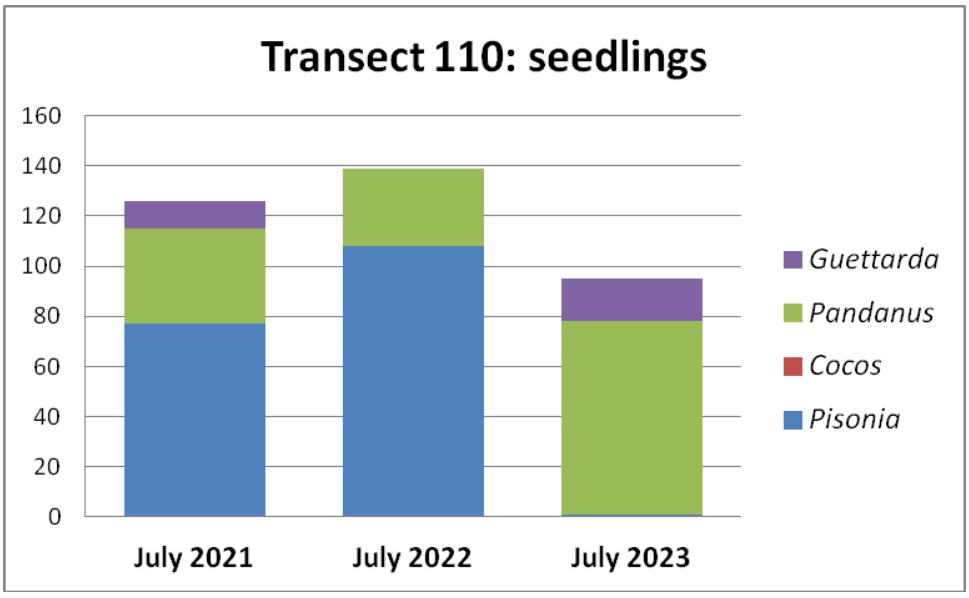
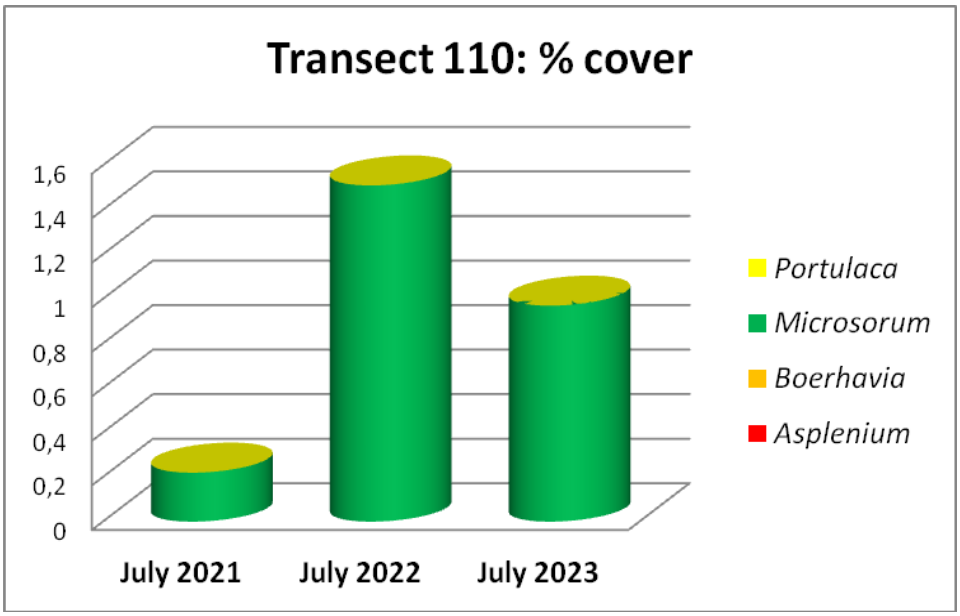

Transect 109: % cover
1,2
1
0,8
0,6
0,4
0,2
0
July 2021
July 2022
July 2023
Portulaca
Microsorum
Boerhavia
Asplenium

Figure 12. Forest composition and woody species cover (%BA) in circular plot CP110, and evolution of the seedlings number in the permanent transect TR110 between 2018 and 2023.







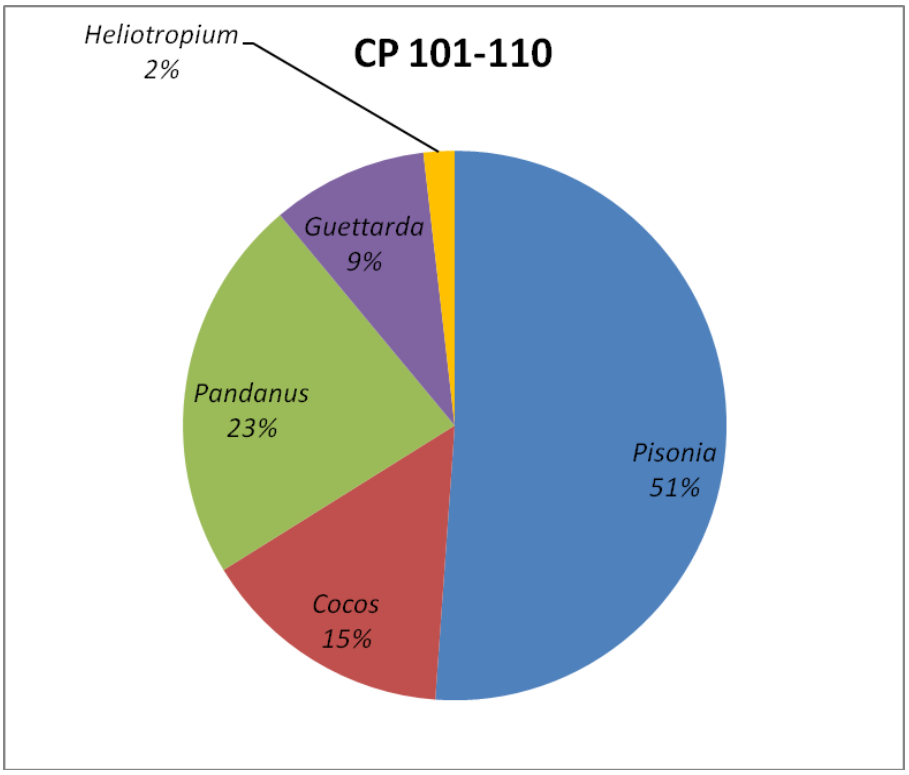
Conclusions and future prospects

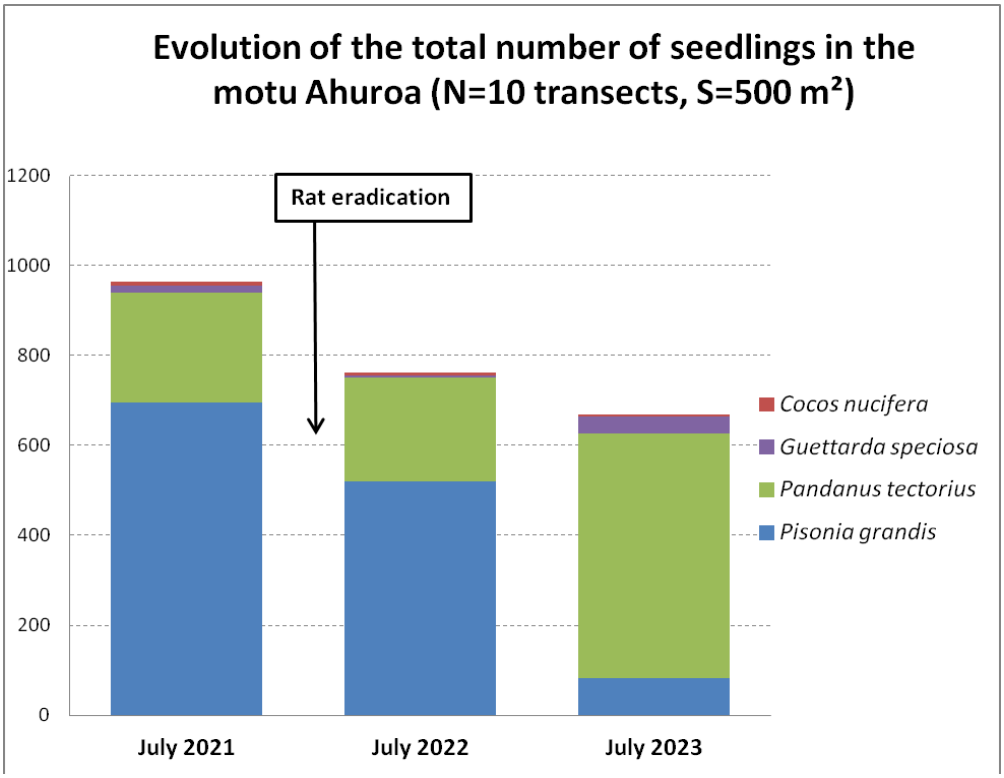
The 10 permanent transects installed in Motu Ahuroa in July 2021 in well-described forest types allowed us to start monitoring native woody plant species recruitment and herbaceous plant cover at a fine scale (number of seedlings per m² and % plant cover in 500 quadrats) after the rat eradication operation conducted in June 2022.

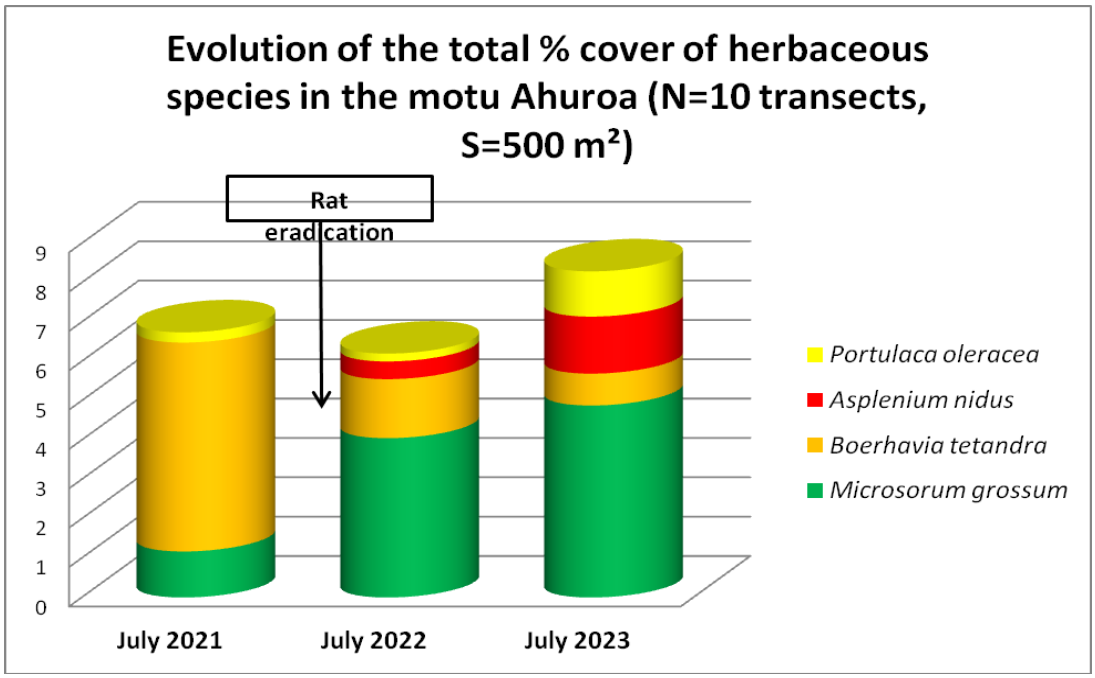
Contrarily to the vegetation study conducted after rat eradication in Palmyra atoll (WOLF *et al.*, 2018 ; MILLER-TER KUILE *et al.*, 2021) and in Motu Reiono (MEYER, 2022), no significant increase of *Pisonia grandis* seedlings was observed in Motu Ahuroa one year after rat eradication, but rather a strong recruitment of *Pandanus tectorius* and *Guettarda speciosa* seedlings (**Fig. 13**). The percentage of plant cover of two native ferns *Asplenium nidus* and *Microsorum grossum* also increased after rat eradication, as well as the non-native *Portulaca oleracea* (**Fig. 13**) whose fleshy stems and leaves are probably eaten by rats. Surprisingly, we didn't observed an expected increase of coconut seedlings as it was observed in Motu Reiono but where coconut plantations are more important.

We strongly recommend a long-term monitoring (up to 5-10 years) of all these permanent transects and quadrats in Motu Ahuroa, to have a more comprehensive view of atoll forest dynamics and successional trajectories after rat eradication in different motus and forest types that are present in Teti'aroa atoll.

Figure 13. Forest composition and woody species cover (%BA) in circular plots (CP101-110) and evolution of seedlings number and herbaceous plant cover (%) in the 10 permanent transects (TR101-110) between 2021 and 2023.







Acknowledgements

This study was conducted in collaboration with the Tetiaroa Society (TS) who funded my airplane tickets between Tahiti and Teti'aroa, and accomodation at the TS Ecostation Research Facility for my field trips in 2021, 2022 and 2023. I deeply thank TS Executive director Frank MURPHY, and the past and current TS head rangers Teva BEGUET and Antonin FIORETTI for organizing my numerous relatively short-term (but intense!) field trips, the TS rangers Lusiano KOLOKILAGI, Guillaume MARREC for the boat drives, the volunteer Poevai NOUVEAU for her assistance on the field in July 2021, Solène FABRE BARROSO (Master 2 EIO, Université de la Polynésie française) for all the tree measurements in the circular plots in January 2022, and the Brando guide Rémi CONTE and Tobias FISCHER (PhD candidate, Laboratoire Géosciences du Pacifique Sud, UPF) for their assistance in the field in July 2023, as well as Benoît STOLL (GePaSud, UPF) for providing the satellite image with the locations of the study plots. Māuruuru roa!

Literature cited

MEYER, J.-Y. 2022. Five years (2018-2022) monitoring of plant recruitment on Motu Reiono, Teti'aroa atoll (Society Islands): effects of rat eradication and natural disturbances. Délégation à la Recherche, Tetiaroa Society, Papeete, 18 pages + Annexe. *Unpublished report.*

WOLF, C. A., YOUNG, H. S., ZILLIACUS, K. M., WEGMANN, A. S., McKOWN, M., HOLMES, N. D., TERSHY, B. R., DIRZO, R., KROPIDLOWSKI, S. & CROLL, D.A. 2018. Invasive rat eradication strongly impacts plant recruitment on a tropical atoll. *PLoS ONE* 13, e0200743.

YOUNG, H. S., RAAB, T. K., McCAULEY, D. J., BRIGGS, A. A. & DIRZO, R. 2010. The coconut palm, *Cocos nucifera*, impacts forest composition and soil characteristics at Palmyra atoll, Central Pacific: palms impact forest and soil characteristics. *Journal of Vegetation Science* 21: 1058-1068.

APPENDIX: Photos of some woody plant seedlings and herbaceous plants in the permanent transects and quadrats of motu Ahuroa in July 2023 *i.e.* one year after rat eradication (credit: J.-Y. MEYER©)

Photo 1. *Pisonia grandis* germinating seed in a quadrat of TR109.

Photo 2. *Pandanus tectorius* seedlings and ripe drupes in a quadrat of TR110.

Photo 3. *Guettarda speciosa* young seedlings in a quadrat of TR104.

Photo 4. The native fern *Asplenium nidus* in TR104, with a few coconuts on the ground.

Photo 5. The native fern *Microsorum commutatum* in TR110, with a few coconuts on the ground.

Photo 6. The non-native *Portulaca oleracea* near TR101 with its fleshy stems and leaves.