Biodiversity evaluation with eDNA

Missions 2022 with Beauval Nature

Sabah – Bornéo in collaboration with the association of **HUTAN** and **Danau Girand Field Centre.**

Redactors: Marc Ancrenaz, Gabriel Michelin
Statistical analysis: Gilles Maurer

Acknowledgement

We extend our sincere gratitude to Dr Symphorosa Sipangkui, Veterinary Officer from Sabah Wildlife Department

We would like to thank Eric Bairrão Ruivo, Benoit Goossens, and Karel Soulard for their contribution to this project.

Preamble

This mission follows on from an initial test conducted in 2019 on the Kinabatangan River and its tributaries. This initial study enabled the eDNA method to be evaluated in conditions typical of Borneo's tropical climate, the results of different primers to be analyzed, the distribution of biodiversity along the river to be studied, and HUTAN teams to be trained in the use of this innovative method.

In 2022, two series of samples were taken from different areas studied by HUTAN, including oil palm plantations, ecological corridors, and forests less impacted by human activity. The vertebrate primer was used to verify the effectiveness of the eDNA method in biodiversity monitoring protocols. It was also used to evaluate the detection capacity of certain cryptic species compared to methods traditionally used to conduct wildlife inventories.

Additional data was collected from several aquatic environments, both from sites already surveyed in the past in order to analyze changes in results, and from new areas favorable to certain fish species in order to search for a discreet species, the kaloi.

Table des matières

Project objectives

- Evaluate the effectiveness of eDNA in stagnant water (2nd campaign) compared to running water (1st campaign),
- Evaluate biodiversity at various treatment sites monitored by Hutan teams,
- Quickly collect data for comparison with data already acquired by Hutan as part of their long-term biodiversity monitoring,
- Detect rare and/or cryptic species,
- Train Hutan teams in the eDNA approach,
- Evaluate the feasibility of this new approach for biodiversity monitoring in an agricultural landscape dominated by oil palm plantations.

Figure 1: Palm oil plantation and forest

eDNA methodology

Protocol :

Thirty-two Spygen stagnant water ladle kits were used. We can analyze 400 meters of banks in a stagnant aquatic site with one kit (ponds, lakes, marshes, etc.).

Two liters of water are collected using a ladle, with 20 meters separating two samples (Spygen stagnant water protocol). The collected water is then filtered to collect eDNA. After filtration, a buffer solution preserved in a buffer solution until laboratory analysis in France.

Once at the laboratory, the eDNA from the filters is extracted and then amplified by PCR.

The laboratory then transmits the results for the different MOTUs identified. A MOTU (Molecular Operational Taxonomic Unit) is compared with sequences contained in the public reference database GenBank. In some cases, the comparison allows us to identify the MOTU down to the species level, but in others, the MOTU is identified at lower levels: *Genus, Family, Order, Class*, etc.

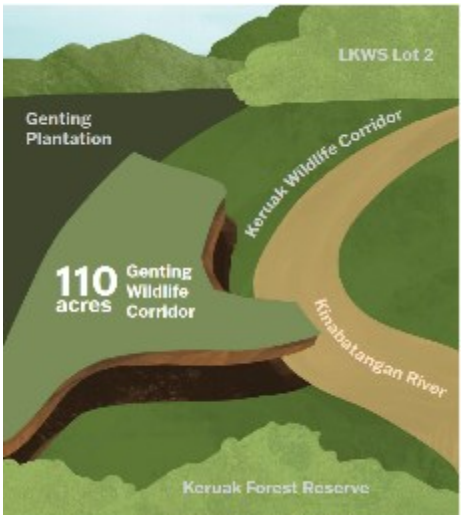
Here, we have kept only the MOTUs with the Species and Genus levels. A review of the results and a comparison with existing knowledge of species distribution allowed us to refine some of the MOTUs.

We opted for this stagnant water kit to analyze several environments, including lakes, marshes, ditches, and puddles. Indeed, depending on the habitats examined, the water may be drained, collected in ditches such as in oil palm plantations, or, quite rarely, found as puddles in forests with little human impact.

Figure 2 : Mangrove in a brackish environment

Figure 3 : Oxbow lake

Sampling plan



Sampling was carried out in different landscapes, all of which were studied by Hutan:

- Industrial palm plantations,

- Agroforestry landscapes (trees and palms planted together at the same time),

- Restored ecological corridors between isolated forest blocks at different stages of regeneration,

- Oxbow lakes,

- Natural forests,

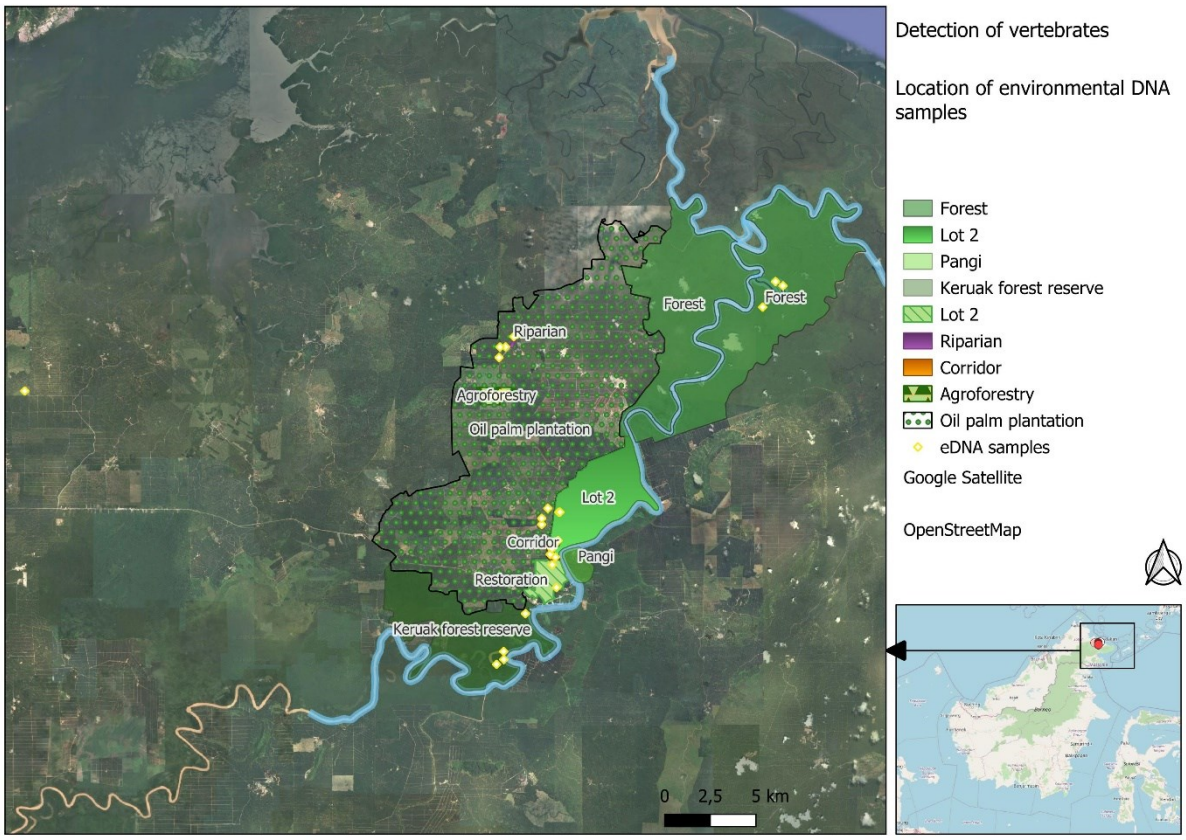


Figure 4 : Location of eDNA sampling sites

Overall results

There are several levels to read the results

This section provides an overview of the results obtained. In total, samples of the second campaign identified 84 species, with mammals representing the most diverse class with 33 different species, followed by birds (25), fish (13), amphibians (9), and reptiles (4): Figure 5. Unlike fish, mammals are generally more studied and better identified in genetic databases, contributing to a significantly higher identification rate.

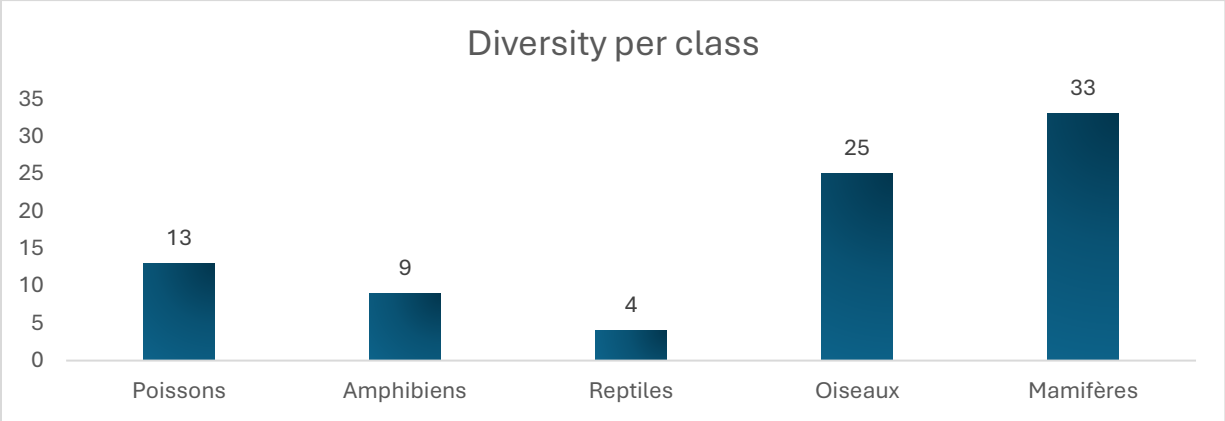


Figure 5 : Diversity per class : Fish, Amphibians, Reptiles, Birds, Mammals

In terms of the IUCN vulnerability risks, **25% of the species are vulnerable to critically endangered:** Fig. 6.

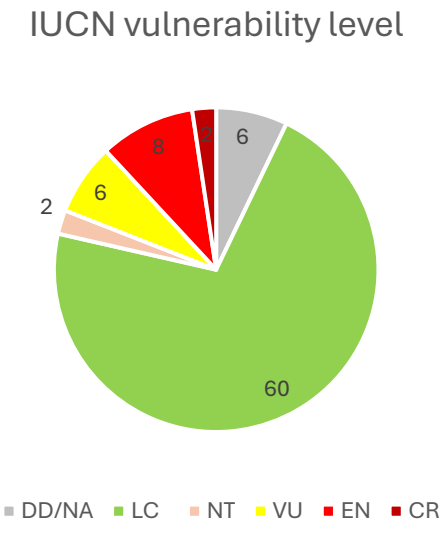


Figure 6 : Levels of vulnerability of species detected

Species with a conservation status of Vulnerable (VU) or higher are specially mapped and an extract from their IUCN data sheet is provided below.

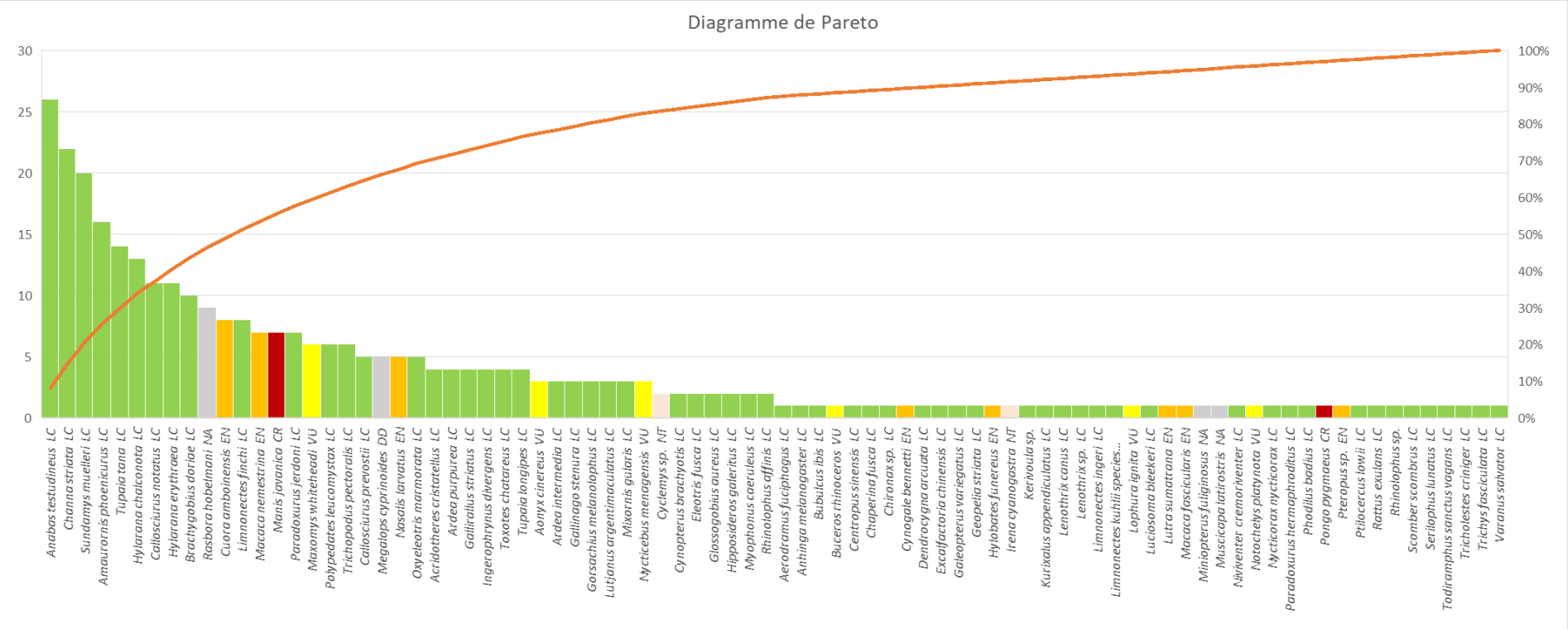


Figure 7 : Pareto chart

The Pareto chart shows the frequency of species detection. It allows to visualize and evaluate the representativeness of each species across all samples collected. For example, the graph indicates that the Mueller's rat, *Sundamys muelleri* is detected in 20% of the samples.

The terrestrial species that are the most frequently identified in the Pareto chart (score >10% or even >5%) are all common species regularly detected by Hutan teams during biodiversity monitoring. These species are generalists and highly adaptable, explaining their relative abundance in eDNA inventories.

- **Fish** : the two common fish species are identical to the results from our 2019 analyses. ***Anabas testudineus*** **(LC),** the climbing perch, is present in over 25% of our surveys. It is a freshwater fish species adapted to low-oxygen environments. Individuals of this species are very resilient and can even survive out of water for several days and move across land between two bodies of water. This fish is therefore very common and is found in all the environments tested. Another fish species that is very common in our samples is ***Channa striata*** **(LC)** or Sankehead murrel (Haruan). This carnivorous species is widespread throughout most of Asia. This top predator can also survive in muddy conditions because it breathes air through its skin.
  It is interesting to note that the Bumblebee Goby (Brachydorius doriae) is also commonly found in our samples. This small fish is prized by aquarium enthusiasts because of its yellow and black colouring. It can be found in clear, turbid and polluted drain water.

- **Mammals** : small mammals species like the Muller's rat, the common tree shrew and the plantain squirrel are common species that Hutan teams have identified in all environments included in the biodiversity monitoring plots. This abundance is reflected in the results of the Pareto diagram, as these species are present in more than 10% of the sampled sites.

- **Amphibians** : the two species classed in the top group (>10%) are also common species found particularly in degraded and heavily anthropized areas.

- **Birds** : one bird species, the white-bellied waterhen was prevalent in our eDNA samples. This species is dependent on open degraded aquatic environments, which explains its abundance in our results.

The commonest endangered species in our samples is a turtle, ***Cuora amboinensis*** **(EN)**, or Southeast Asian Box Turtle. This species is common in the Kinabatagan but is declining in many areas due to trafficking for meat and captivity.

The Pig-tailed macaque, very common in the Kinabatangan, moves across very large areas, explaining its high score on the Pareto chart (figure 7). This species of macaques, which is endangered in many areas of its range, is quite common in kinabatangan. It moves mainly on the ground, explaining the abundance of genetic material collected in our samples.

.

The Venn diagram identifies the specific and common diversity of the three environments studied: the forest, the oil palm plantation and the corridor created to connect two forest island.

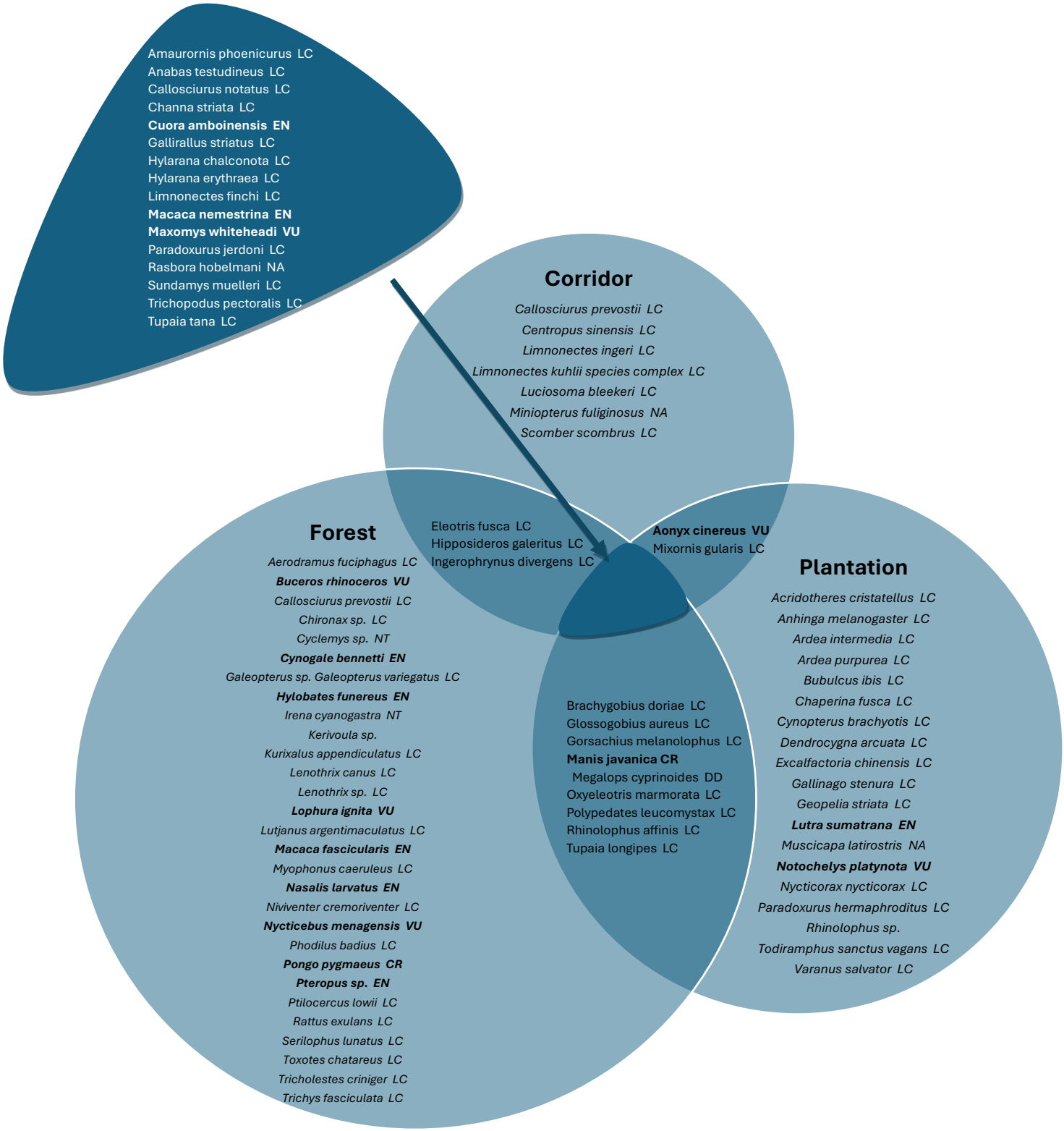


Figure 8 : Venn diagram

As expected, species found at the intersection of the three habitat types are mostly generalists that can survive and adapt fairly well to habitat disturbance. It is noteworthy that we detected the endangered *Lutra sumatrana* only in the plantations, while the CE pangolin was found not only in plantations but also in the forest (see below).

Figure 8 : List of taxa identified down to the species level

Classes	Ordres	Familles	Espèces
Actinopteri	Anabantiformes	Anabantidae	Anabas testudineus LC
		Channidae	Channa striata LC
		Osphronemidae	Trichopodus pectoralis LC
	Cypriniformes	Danionidae	Luciosoma bleekeri LC
			Rasbora hobelmani NA
	Elopiformes	Megalopidae	Megalops cyprinoides DD
	Gobiiformes	Eleotridae	Eleotris fusca LC
			Oxyeleotris marmorata LC
		Gobiidae	Brachygobius doriae LC
			Glossogobius aureus LC
	Lutjaniformes	Lutjanidae	Lutjanus argentimaculatus LC
	Scombriformes	Scombridae	Scomber scombrus LC
	(vide)	Toxotidae	Toxotes chatareus LC
Aves	Anseriformes	Anatidae	Dendrocygna arcuata LC
	Apodiformes	Apodidae	Aerodramus fuciphagus LC
	Bucerotiformes	Bucerotidae	Buceros rhinoceros VU
	Charadriiformes	Scolopacidae	Gallinago stenura LC
	Columbiformes	Columbidae	Geopelia striata LC
	Coraciiformes	Alcedinidae	Todiramphus sanctus vagans LC
	Cuculiformes	Centropidae	Centropus sinensis LC
	Galliformes	Phasianidae	Excalfactoria chinensis LC
			Lophura ignita VU
	Gruiformes	Rallidae	Amaurornis phoenicurus LC
			Gallirallus striatus LC

	Passeriformes	Eurylaimidae	Serilophus lunatus LC
		Irenidae	Irena cyanogastra NT
		Muscicapidae	Muscicapa latirostris NA
			Myophonus caeruleus LC
		Pycnonotidae	Tricholestes criniger LC
		Sturnidae	Acridotheres cristatellus LC
		Timaliidae	Mixornis gularis LC
	Pelecaniformes	Anhingidae	Anhinga melanogaster LC
		Ardeidae	Ardea intermedia LC
		Ardeidae	Ardea purpurea LC
		Ardeidae	Bubulcus ibis LC
		Ardeidae	Gorsachius melanolophus LC
		Ardeidae	Nycticorax nycticorax LC
	Strigiformes	Tytonidae	Phodilus badius LC
Amphibia	Anura	Bufonidae	Ingerophrynus divergens LC
		Dicroglossidae	Limnonectes finchi LC
			Limnonectes ingeri LC
			Limnonectes kuhlii species complex LC
		Microhylidae	Chaperina fusca LC
		Ranidae	Hylarana chalconota LC
			Hylarana erythraea LC
		Rhacophoridae	Kurixalus appendiculatus LC
			Polypedates leucomystax LC
Mammalia	Carnivora	Mustelidae	Aonyx cinereus VU
			Lutra sumatrana EN
		Viverridae	Cynogale bennetti EN
			Paradoxurus jerdoni LC
			Paradoxurus hermaphroditus LC
	Chiroptera	Hipposideridae	Hipposideros galeritus LC
		Pteropodidae	Chironax sp. LC
			Cynopterus brachyotis LC

		Rhinolophidae	Pteropus sp. EN
			Rhinolophus affinis LC
			Rhinolophus sp.
		Vespertilionidae	Kerivoula sp.
			Miniopterus fuliginosus NA
	Dermoptera	Cynocephalidae	Galeopterus variegatus LC
	Pholidota	Manidae	Manis javanica CR
	Primates	Cercopithecidae	Macaca fascicularis EN
			Macaca nemestrina EN
			Nasalis larvatus EN
		Hominidae	Pongo pygmaeus CR
		Hylobatidae	Hylobates funereus EN
		Lorisidae	Nycticebus menagensis VU
	Rodentia	Hystricidae	Trichys fasciculata LC
		Muridae	Lenothrix canus LC
			Lenothrix sp. LC
			Maxomys whiteheadi VU
			Niviventer cremoriventer LC
			Rattus exulans LC
			Sundamys muelleri LC
		Sciuridae	Callosciurus notatus LC
			Callosciurus prevostii LC
	Scandentia	Tupaiidae	Ptilocercus lowii LC
			Tupaia longipes LC
			Tupaia tana LC
Reptilia	Squamata	Varanidae	Varanus salvator LC
	Testudines	Geoemydidae	Cuora amboinensis EN
			Cyclemys sp. NT
			Notochelys platynota VU

When reading the list of species detected, it appears that some species are common to all three habitats studied, some of which have a proven level of vulnerability, such as *Cuora amboinensis* (EN), *Macaca nemestrina* (EN) and *Maxomys whiteheadi* (VU). All these species are characterised by proven properties of adaptation to environmental degradation; they are mainly terrestrial but live close to wetlands.

It is surprising to note that common species that are regularly detected by our teams in all the environments studied have only been identified in one or two environments using eDNA. For example :

- ***Ardea intermedia*** *(middle egret),* ***Bulbulus ibicus*** *(cattle egret),* ***Varanus salvator*** *(monitor lizard): only found in plantations, whereas these species, which are mainly aquatic, are present in all ecosystems in Kinabatangan*
- ***Macaca fascicularis*** *(long-tailed macaque) is only found in forests, although it is present in all environments.*

This finding is explained by the fact that eDNA method is more effective with mammals and fish rather than reptiles and birds, as the former species release more genetic material into the environments than the later ones.

Several remarkable results:

- ***Lutra sumatrana*** (hairy nosed otter): this extremely elusive species was only detected in oil palm plantations. This finding is noteworthy since only a few records of this species exist for Kinabatangan and all in forest or oxbow lakes.
- ***Scomber scombrus*** (mackerel): this species is widely consumed by people in canned food or fresh (from the market) and appear thus to be a “pollutant” from food-related origin,
- **Orang-outang:** the species was only detected in the forest, although it also ranges in oil palm plantations and forest corridors.
- Surprisingly, we failed to detect any DNA from the Asian elephant, a common and generalist species found in all habitats in Kinabatangan. However, this species is currently absent from the genetic database used for this study, explaining the result. For this species, eDNA is not useful to study this species, is not a cryptic species.

Unsurprising, we identified more species in the forest, this environment being the richest in endangered or vulnerable species.

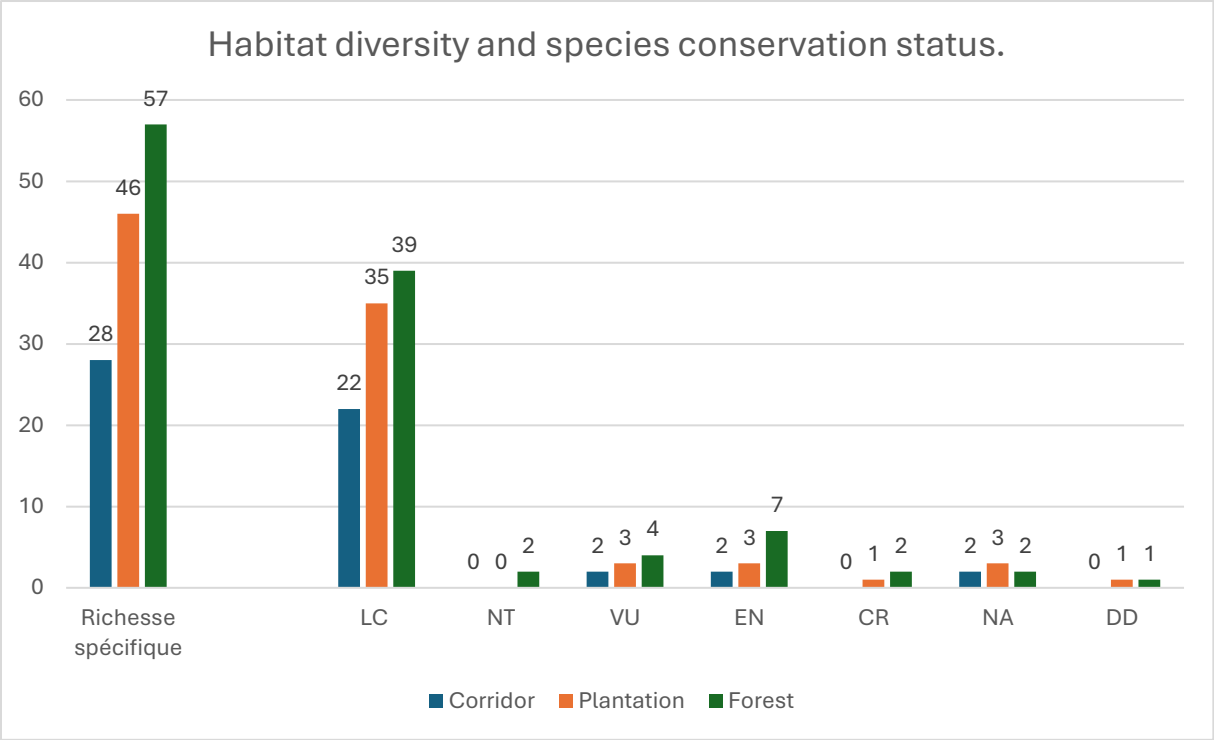


Figure 9 : Habitat diversity and species conservation status.

The figure above (Fig. 9) shows another interpretation of the results. When comparing the three habitats studied, the forest shows the most diverse and a greater number of animals species with an unfavourable conservation status.

The eDNA results concerning the ecological corridor contrast a lot with the results of the biodiversity monitoring carried out by Hutan teams. First, the latter indicates a number of intermediate species between forest and plantations, whereas the eDNA result indicates a lower number of species in the corridor. It's important to remember that the role of the corridor is not to accommodate species so they can complete their entire life cycle, but rather to provide passageways between forest islands. Thus, the presence of animal species on the corridor is therefore short-lived. They are merely passing through and, as a result, leave proportionally less genetic material behind, which may explain this low eDNA diversity. For this reason, the eDNA methodology may not the most suitable tool for verifying the effectiveness of the corridor for wildlife.

The graph (figure 10) below models the differences between the three habitats with a projection of the results (100 samples).

As expected, the forest habitat has the greatest diversity and variability (very poor Forest 2 and very high diversity Forest1 and Forest lot 2).

Old plantation (palm old) appears to be less diverse than the forest (Forest 1 and Forest lot 2) but more diverse than young plantations. Indeed, the tridimensional environment characterizing mature plantations can accommodate a certain number of species that are not found in the early

development stages of an oil palm plantation. Finally, corridors, as shown by the results of Hutan's biodiversity monitoring, appear to constitute an intermediate habitat between forest and plantation.

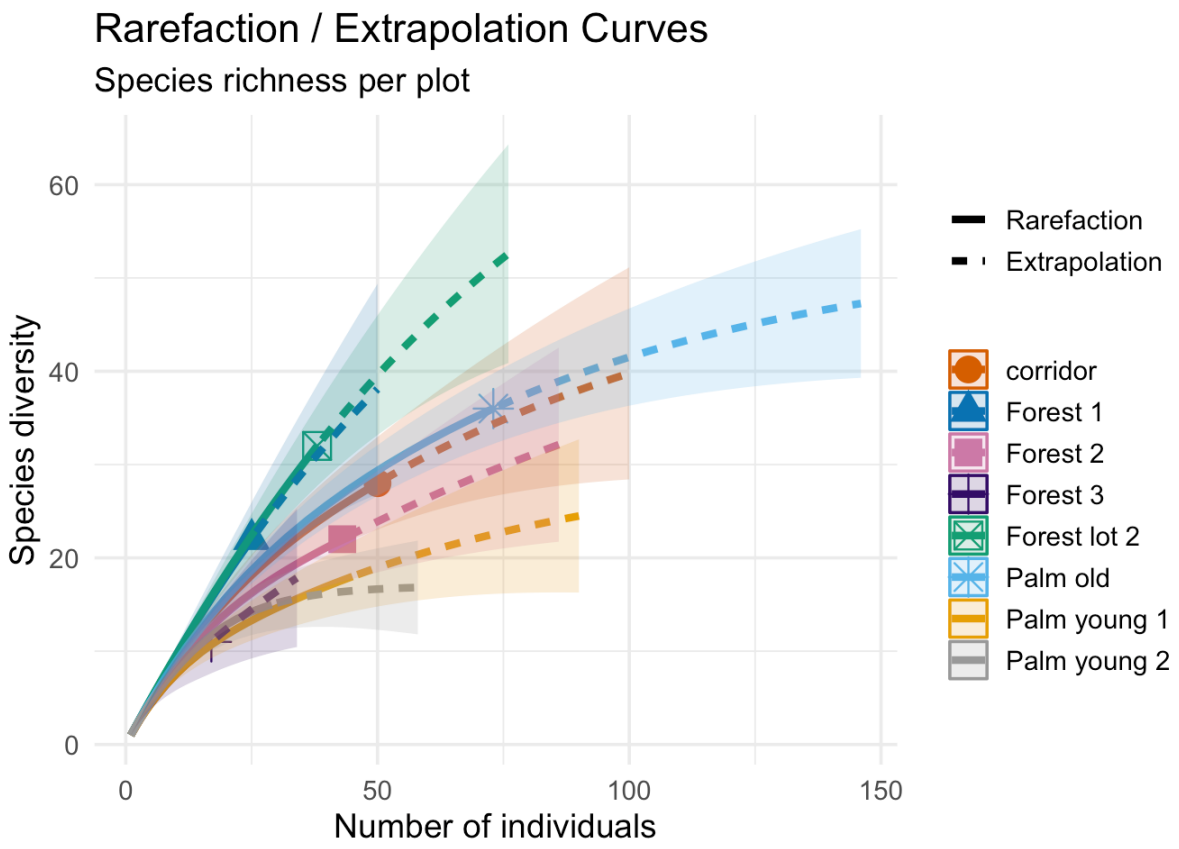


Figure 10 : Extrapolation curves. Richness per habitat based on the number of samples.

After assessing habitat diversity and its potential role in the conservation of endangered species, we will look at the proportion of animal classes, and their diets present in each habitat.

Animal composition of the three habitats studied

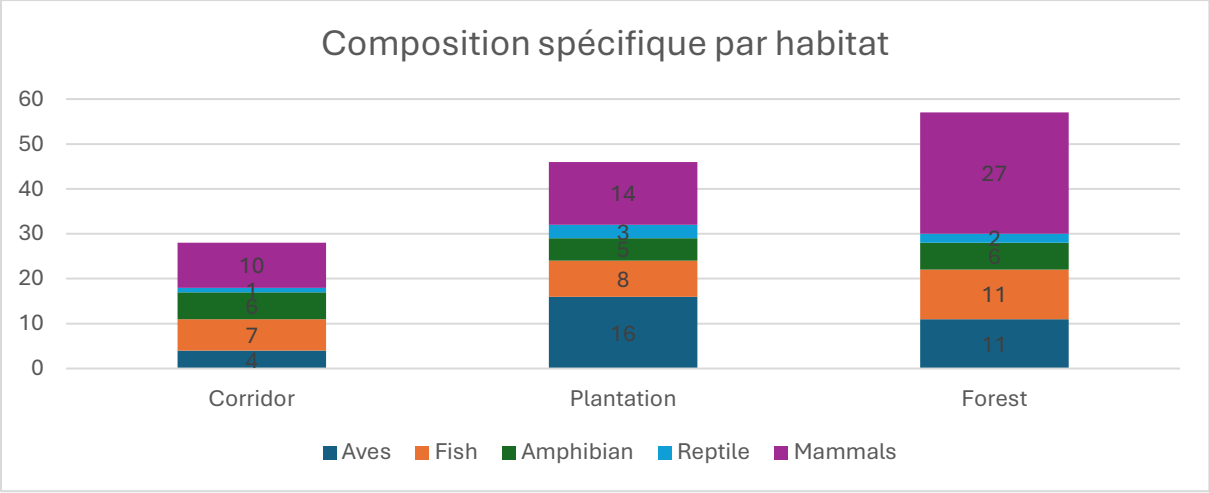


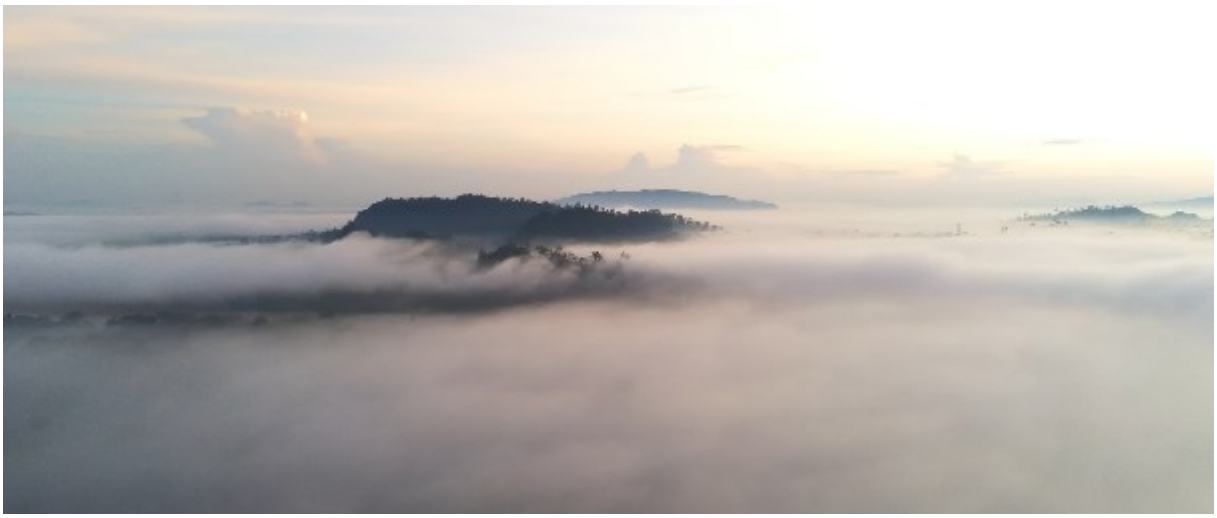
Figure 11 : Specific composition by habitat

We will systematically compare the results of the plantations and the corridor with those obtained in the **forest environment**, which is the **reference** state for biodiversity in Kinabatangan.

Even degraded forests play an important role in the survival of certain animal species that cannot survive in non-forest environments.

A more detailed functional analysis would enable species assemblages to be differentiated according to the lifestyles of the species detected (arboreal, burrowing, flying, etc.), body mass or diet.

For the moment, only the **diet** of the species identified in each habitat will be presented and compared, as well as the faunal composition by class.



FOREST

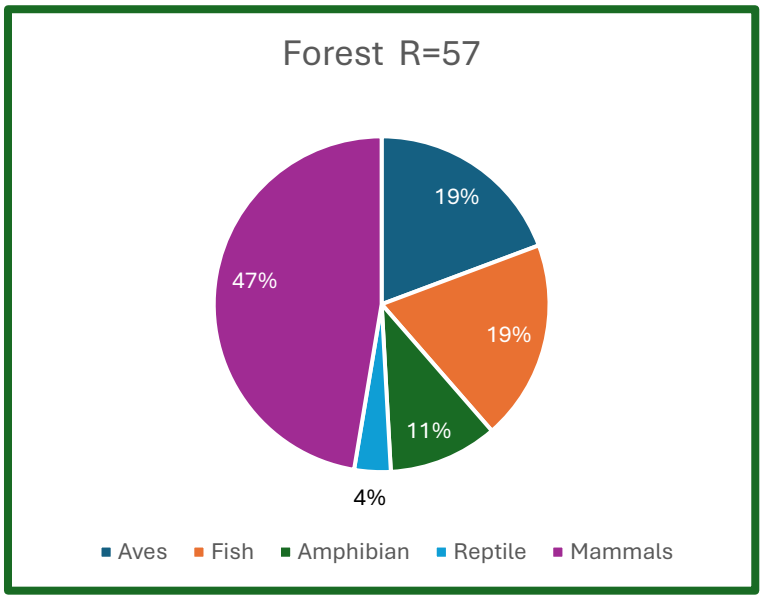


Figure 12 : Fauna composition of species detected in the forest class.

Nearly 50% of the species detected in the forest habitat are mammals. Birds and fish are half as common, followed by amphibians and finally reptiles.

These results are explained by the recent presence of the species in this ecosystem and their ability to disseminate genetic material in their environment.

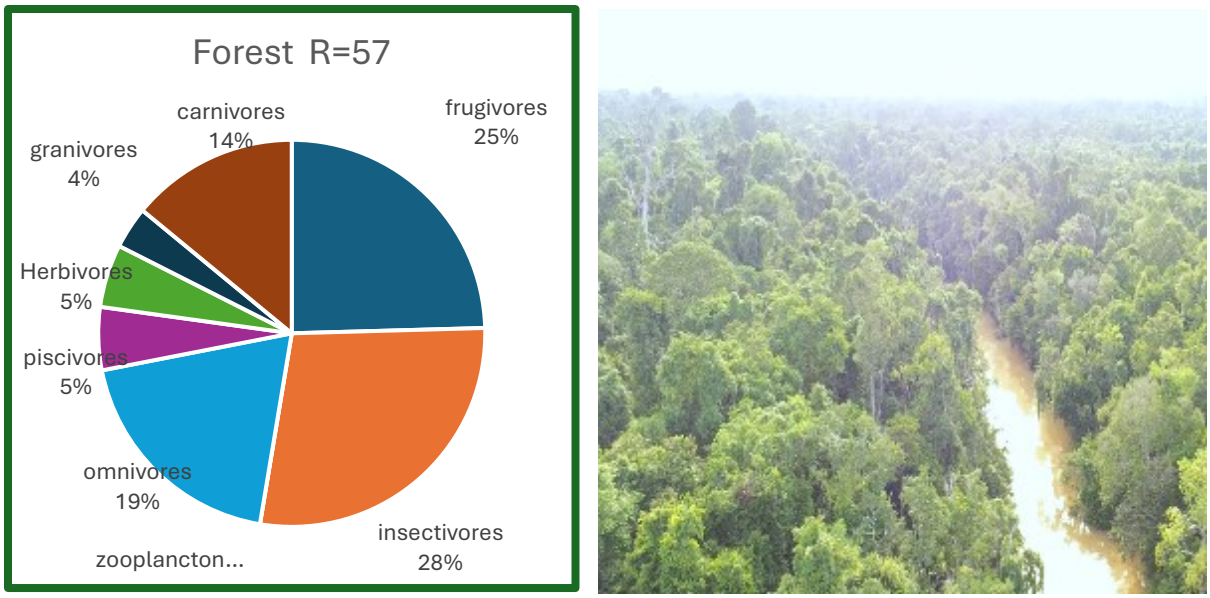


Figure 13 : Fauna composition of species detected in forests by diet

The diets of animals detected in the forest are divided between frugivores and insectivores, omnivores and carnivores.

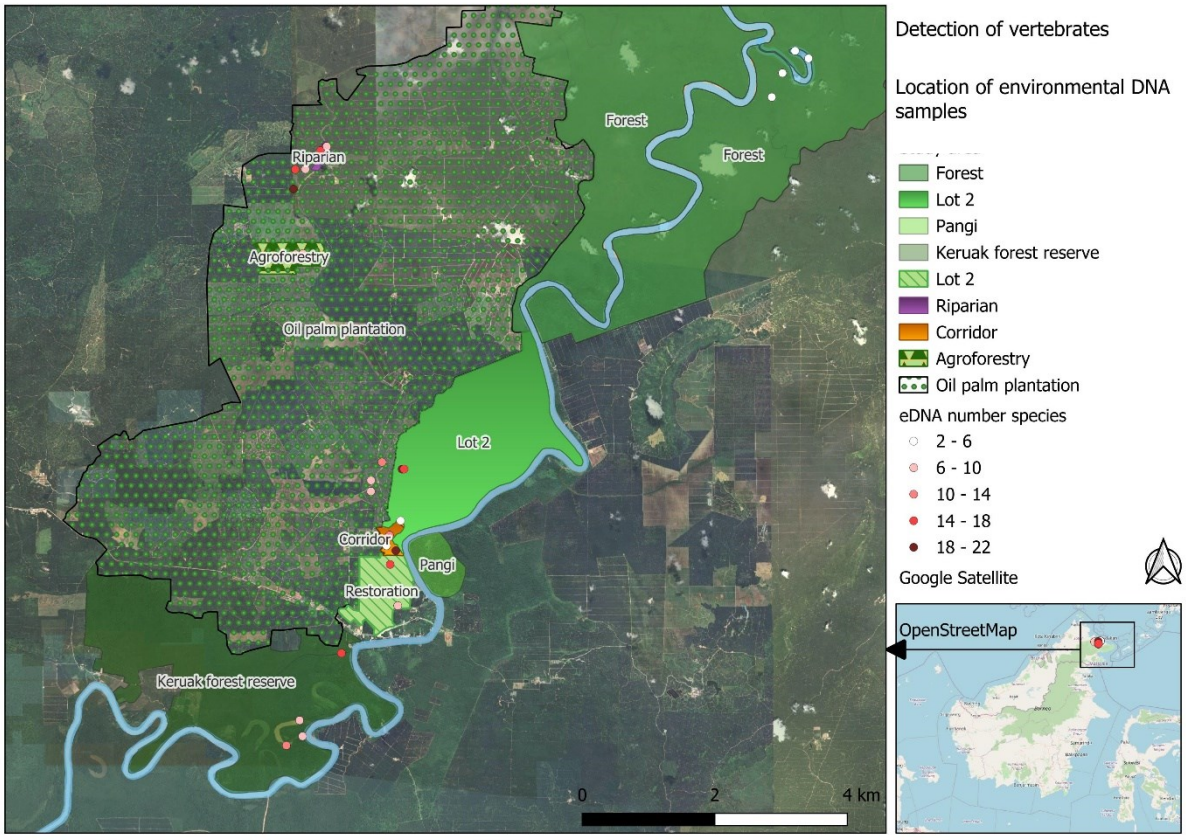


Figure 14 : Location map of analysed forests

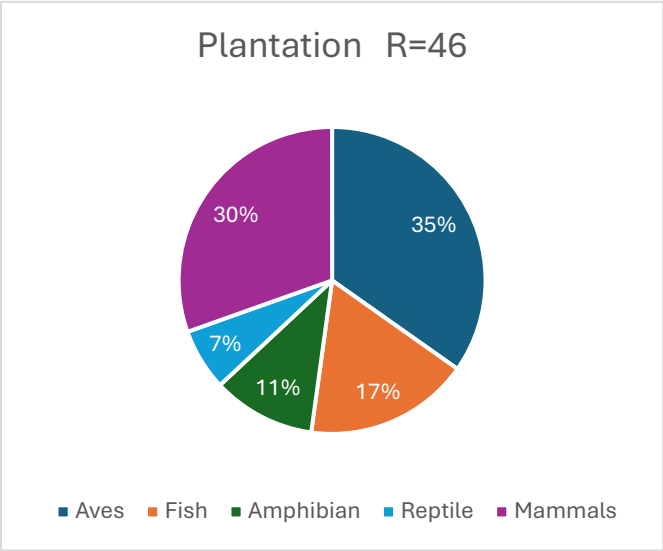
From South to North, samples were taken in the Keruak forest reserve, then in an area undergoing restoration, in Lot 2 of the Lower Kinabatangan Wildife Sanctuary and further north on an oxbow lake surrounded by a relatively undisturbed forest.

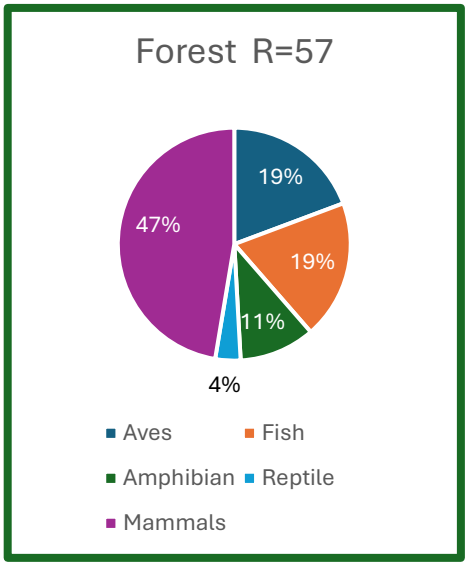
Species	Class	Diet
Aerodramus fuciphagus LC	Aves	insectivores
Buceros rhinoceros VU	Aves	frugivores
Callosciurus prevostii LC	Mammalia	frugivores
Chironax sp. LC	Mammalia	frugivores
Cyclemys sp. NT	Reptilia	carnivores
Cynogale bennetti EN	Mammalia	piscivores
Galeopterus sp. Galeopterus variegatus LC	Mammalia	Herbivores
Hylobates funereus EN	Mammalia	omnivores
Irena cyanogastra NT	Aves	frugivores
Kerivoula sp.	Mammalia	insectivores
Kurixalus appendiculatus LC	Amphibia	insectivores
Lenothrix canus LC	Mammalia	frugivores
Lenothrix sp. LC	Mammalia	frugivores
Lophura ignita VU	Aves	insectivores
Lutjanus argentimaculatus LC	Actinopteri	piscivores
Macaca fascicularis EN	Mammalia	frugivores
Myophonus caeruleus LC	Aves	insectivores
Nasalis larvatus EN	Mammalia	frugivores
Niviventer cremoriventer LC	Mammalia	granivores
Nycticebus menagensis VU	Mammalia	omnivores
Phodilus badius LC	Aves	carnivores
Pongo pygmaeus CR	Mammalia	frugivores
Pteropus sp. EN	Mammalia	frugivores
Ptilocercus lowii LC	Mammalia	frugivores
Rattus exulans LC	Mammalia	omnivores
Serilophus lunatus LC	Aves	insectivores
Toxotes chatareus LC	Actinopteri	carnivores
Tricholestes criniger LC	Aves	granivores
Trichys fasciculata LC	Mammalia	omnivores
Eleotris fusca LC	Actinopteri	carnivores
Hipposideros galeritus LC	Mammalia	insectivores
Ingerophrynus divergens LC	Amphibia	insectivores
Brachygobius doriae LC	Actinopteri	carnivores
Glossogobius aureus LC	Actinopteri	carnivores
Gorsachius melanolophus LC	Aves	insectivores
Megalops cyprinoides DD	Actinopteri	piscivores
Oxyeleotris marmorata LC	Actinopteri	omnivores
Polypedates leucomystax LC	Amphibia	insectivores
Rhinolophus affinis LC	Mammalia	insectivores

Tupaia longipes LC	Mammalia	omnivores
Manis javanica CR	Mammalia	insectivores
Amaurornis phoenicurus LC	Aves	insectivores
Anabas testudineus LC	Actinopteri	Herbivores
Callosciurus notatus LC	Mammalia	frugivores
Channa striata LC	Actinopteri	carnivores
Cuora amboinensis EN	Reptilia	Herbivores
Gallirallus striatus LC	Aves	carnivores
Hylarana chalconota LC	Amphibia	insectivores
Hylarana erythraea LC	Amphibia	insectivores
Limnonectes finchi LC	Amphibia	insectivores
Macaca nemestrina EN	Mammalia	frugivores
Maxomys whiteheadi VU	Mammalia	omnivores
Paradoxurus jerdoni LC	Mammalia	frugivores
Rasbora hobelmani NA	Actinopteri	omnivores
Sundamys muelleri LC	Mammalia	omnivores
Trichopodus pectoralis LC	Actinopteri	omnivores
Tupaia tana LC	Mammalia	omnivores

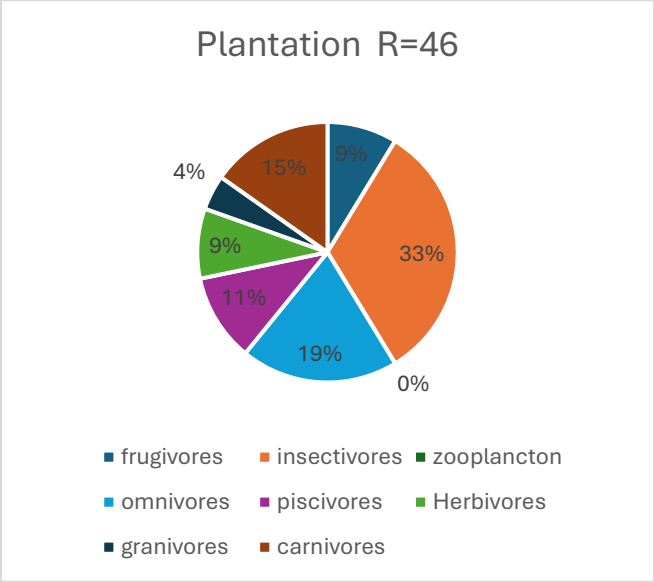
Figure 15 : List of species detected in the forest

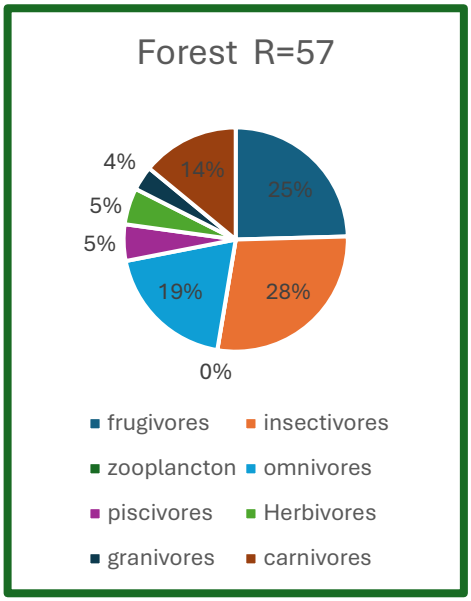
PLANTATION





Plantations are seeing a decline in their mammal diversity, with birds becoming more prevalent. It is hypothesised that the decline in mammals in oil palm plantations is due to drier conditions (Kay and Madden 1997); lack of suitable resting or feeding resources; competition with domestic animals; hunting and killing; etc.





The proportion of **frugivores** falls from 25% in the forest to 9% in plantations, showing the rarefaction of flower diversity in agricultural landscapes. In the contrary the insectivore proportion tends to increase very slightly.

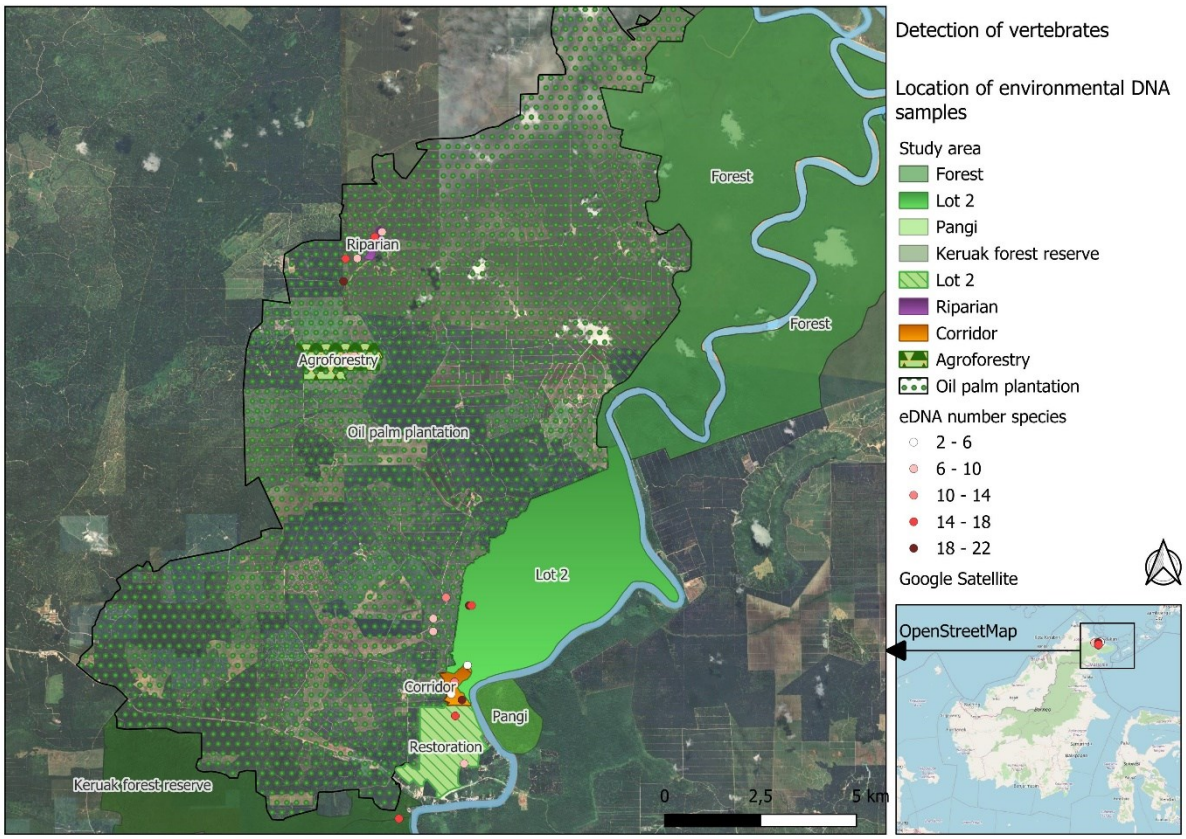
For frugivores, the result can be explained by the presence of only one type of fruit tree in plantations. Besides the fruits of oil palm, there is relatively little other fruit available. In tropical forest in the contrary, frugivores have access to a significantly higher diversity of fruits than in a monoculture habitat (Kissling, Gaese, 2009).

We also note a decline (although less sever than for frugivorous) of insectivore species , in plantations compared to the forests.

Indeed, former studies have already shown a decline in insectivore diversity in the palm oil plantation. Iinsectivore abundance and species richness are greater in degraded forest than in palm oil plantations (Soon et al, 2022), stressing out the importance of maintaining natural forests within and around plantations to increase the diversity of insectivores in plantation.

Figure 16 : Aerial view of a single-species oil palm plantation

Figure 17 : Plantation with forest island



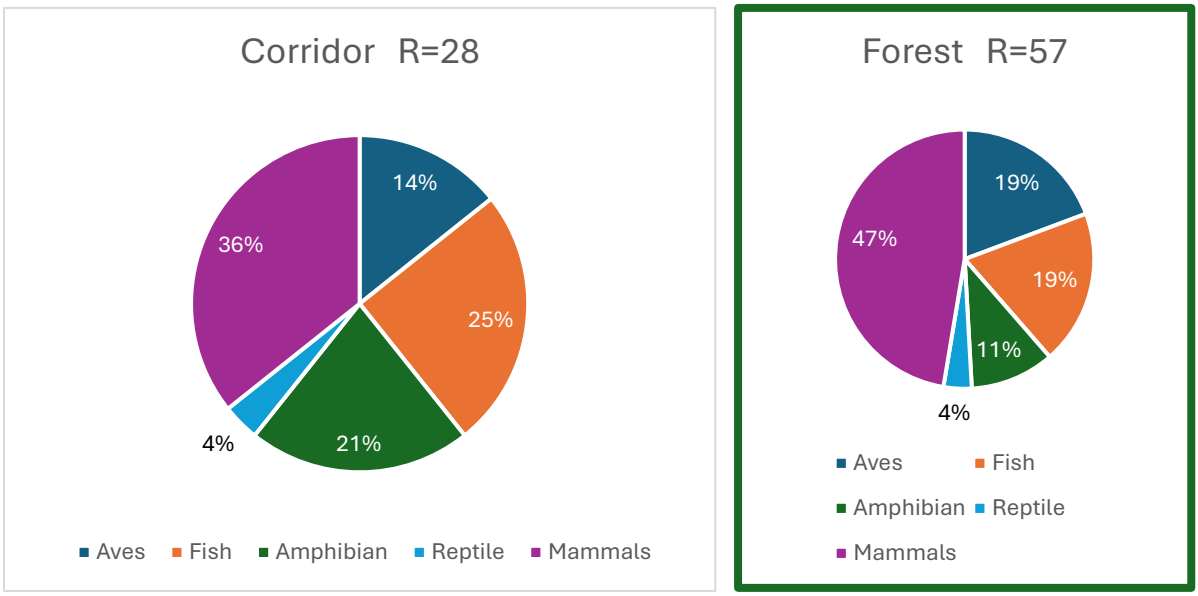
Samples were taken from different plots of oil palm trees of varying ages.

Species	Class	Diet
Acridotheres cristatellus LC	Aves	omnivores
Anhinga melanogaster LC	Aves	piscivores
Ardea intermedia LC	Aves	piscivores
Ardea purpurea LC	Aves	piscivores
Bubulcus ibis LC	Aves	insectivores
Chaperina fusca LC	Amphibia	insectivores
Cynopterus brachyotis LC	Mammalia	frugivores
Dendrocygna arcuata LC	Aves	Herbivores
Excalfactoria chinensis LC	Aves	granivores
Gallinago stenura LC	Aves	insectivores
Geopelia striata LC	Aves	granivores
Lutra sumatrana EN	Mammalia	carnivores
Muscicapa latirostris NA	Aves	insectivores
Notochelys platynota VU	Reptilia	Herbivores
Nycticorax nycticorax LC	Aves	piscivores
Paradoxurus hermaphroditus LC	Mammalia	carnivores
Rhinolophus sp.	Mammalia	insectivores
Todiramphus sanctus vagans LC	Aves	insectivores
Varanus salvator LC	Reptilia	omnivores
Aonyx cinereus VU	Mammalia	carnivores

Mixornis gularis LC	Aves	insectivores
Brachygobius doriae LC	Actinopteri	carnivores
Glossogobius aureus LC	Actinopteri	carnivores
Gorsachius melanolophus LC	Aves	insectivores
Megalops cyprinoides DD	Actinopteri	piscivores
Oxyeleotris marmorata LC	Actinopteri	omnivores
Polypedates leucomystax LC	Amphibia	insectivores
Rhinolophus affinis LC	Mammalia	insectivores
Tupaia longipes LC	Mammalia	omnivores
Manis javanica CR	Mammalia	insectivores
Amaurornis phoenicurus LC	Aves	insectivores
Anabas testudineus LC	Actinopteri	Herbivores
Callosciurus notatus LC	Mammalia	frugivores
Channa striata LC	Actinopteri	carnivores
Cuora amboinensis EN	Reptilia	Herbivores
Gallirallus striatus LC	Aves	carnivores
Hylarana chalconota LC	Amphibia	insectivores
Hylarana erythraea LC	Amphibia	insectivores
Limnonectes finchi LC	Amphibia	insectivores
Macaca nemestrina EN	Mammalia	frugivores
Maxomys whiteheadi VU	Mammalia	omnivores
Paradoxurus jerdoni LC	Mammalia	frugivores
Rasbora hobelmani NA	Actinopteri	omnivores
Sundamys muelleri LC	Mammalia	omnivores
Trichopodus pectoralis LC	Actinopteri	omnivores
Tupaia tana LC	Mammalia	omnivores

Figure 18 : List of species found in the plantations

CORRIDOR



We would like to point out that in this study, only one corridor with a limited surface could be analysed, limiting the conclusions of the analysis. .

About half as much species diversity was documented in the corridor compared to the forest, with a higher proportion of amphibians and fish than mammals. It should be noted that the corridor is an old plantation that was not cut down when it reached a stage of low or no productivity. However, this plot has been enriched with local plant to increase its tree diversity.

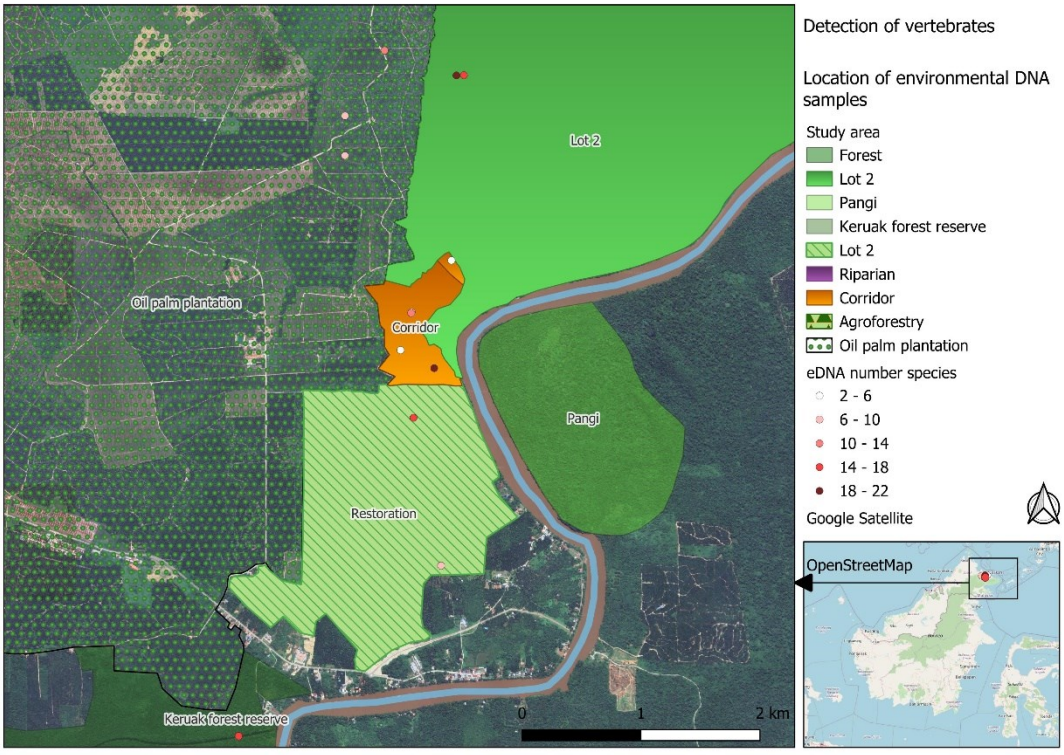
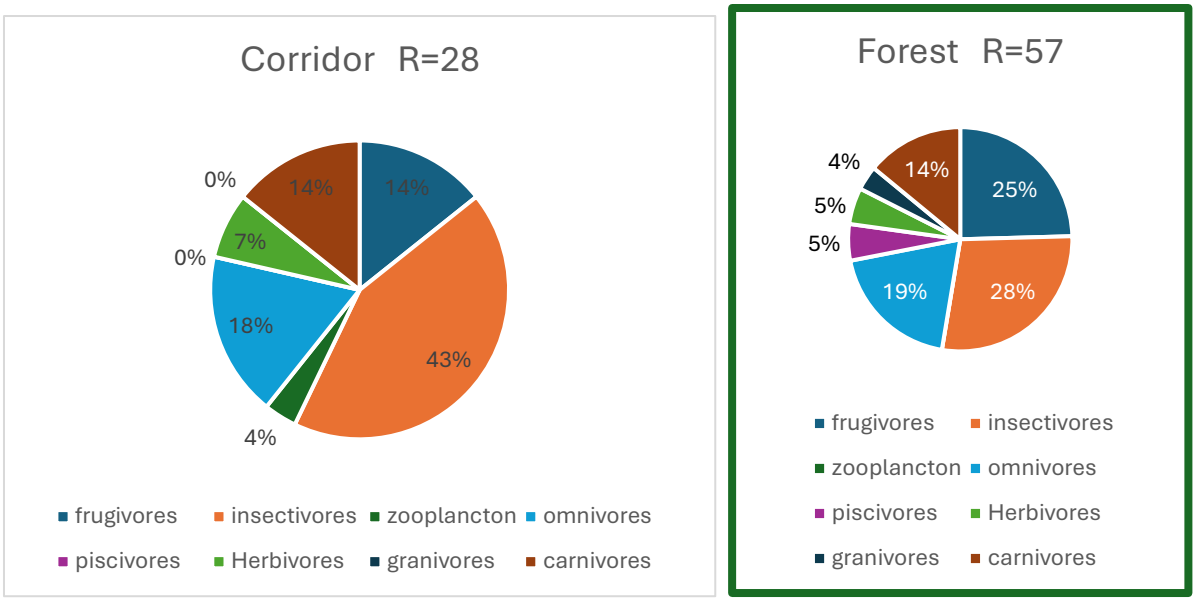


Figure 19 : Location of the forest corridor



This habitat has half the species diversity of the forest, but its insectivores proportion remains significant. We also detected several species of amphibians and bats that were not found anywhere else in this study.

Figure 20 :Example of a corridor created in a plantation after harvesting.

Here, the riverbanks are still lined with old palm trees that should have been cut down like those on neighbouring plot. This prevents the banks from being destabilised and also preserves a significant amount of vegetation along the watercourse.

Figure 21 : The isolated tree after cutting down a plot of cultivated palm trees.

Here, after palm tree harvesting, only one local tree has been preserved. Plantations around it would help restore area.

Species	Class	Diet
Callosciurus prevostii LC	Mammalia	frugivores
Centropus sinensis LC	Aves	insectivores
Limnonectes ingeri LC	Amphibia	insectivores
Limnonectes kuhlii species complex LC	Amphibia	insectivores
Luciosoma bleekeri LC	Actinopteri	insectivores
Miniopterus fuliginosus NA	Mammalia	insectivores
Scomber scombrus LC	Actinopteri	zooplancton
Aonyx cinereus VU	Mammalia	carnivores
Mixornis gularis LC	Aves	insectivores
Eleotris fusca LC	Actinopteri	carnivores
Hipposideros galeritus LC	Mammalia	insectivores
Ingerophrynus divergens LC	Amphibia	insectivores
Amaurornis phoenicurus LC	Aves	insectivores
Anabas testudineus LC	Actinopteri	Herbivores
Callosciurus notatus LC	Mammalia	frugivores
Channa striata LC	Actinopteri	carnivores
Cuora amboinensis EN	Reptilia	Herbivores
Gallirallus striatus LC	Aves	carnivores
Hylarana chalconota LC	Amphibia	insectivores
Hylarana erythraea LC	Amphibia	insectivores
Limnonectes finchi LC	Amphibia	insectivores
Macaca nemestrina EN	Mammalia	frugivores
Maxomys whiteheadi VU	Mammalia	omnivores
Paradoxurus jerdoni LC	Mammalia	frugivores
Rasbora hobelmani NA	Actinopteri	omnivores
Sundamys muelleri LC	Mammalia	omnivores
Trichopodus pectoralis LC	Actinopteri	omnivores
Tupaia tana LC	Mammalia	omnivores

Figure 22 : List of species detected in the corridor

IUCN technical data sheets for detected species with a confirmed vulnerability level.

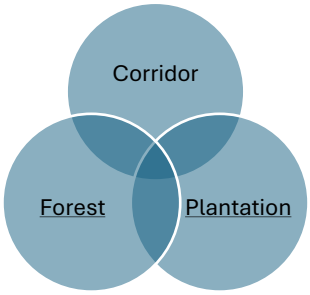
The focus is on the species with a confirmed vulnerability level. Mammals rank highest in the classification of vulnerable species. This class is the most studied and the most impacted by deforestation and habitat fragmentation.

Class	IUCN	Latin name - IUCN
Mammalia	Critically endangered	*Manis javanica CR*
Mammalia		*Pongo pygmaeus CR*
Mammalia	Endangered	*Cynogale bennetti EN*
Mammalia		*Hylobates funereus EN*
Mammalia		*Lutra sumatrana EN*
Mammalia		*Macaca fascicularis EN*
Mammalia		*Macaca nemestrina EN*
Mammalia		*Nasalis larvatus EN*
Mammalia		*Pteropus sp. EN*
Reptilia		*Cuora amboinensis EN*
Aves	Vulnerable	*Buceros rhinoceros VU*
Aves		*Lophura ignita VU*
Mammalia		*Aonyx cinereus VU*
Mammalia		*Maxomys whiteheadi VU*
Mammalia		*Nycticebus menagensis VU*
Reptilia		*Notochelys platynota VU*
Aves	Near threatened	*Irena cyanogastra NT*

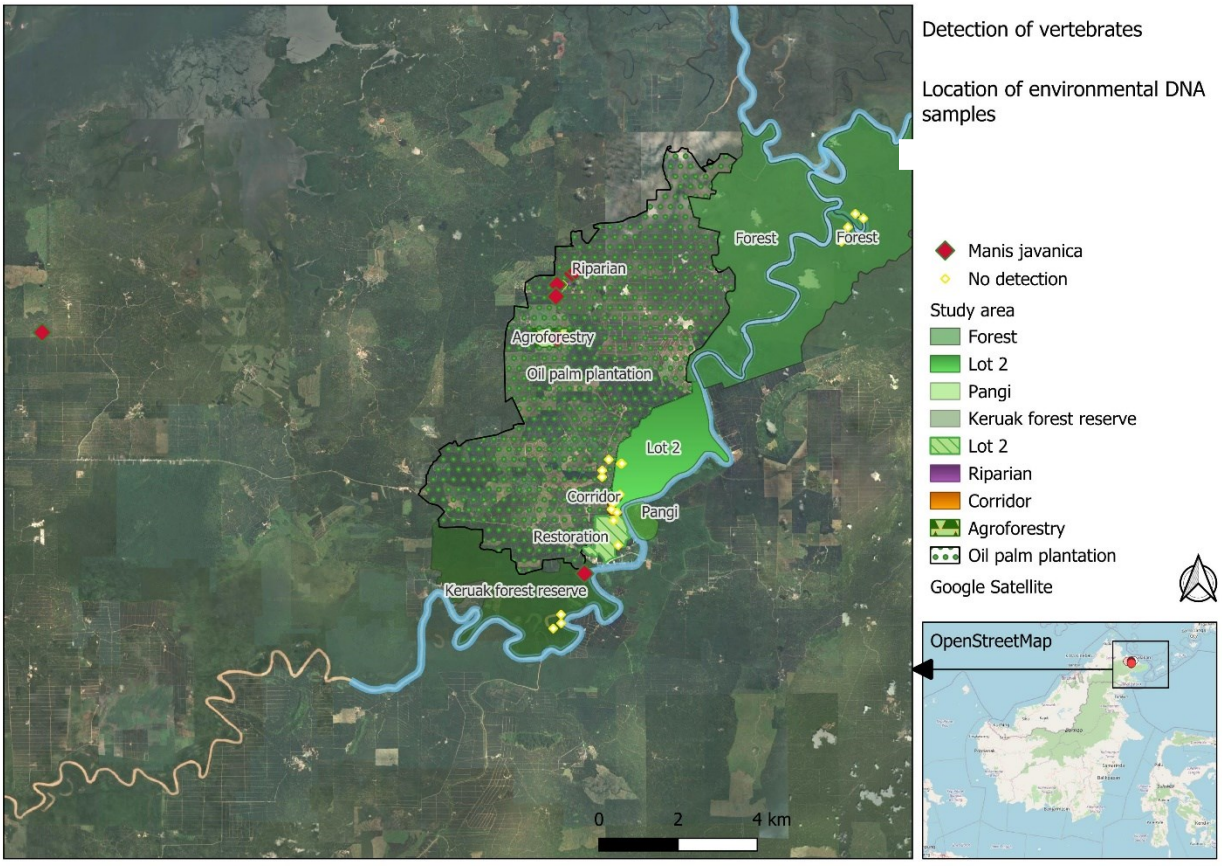
Figure 23 : Species detected and with a proven level of vulnerability according to the IUCN Red List

CLASS	Level Red List IUCN	Latin name
Mammalia	CR	Manis javanica

Sunda Pangolin



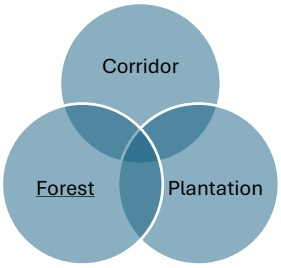
https://www.iucnredlist.org/species/12763/123584856

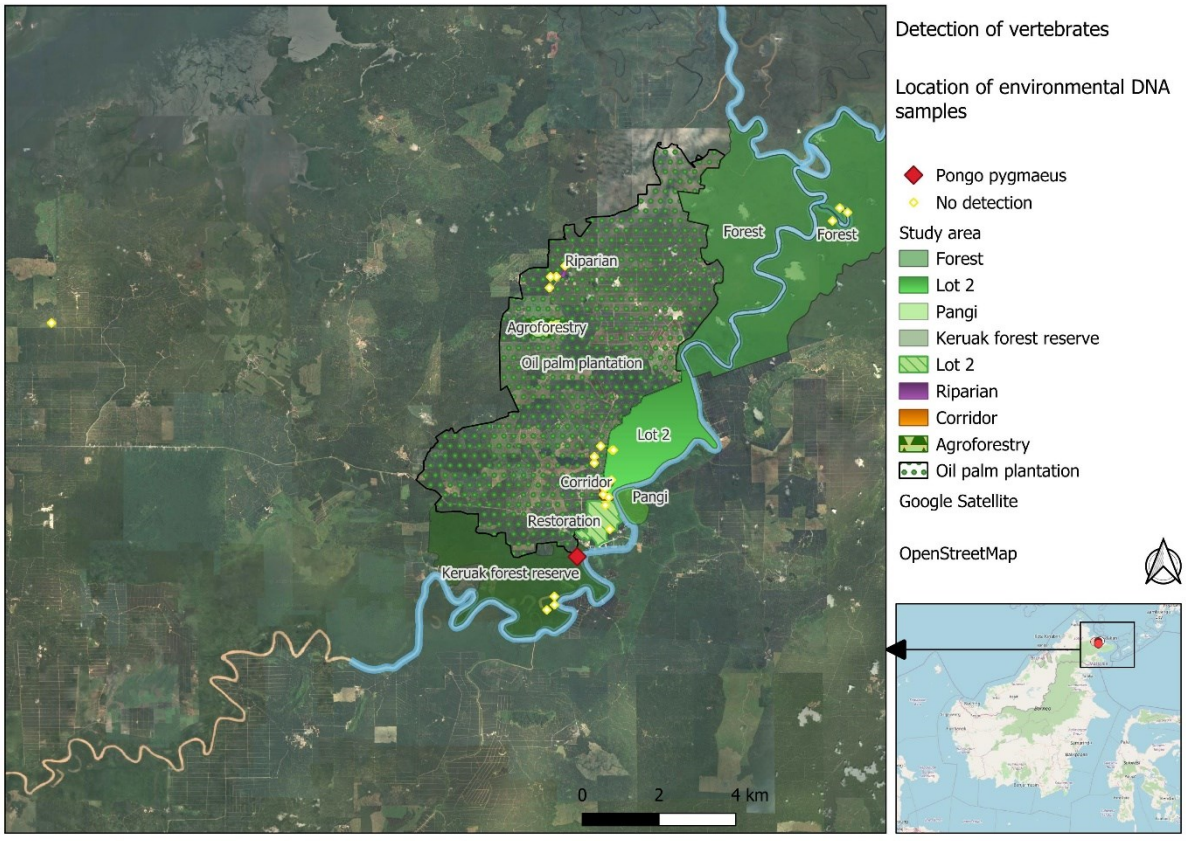


Present of 22% of the sites analysed, the species is found in forests and plantations.

CLASS	Level Red List IUCN	Latin name
Mammalia	CR	*Pongo pygmaeus*

Bornean Orangutan

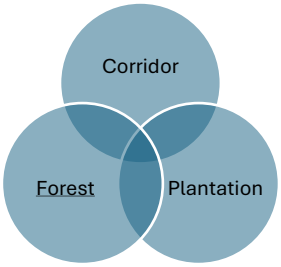


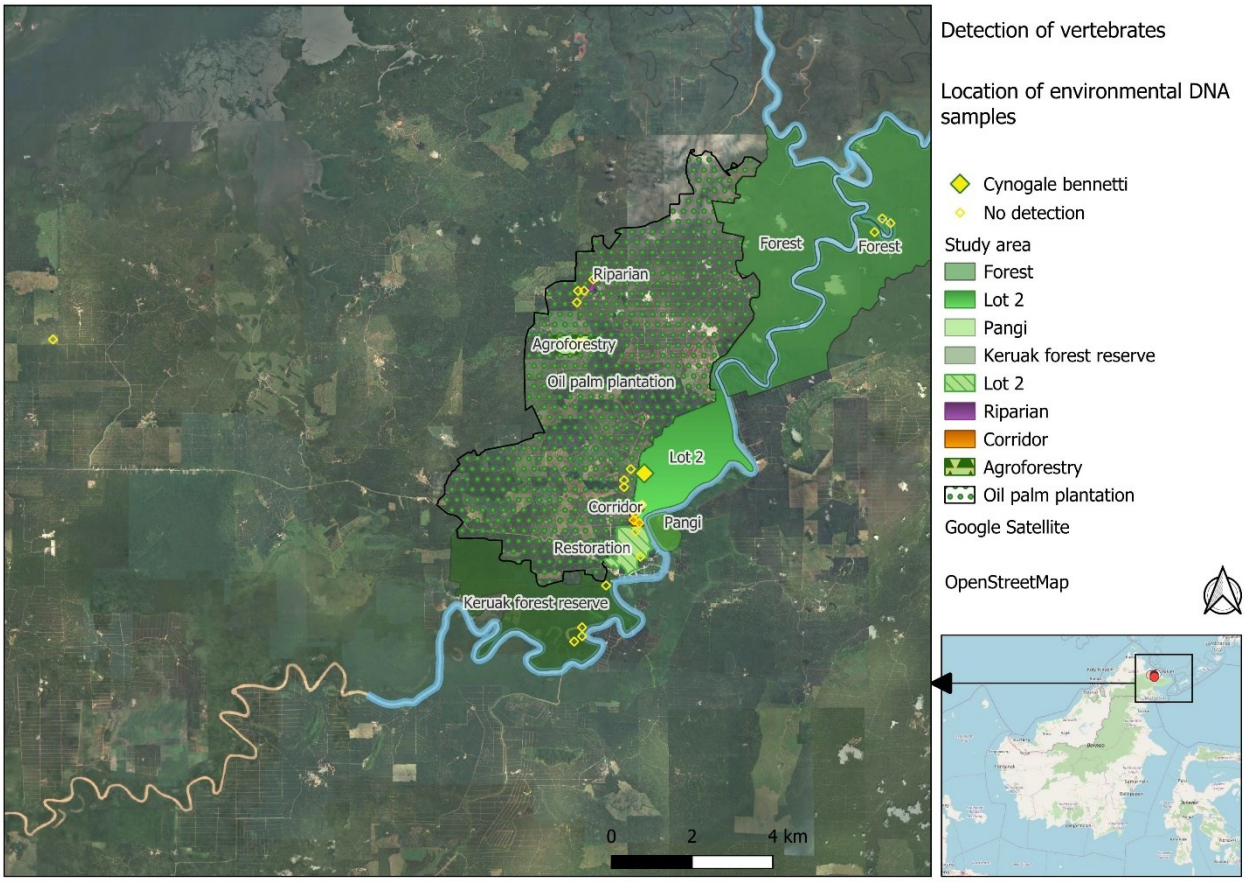


Species with at only 3% of the sites analysed.

CLASS	Level Red List IUCN	Latin name
Mammalia	EN	*Cynogale bennetti*

Otter Civet





Species with at only 3% of the sites analysed.

CLASS	Level Red List IUCN	Latin name
Mammalia	EN	*Hylobates funereus* EN

Northern Gray Gibbon

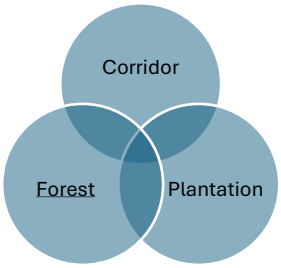
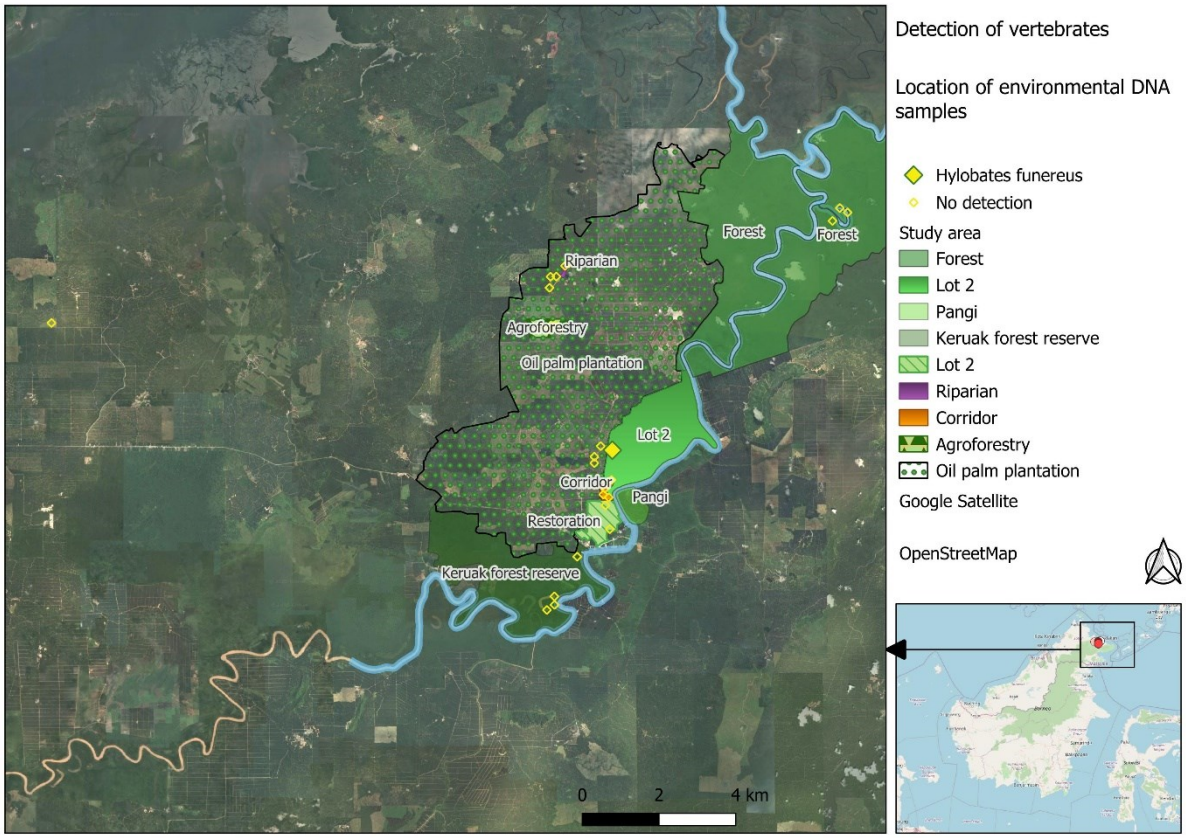


photo source wikipédia



Species with at only 3% of the sites analysed.

CLASS	Level Red List IUCN	Latin name
Mammalia	EN	*Lutra sumatrana* EN

Hairy-nosed Otter

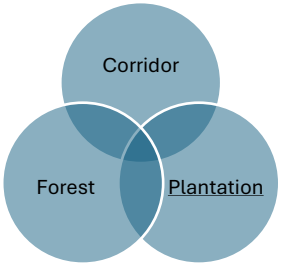
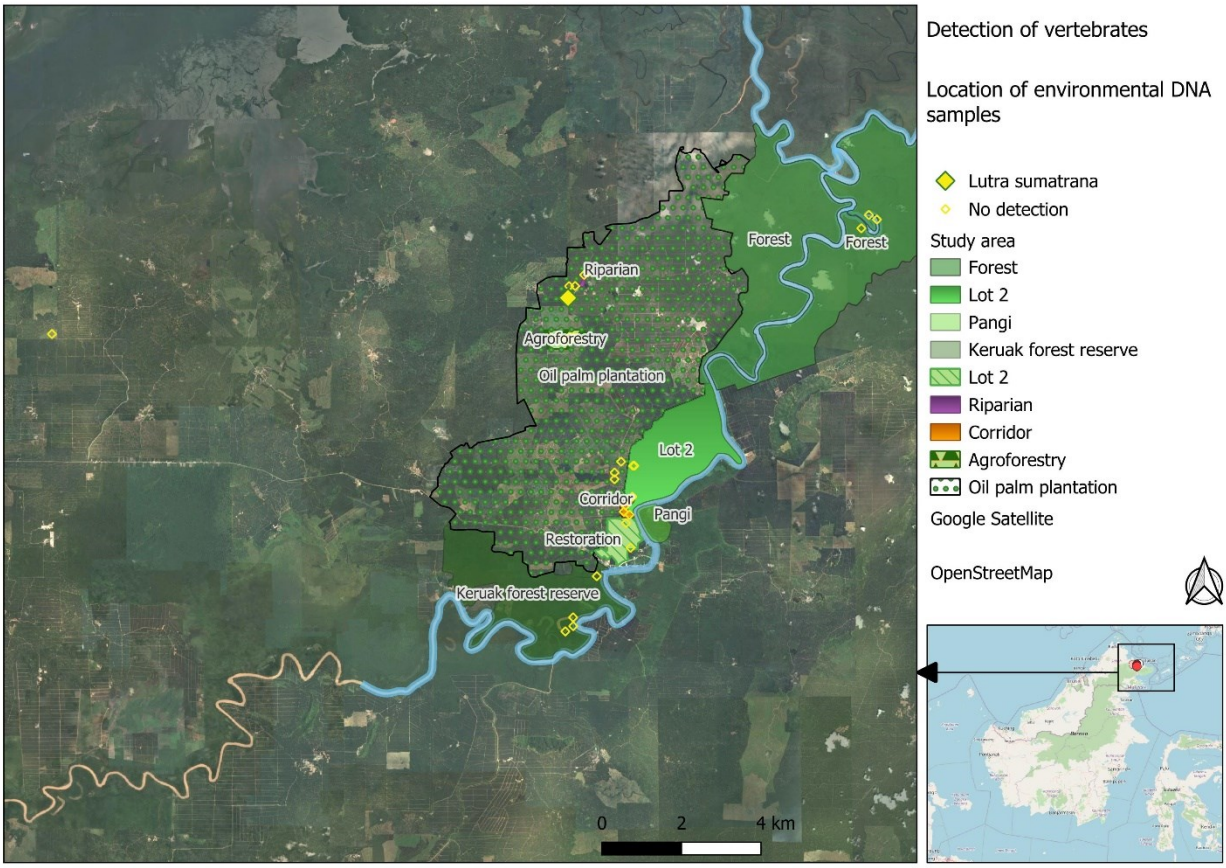


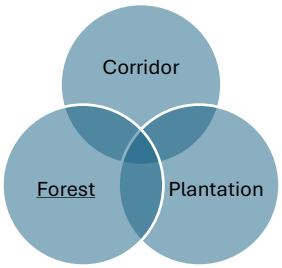
photo source wikipédia

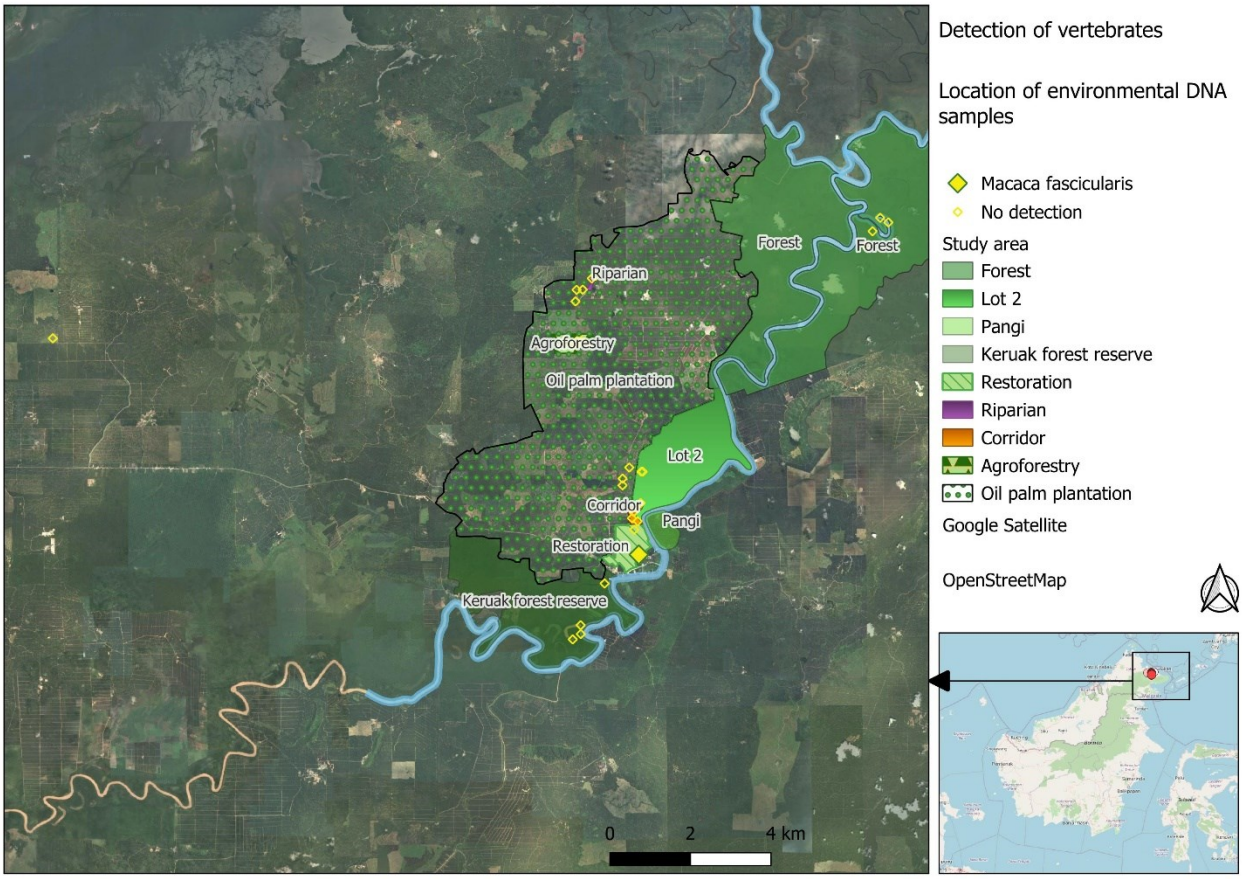


Species with at only 3% of the sites analysed.

CLASS	Level Red List IUCN	Latin name
Mammalia	EN	*Macaca fascicularis* EN

Common Long-tailed Macaque

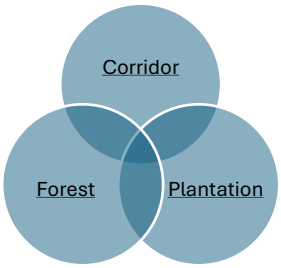


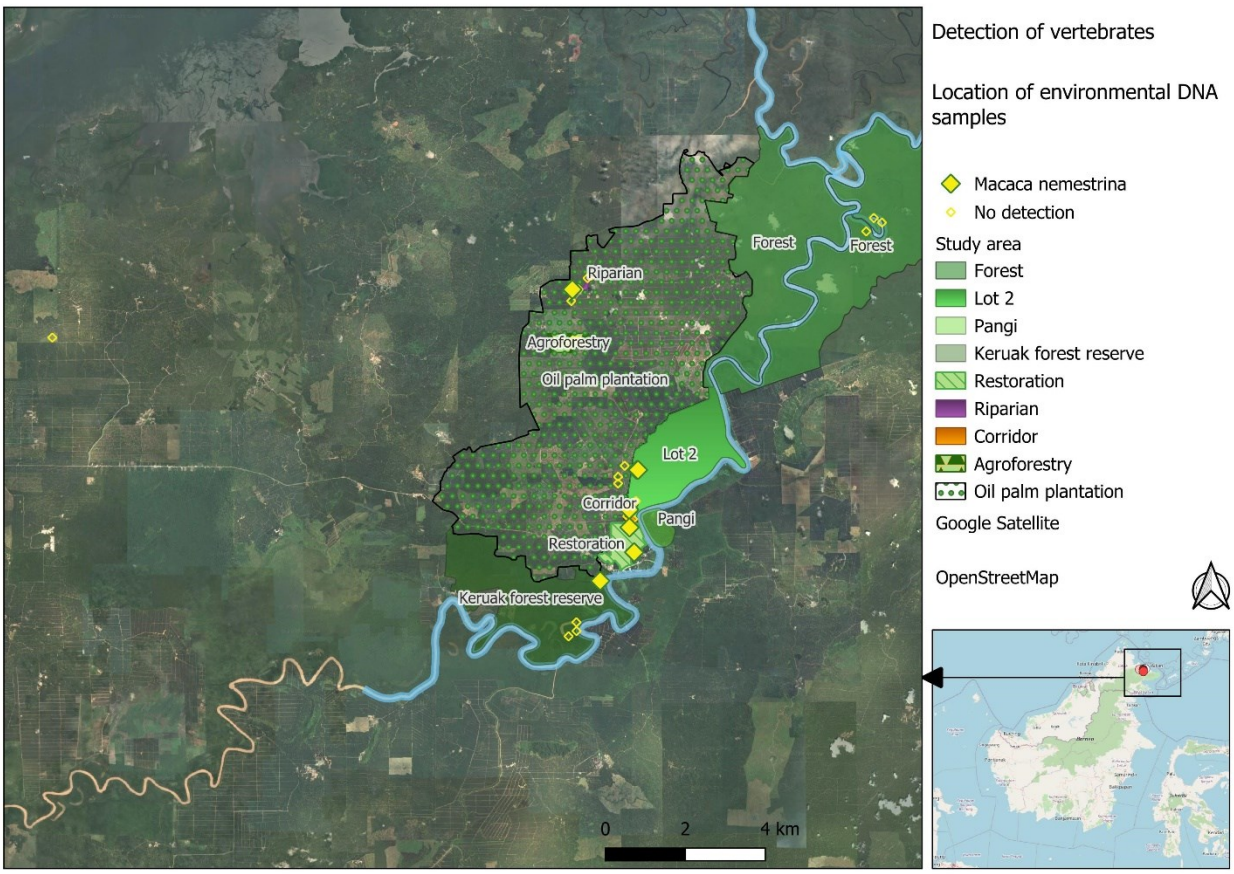


Species with at only 3% of the sites analysed.

CLASSE	Level Red List IUCN	Latin name
Mammalia	EN	Macaca nemestrina EN

Southern Pig-tailed Macaque

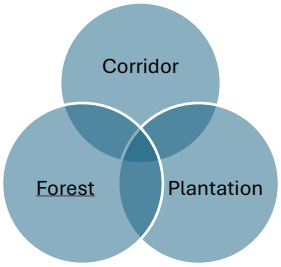


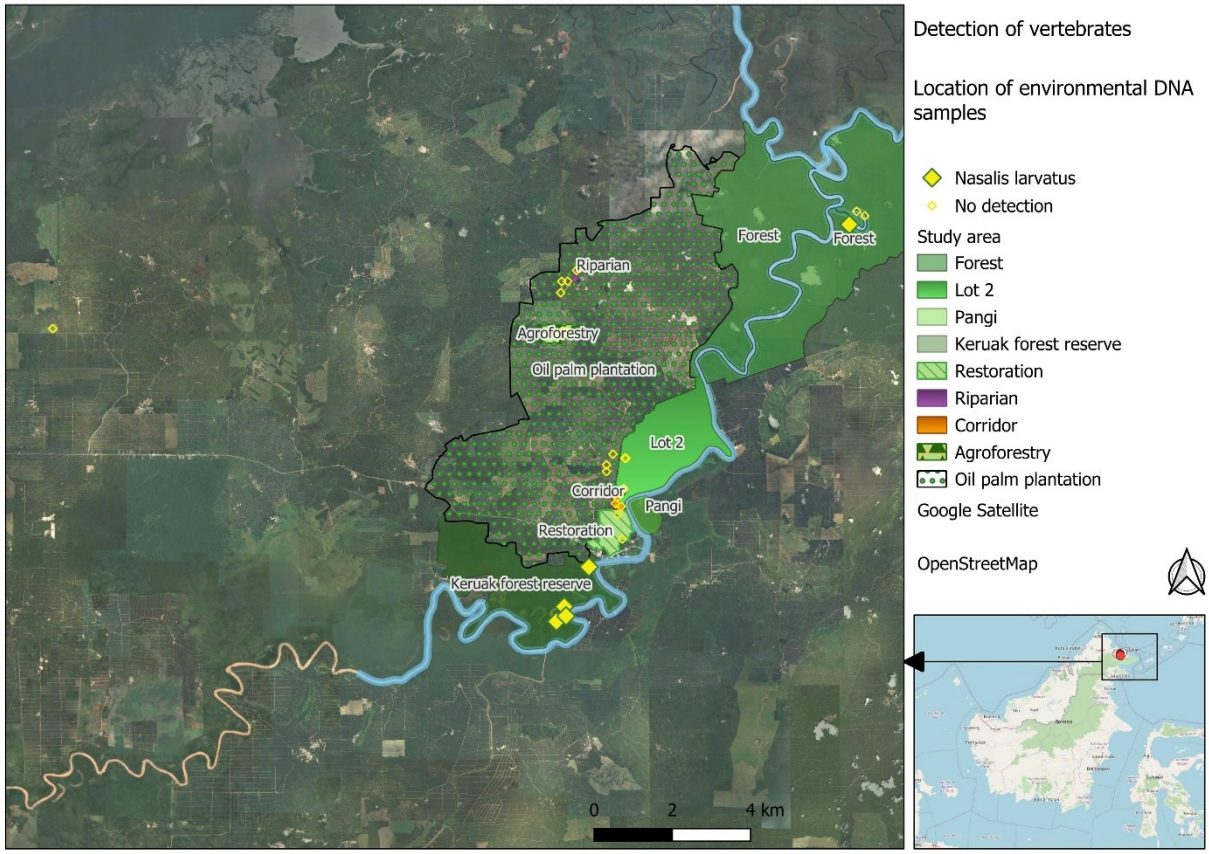


Species with at 22% of the sites analysed.

CLASS	Level Red List IUCN	Latin name
Mammalia	EN	*Nasalis larvatus* EN

Proboscis Monkey

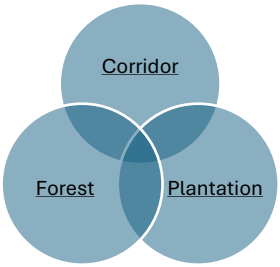


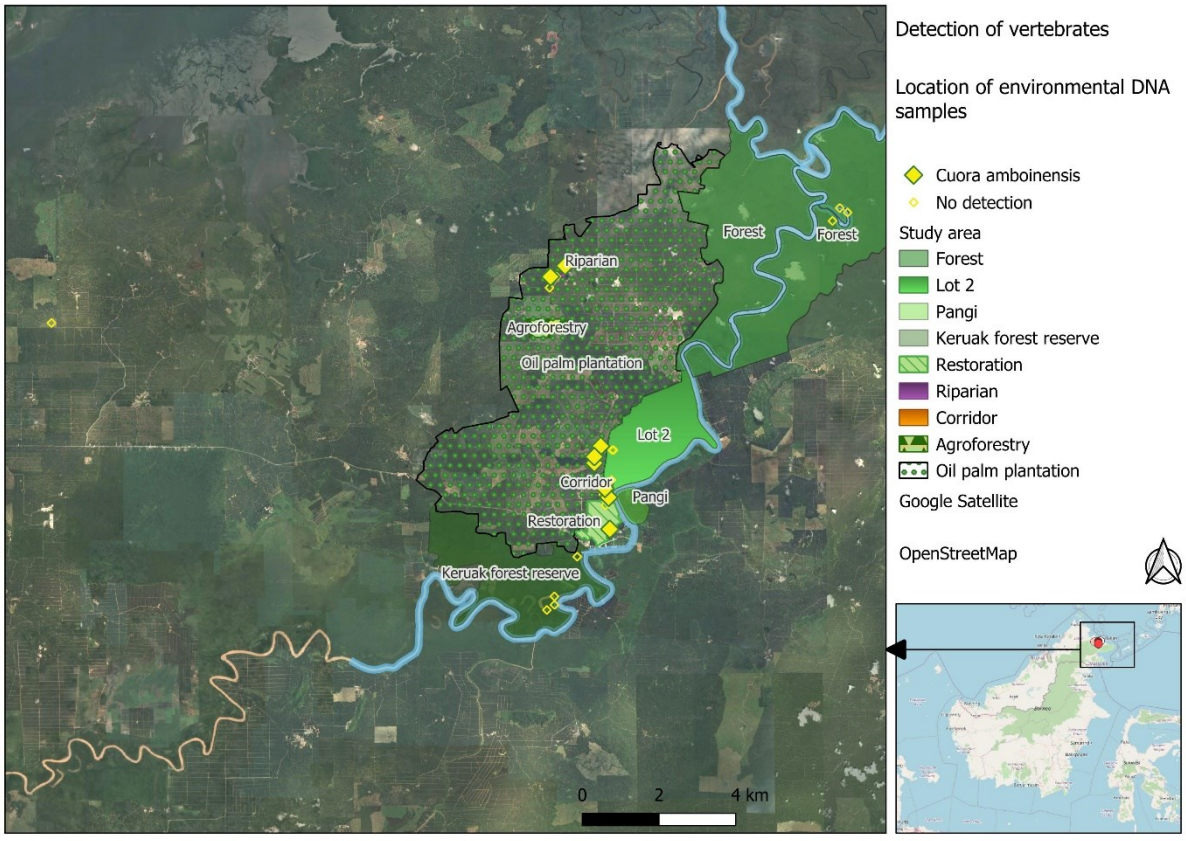


Species present at 22% of the sites analysed.

CLASS	Level Red List IUCN	Latin name
Reptilia	EN	*Cuora amboinensis* EN

Southeast Asian Box Turtle

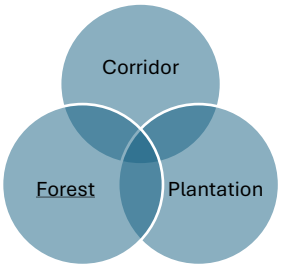


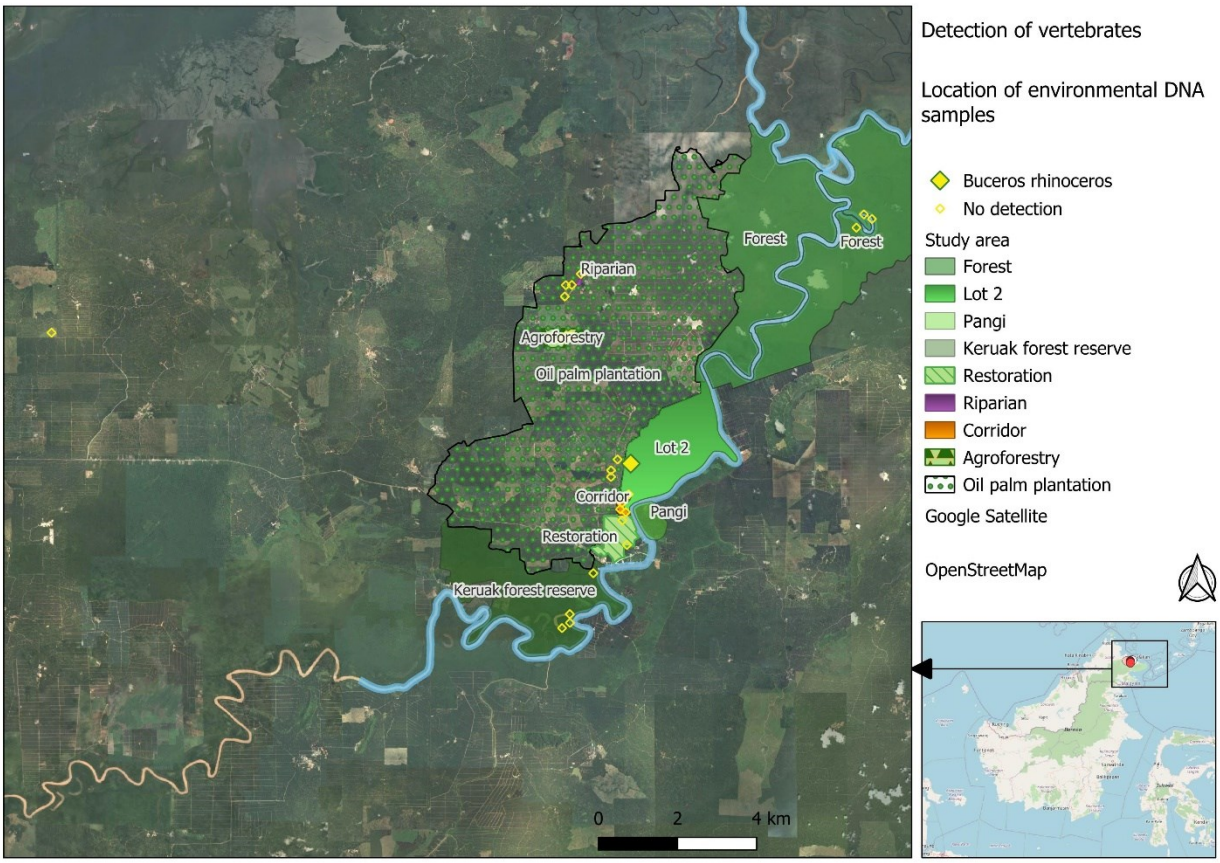


Species present at 25% of the sites analysed. This response for an aquatic reptile is quite strong, suggesting a relatively widespread presence of the species.

CLASS	Level Red List IUCN	Latin name
Aves	VU	*Buceros rhinoceros* VU

Rhinoceros Hornbill

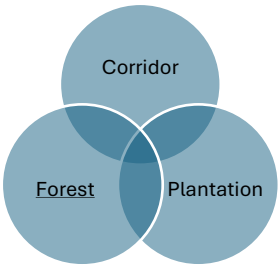


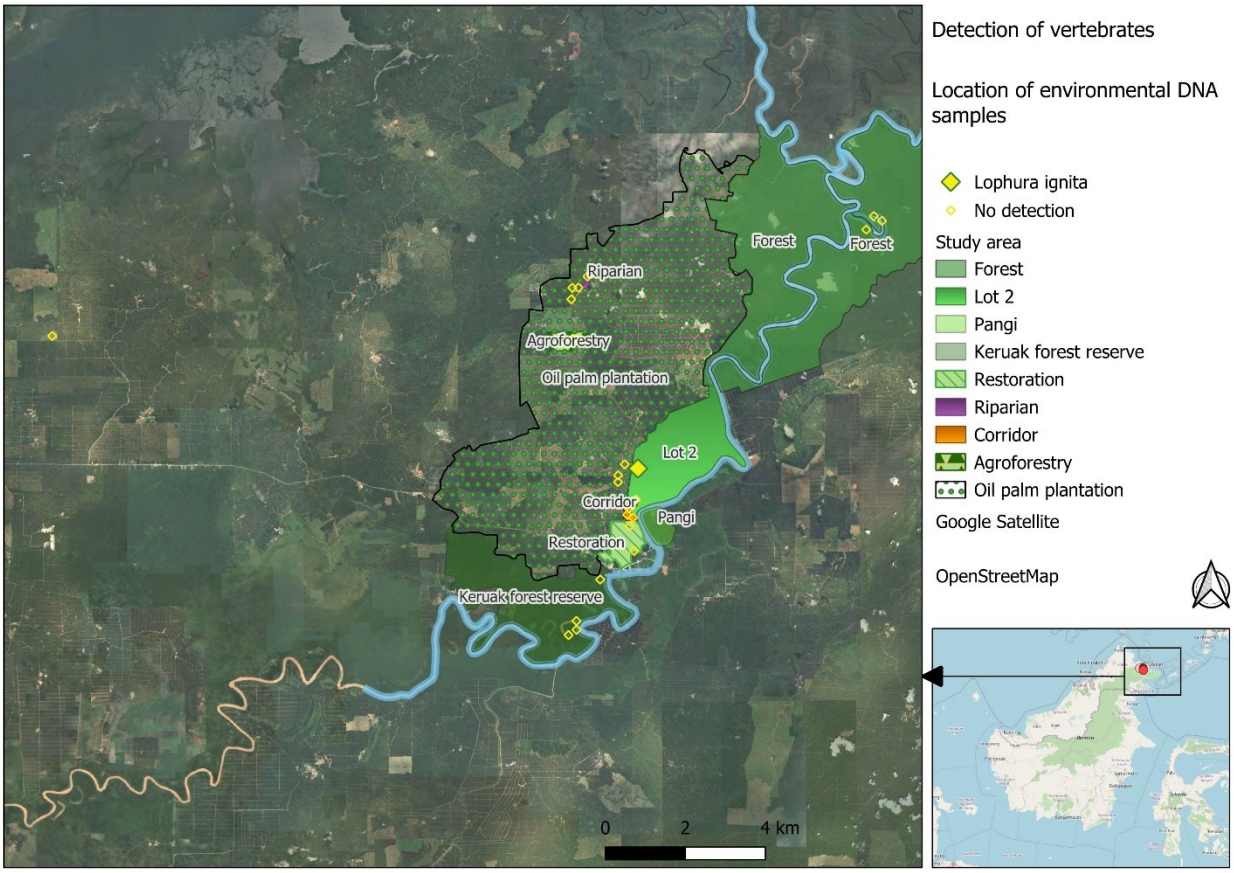


Species present at only 3% of the sites analysed. Bird detections are often underestimated for the bird class.

CLASS	Level Red List IUCN	Latin name
Aves	VU	*Lophura ignita* VU

Bornean Crested Fireback

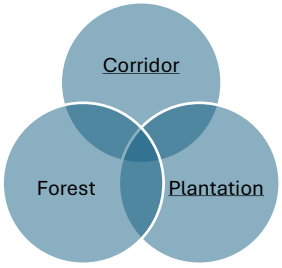


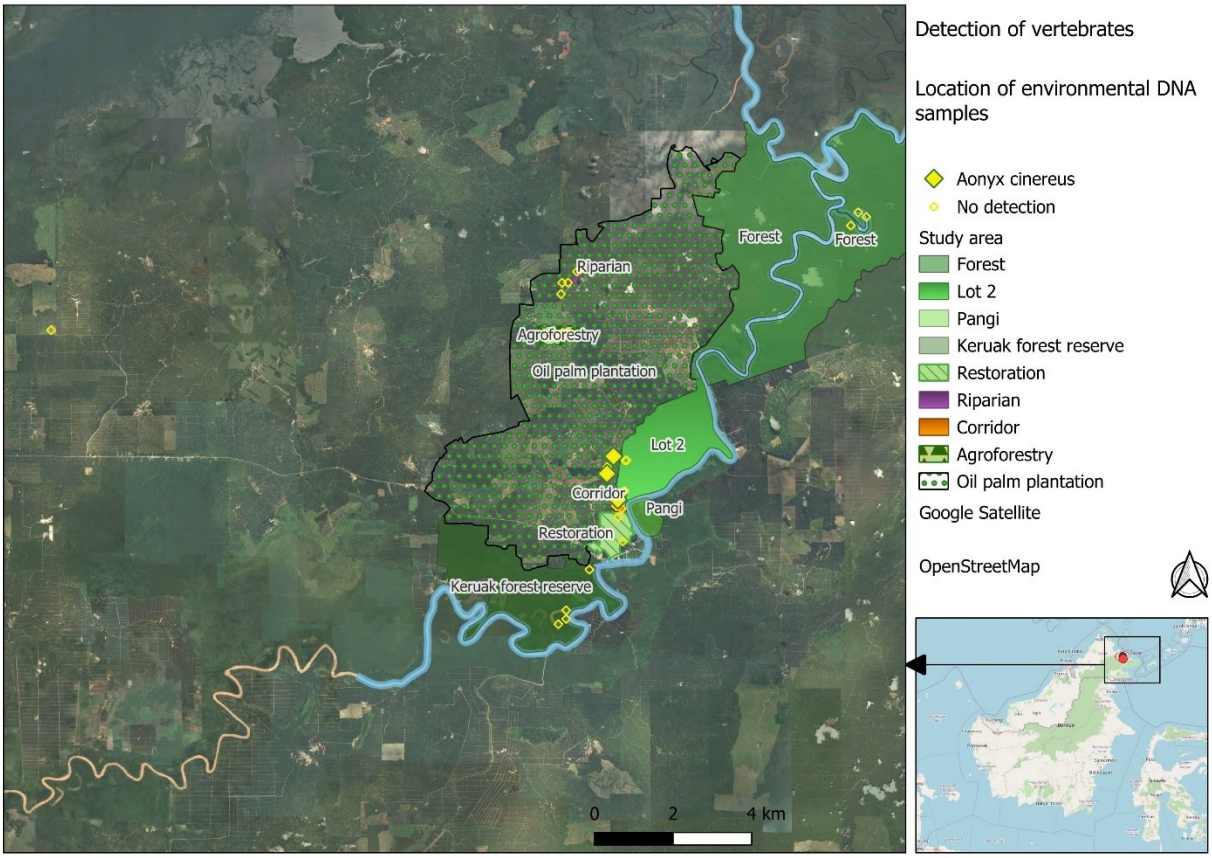


Species present in only 3% of the sites analysed. Bird detections are often underestimated for the bird class.

CLASS	Level Red List IUCN	Latin name
Mammalia	VU	*Aonyx cinereus* VU

Asian Small-clawed Otter

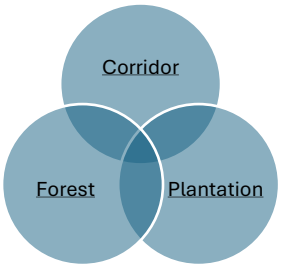


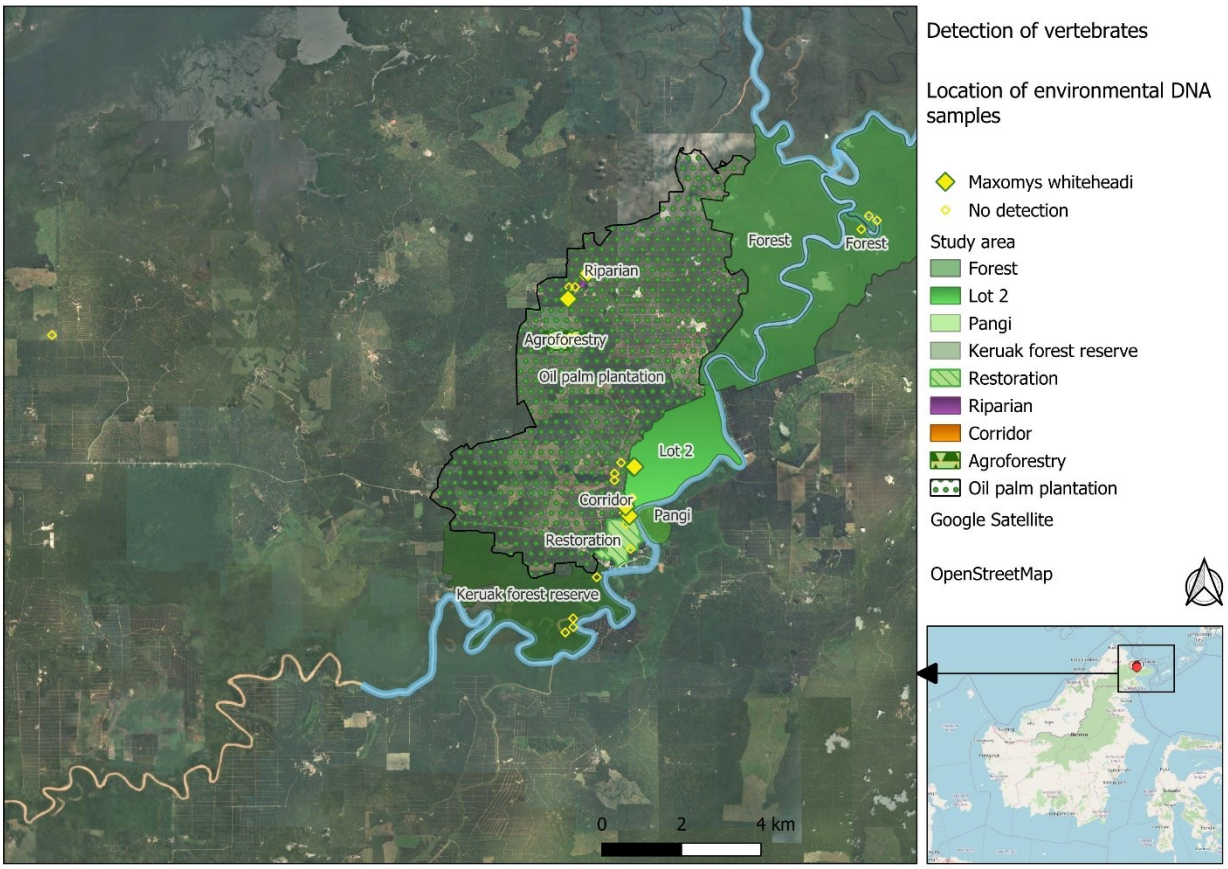


Species present at only 9% of the sites analysed.

CLASS	Level Red List IUCN	Latin name
Mammalia	VU	*Maxomys whiteheadi* VU

Whitehead's Sundaic Maxomys

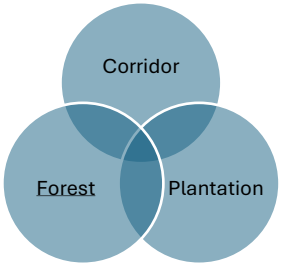


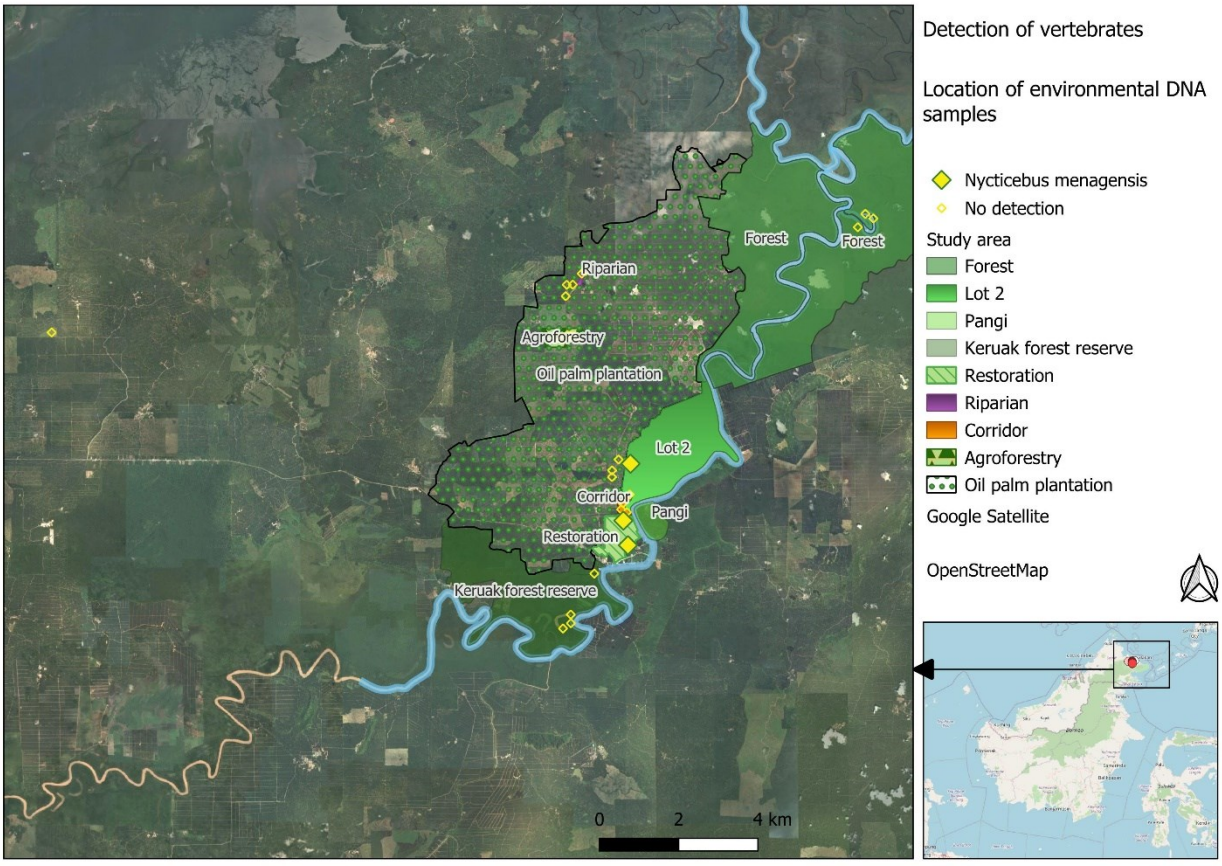


Species present at 19% of the sites analysed.

CLASS	Level Red List IUCN	Latin name
Mammalia	VU	*Nycticebus menagensis* VU

Philippine Slow Loris

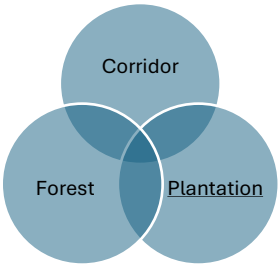


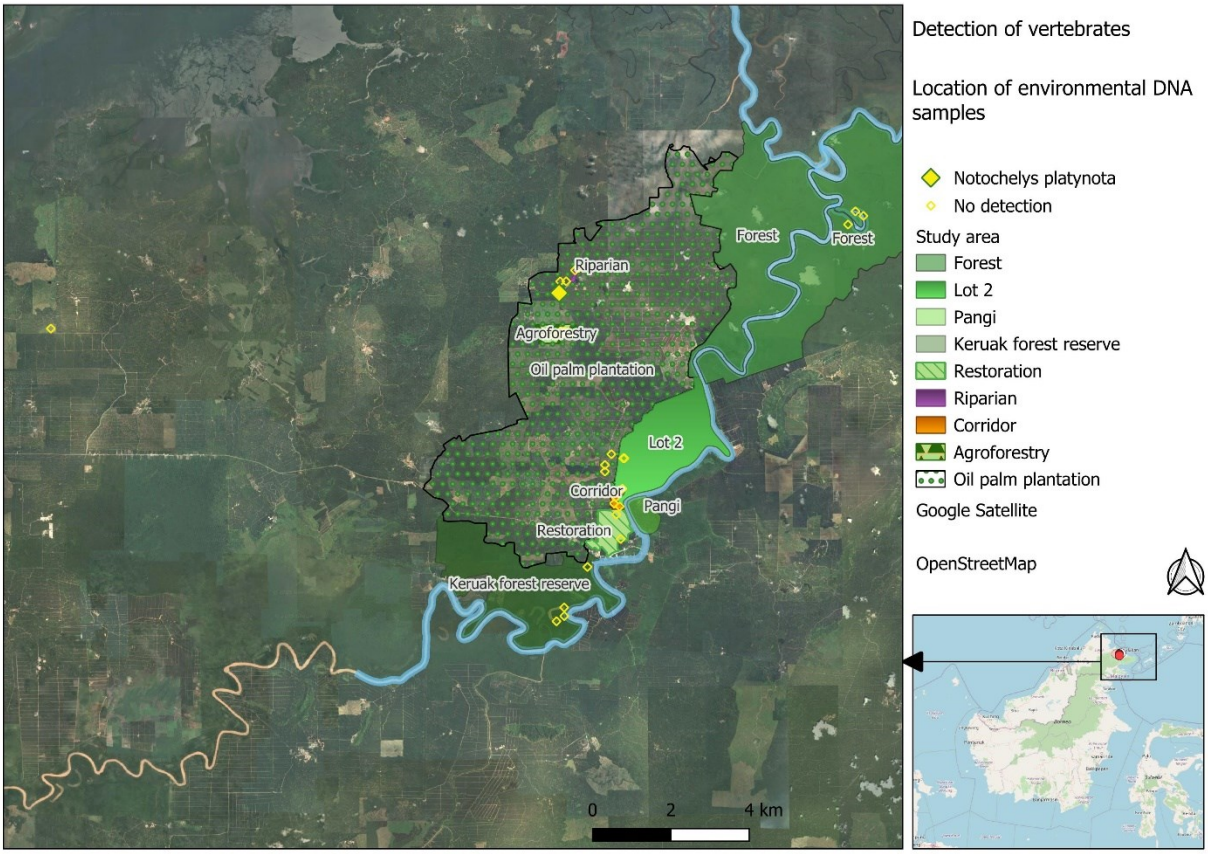


Species present at 9% of the sites analysed.

CLASS	Level Red List IUCN	Latin name
Reptilia	VU	*Notochelys platynota* VU

Malayan Flat-shelled Turtle

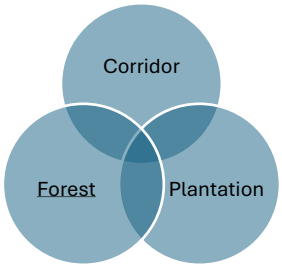


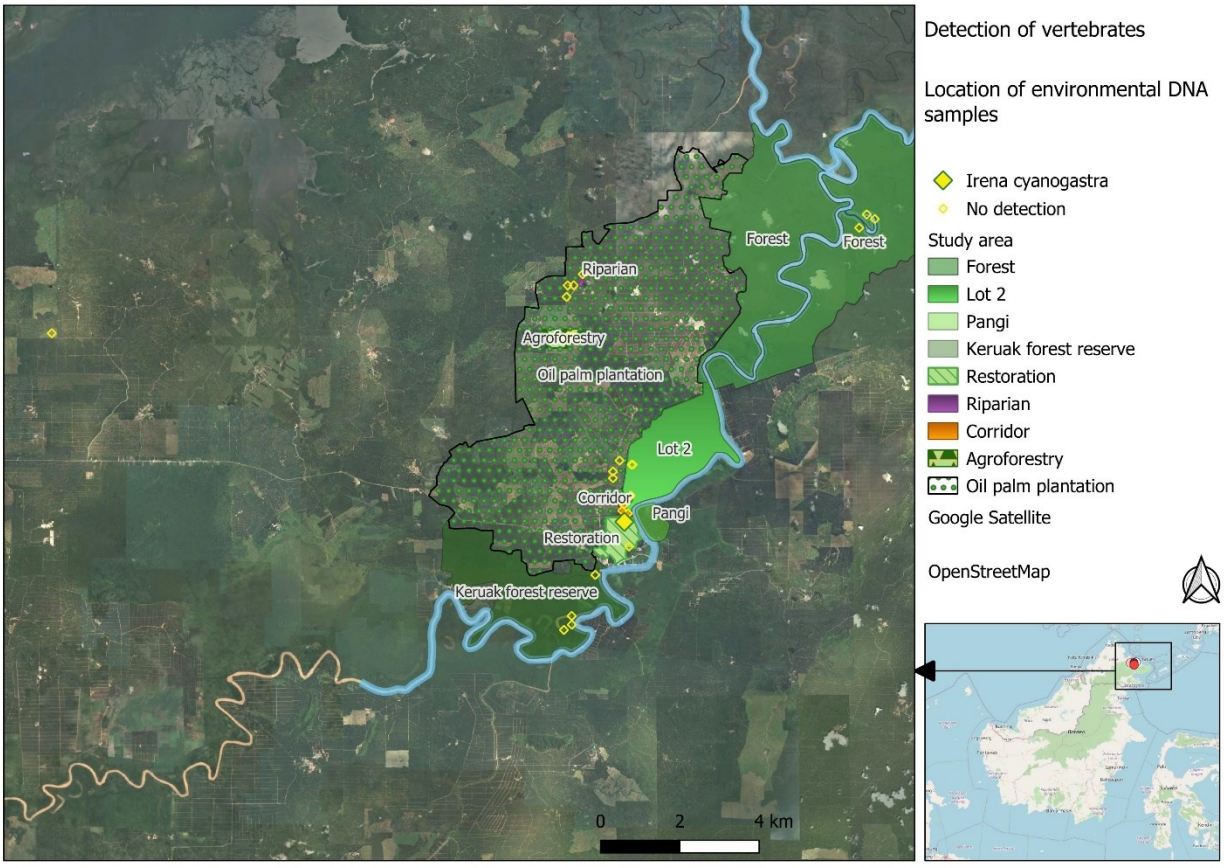


Species present at only 3% of the sites analysed.

CLASS	Level Red List IUCN	Latin name
Aves	NT	Irena cyanogastra NT

Philippine Fairy-bluebird





Species present at 3% of the sites analysed. As a bird species, it is highly likely that detection by eDNA is underestimated for this species.

Comparison between two palm groves of different ages

Here we compare the diversity of an old plantation with a young plantation.

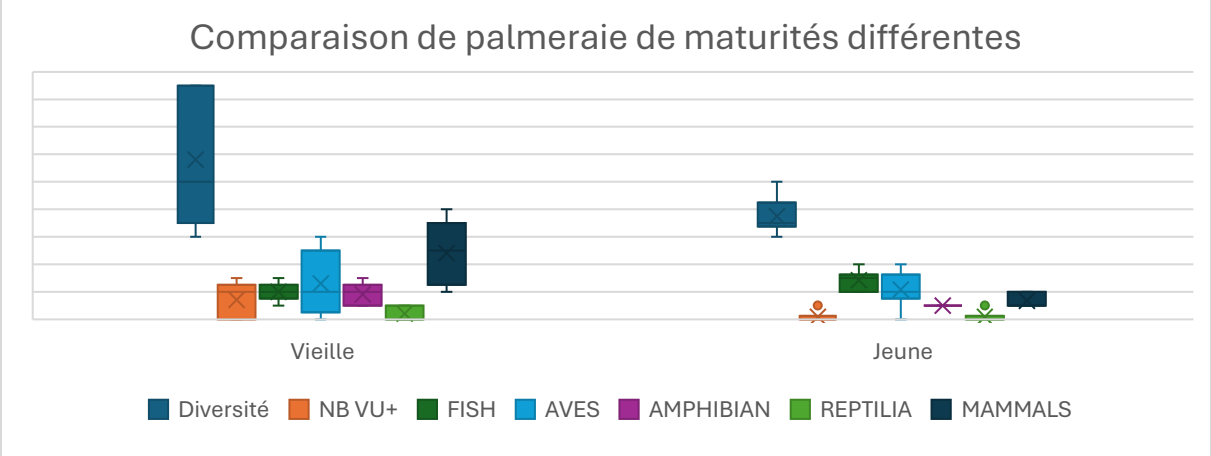


Figure 24 : Comparison between two palm groves of different ages

As expected, the **specific richness** is greater for **ancient palm groves**.

This translates into a significant increase in the number of mammal and amphibian species. To a lesser extent, bird diversity tends to increase with the age of the palm grove.

In terms of conservation, older palm groves are home to more vulnerable species than younger ones. This finding has important implications for managing new palm rotation cycles. Rotation cycles span approximately 25 years, and in order to fulfil the various certification requirements, land-use planning for a new rotation may strategically designate certain areas as High Conservation Value Areas that will no longer be used for palm production. In these areas, the restoration approach should involve retaining the existing mature palm plants rather than felling them, while establishing new tree seedlings in the understory beneath the palm canopy.

Factor	older plantation	Younger plantation
Overall diversity	12+-7	8+-1
Vulnerable species	1.4	0.166
Fish diversity	2	2.8
Bird diversity	2.6	2
Amphibian diversity	1.8	1
Reptile diversity	0.4	0.1
Mammal diversity	4.8	1.3
	++	--

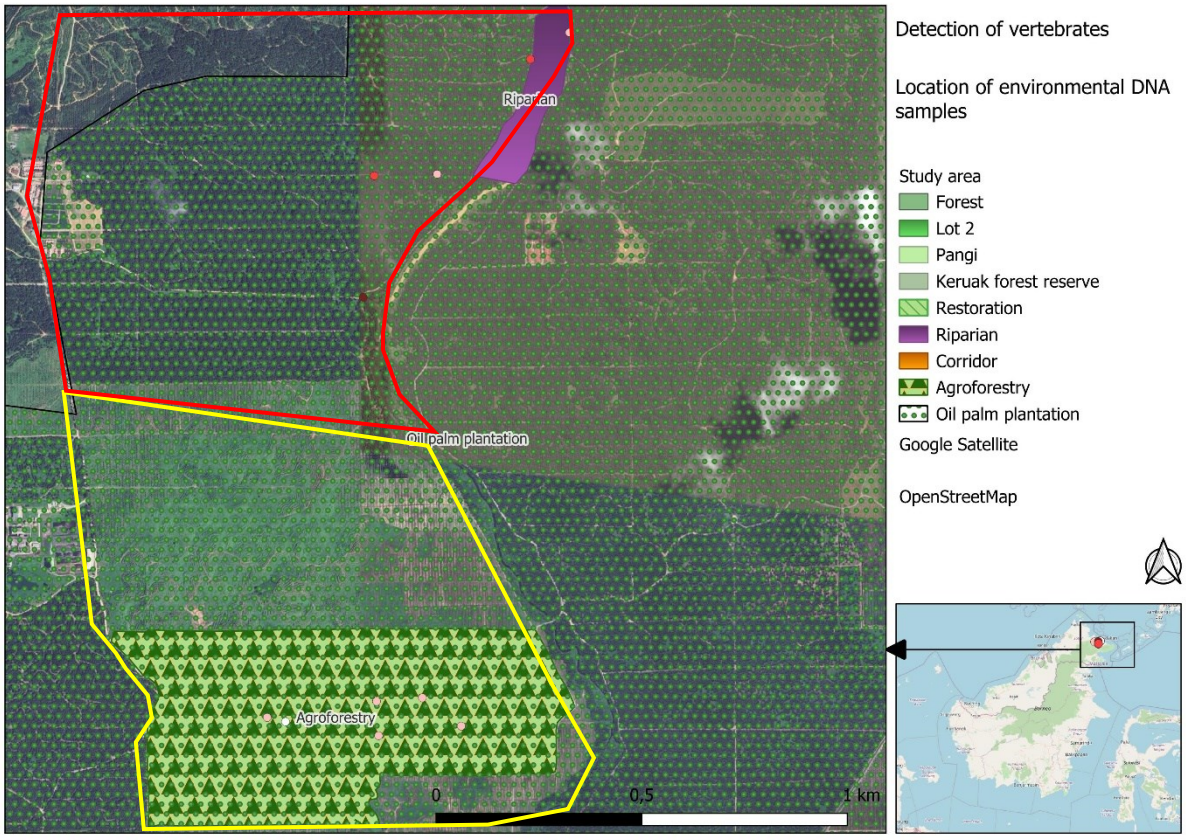


Figure 25 : Map showing the location of samples from two palm groves old different ages

In figure 25, younger palm groves are located in the south and the older ones in the north.

The "Young Palms" sites are part of an agroforestry experiment called TRAILs, where native trees and oil palms are intercropped and planted together. This experiment began in 2022, meaning both the trees and palms are still very young and do not yet support the same level of biodiversity as mature palm stands. However, the data collected during this eDNA campaign provides critical baseline information captured at a pivotal moment–shortly after this habitat underwent a massive transformation through the removal of old mature palms and the establishment of a new rotation cycle integrating both palms and trees. Long-term monitoring by Hutan will reveal how biodiversity in these agroforestry systems compares to that in conventional monoculture oil palm plantations.

Comparison between two palm groves of different ages and an ecological corridor

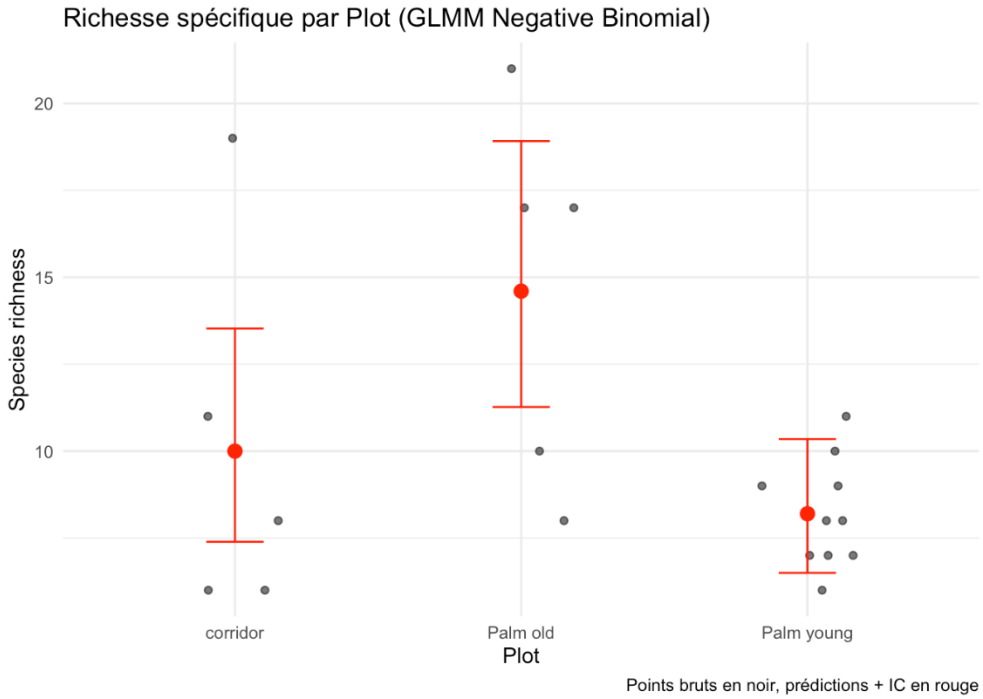


Figure 26 : Specific richness per plot

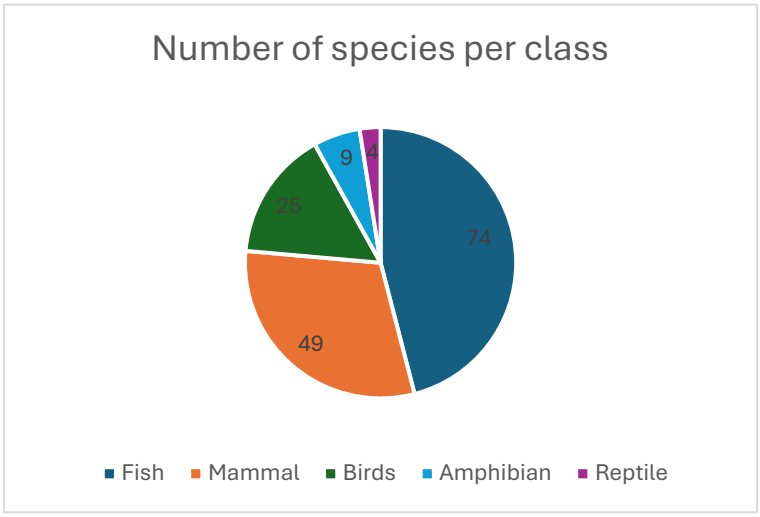
There is a significant difference between the richness specific of old and young palms. The diversity is most important in old palms (see above). For the corridor, the difference between old and young palm is less significant.

The results reveal high variability in both the Corridor and mature palm sites, in contrast to the remarkably low variability observed in the young agroforestry experiment. This finding is significant for several reasons:

- **Sampling bias in biodiversity assessments**: Due to the high spatial variability within the corridor and mature palm habitats, biodiversity monitoring results will be strongly influenced by survey plot placement. This factor is rarely accounted for in oil palm plantation biodiversity research, potentially leading to inconsistent or misleading conclusions.
- **Need for mechanistic understanding**: Further investigation is needed to identify the drivers of this high variability, such as proximity to forest edges, understory vegetation quality, management practices, human intervetions and other factors...
- **Baseline conditions following rotation**: The exceptionally low variability in the young palms within the TRAILs experiment (n=10 samples) reflects the intensive habitat transformation that occurred at the end of the first rotation cycle (approximately one year before replanting). These results demonstrate that the transition to a new rotation effectively eliminates nearly all biodiversity, resetting the habitat to an extremely degraded baseline from which ecological recovery must begin.

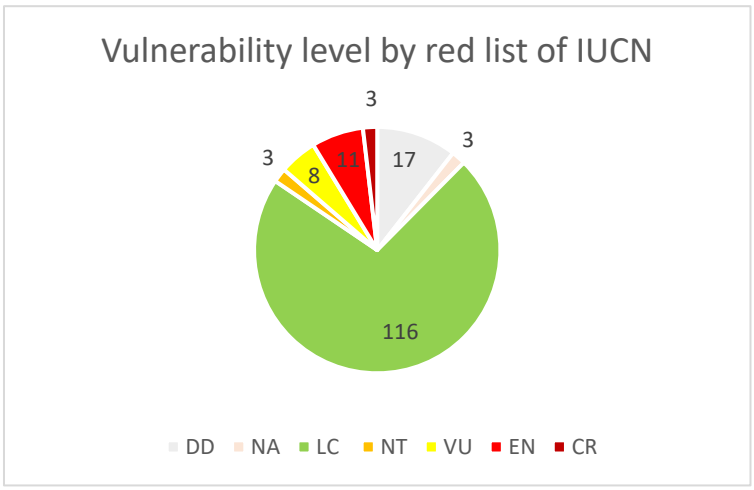
Summary of eDNA data since 2019 on the Kinabatangan

During our first campaign in 2019 we detected **160** species, mostly fishes since we collected water in the rivers, ditch, drain and oxbow lakes.



Mammals was the second most common class with 49 species followed by birds (24 sp.), amphibians (9 sp.) and reptiles (4 sp.).

Figure 27 : Number of species per class since 2019



In this list, 16% species are endangered but we need to acknowledge that the status of several species (especially fishes) has not been assessed yet assessment, and some are unknown in genetic databases. the red list is not completely up to date.

Figure 28 : Vulnerability level by red list of IUCN

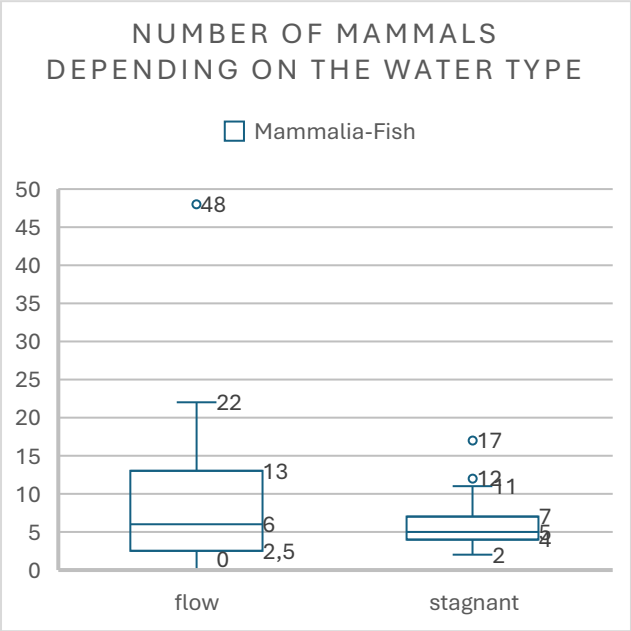


Figure 29 : Number of mammals depending on the water type

We now compare the fish community; we strongly advise to use the flowing water eDNA approach.

eDNA results in stagnant water (puddles, ponds, oxbow lakes: second campaign) and flowing water (drain, ditch, river).

Overall, results seem more complete when we follow the eDNA flowing water protocol. This result is not surprising since more freshwater biodiversity is expected to be found in large flowing water. However more terrestrial species were recorded with the stagnat water samples. So the choice of running vs stagnant water sampling will primarily depend on the questions we want to investigate. For the fish community, we strongly advise using the flowing water eDNA sampling approach. However, undertaking this methodology is more troublesome than using the stagnant water approach.

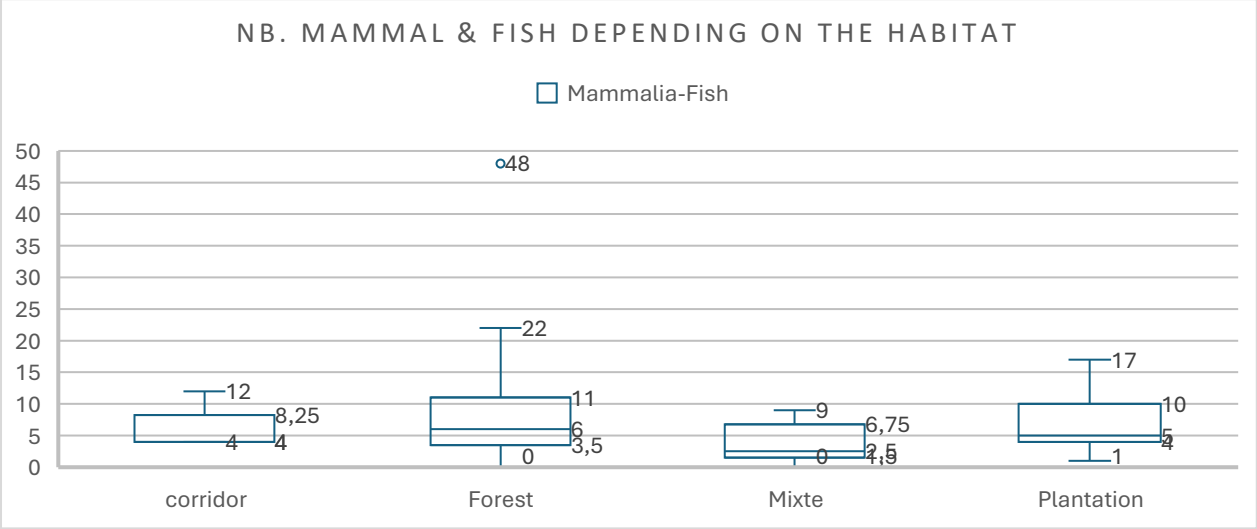


Figure 30 : Number mammal and fish depending on the habitat

As expected, more species were overall identified in the forest habitat.

Conclusion

This second collection campaign aimed to:

- Compare an approach using stagnant water and running water,

- Contribute to the biodiversity monitoring carried out by Hutan,

- Participate in identifying species present in different environments,

- Provide an opportunity to train Hutan teams in new technologies.

The first campaign in stagnant water identified severals new species, including mammals, birds, fish and reptiles.

In total, the eDNA campaigns identified 161 species, including 20 new detections for HUTAN in 2019.

In conclusion, the eDNA approach made it possible to identify certain species that had not yet been detected by Hutan teams during successive inventories, thus demonstrating the value of this approach for detecting rare or cryptic species.

These environmental DNA results will be integrated into Hutan's monitoring data to complete the picture of biodiversity in the different environments of the Kinabatangan.

Bibliographie

GUIDE D'UTILISATION DE L'ADN ENVIRONNEMENTAL, Fleuve et rivières, Patrinat, Vigilife, 79p. https://hal.science/hal-05130877/document

KayR. F.MaddenR. H.1997. Mammals and rainfall: paleoecology of the middle Miocene at La Venta (Colombia, South America). – *J. Hum. Evol.* **32**: 161–199.

Daniel Kissling, W., Böhning–Gaese, K., & Jetz, W. (2009). The global distribution of frugivory in birds. *Global Ecology and Biogeography*, *18*(2), 150-162.

SOON, V., MOHD-AZLAN, J. A. Y. A. S. I. L. A. N., AMIT, B. C., & TUEN, A. A. (2022). The abundance and species richness of insectivorous birds in relation to arthropods assemblages along a distance gradient from secondary forest into oil palm plantation in SALCRA, Sarawak. *Malayan Nature Journal*, *74*(3).

Annexes

Species	Class	Order	Family	Conservation
Acentrogobius janthinopterus	Actinopteri	Gobiiformes	Gobiidae	LC
Acentrogobius viridipunctatus	Actinopteri	Gobiiformes	Gobiidae	LC
Alectis indica	Actinopteri	Carangiformes	Carangidae	LC
Alepes djedaba	Actinopteri	Carangiformes	Carangidae	LC
Anabas testudineus	Actinopteri	Anabantiformes	Anabantidae	LC
Anguilla malgumora	Actinopteri	Anguilliformes	Anguillidae	DD
Anodontostoma chacunda	Actinopteri	Clupeiformes	Clupeidae	LC
Apogon hyalosoma	Actinopteri	Kurtiformes	Apogonidae	LC
Barbonymus gonionotus	Actinopteri	Cypriniformes	Cyprinidae	LC
Boleophthalmus boddarti	Actinopteri	Gobiiformes	Gobiidae	LC
Brachygobius doriae	Actinopteri	Gobiiformes	Gobiidae	LC
Butis koilomatodon	Actinopteri	Gobiiformes	Eleotridae	LC
Caranx ignobilis	Actinopteri	Carangiformes	Carangidae	LC
Channa striata	Actinopteri	Anabantiformes	Channidae	LC
Chanos chanos	Actinopteri	Gonorynchiformes	Chanidae	LC
Chitala ornata	Actinopteri	Osteoglossiformes	Notopteridae	LC
Decapterus macrosoma	Actinopteri	Carangiformes	Carangidae	LC
Decapterus maruadsi	Actinopteri	Carangiformes	Carangidae	LC
Drombus kranjiensis	Actinopteri	Gobiiformes	Gobiidae	DD
Eleotris fusca	Actinopteri	Gobiiformes	Eleotridae	LC
Ellochelon vaigiensis	Actinopteri	Mugiliformes	Mugilidae	LC
Escualosa thoracata	Actinopteri	Clupeiformes	Clupeidae	LC
Eugnathogobius variegatus	Actinopteri	Gobiiformes	Gobiidae	LC
Gerres filamentosus	Actinopteri	Gerreiformes	Gerreidae	LC
Glossogobius aureus	Actinopteri	Gobiiformes	Gobiidae	LC
Glossogobius giuris	Actinopteri	Gobiiformes	Gobiidae	LC

Hemigobius hoevenii	Actinopteri	Gobiiformes	Gobiidae	LC
Hemigobius mingi	Actinopteri	Gobiiformes	Gobiidae	DD
Hemiramphus far	Actinopteri	Beloniformes	Hemiramphidae	no
Hyporhamphus limbatus	Actinopteri	Beloniformes	Hemiramphidae	LC
Hypostomus plecostomus	Actinopteri	Siluriformes	Loricariidae	no
Jaydia novaeguineae	Actinopteri	Kurtiformes	Apogonidae	no
Johnius belangerii	Actinopteri	-	Sciaenidae	LC
Lagocephalus lunaris	Actinopteri	Tetraodontiformes	Tetraodontidae	LC
Lethrinus lentjan	Actinopteri	Spariformes	Lethrinidae	LC
Luciosoma bleekeri	Actinopteri	Cypriniformes	Danionidae	LC
Lutjanus argentimaculatus	Actinopteri	Lutjaniformes	Lutjanidae	LC
Lutjanus johnii	Actinopteri	Lutjaniformes	Lutjanidae	LC
Lutjanus notatus	Actinopteri	Lutjaniformes	Lutjanidae	LC
Lutjanus russellii	Actinopteri	Lutjaniformes	Lutjanidae	LC
Megalops cyprinoides	Actinopteri	Elopiformes	Megalopidae	DD
Monodactylus argenteus	Actinopteri	-	Monodactylidae	LC
Moolgarda engeli	Actinopteri	Mugiliformes	Mugilidae	LC
Moolgarda perusii	Actinopteri	Mugiliformes	Mugilidae	LC
Mugilogobius chulae	Actinopteri	Gobiiformes	Gobiidae	LC
Ophiocara porocephala	Actinopteri	Gobiiformes	Eleotridae	LC
Oxyeleotris marmorata	Actinopteri	Gobiiformes	Eleotridae	LC
Pangasianodon hypophthalmus	Actinopteri	Siluriformes	Pangasiidae	EN
Parapocryptes serperaster	Actinopteri	Gobiiformes	Gobiidae	LC
Pellona ditchela	Actinopteri	Clupeiformes	Pristigasteridae	LC
Periophthalmodon schlosseri	Actinopteri	Gobiiformes	Gobiidae	LC
Periophthalmus argentilineatus	Actinopteri	Gobiiformes	Gobiidae	LC
Periophthalmus novemradiatus	Actinopteri	Gobiiformes	Gobiidae	DD
Photopectoralis bindus	Actinopteri	Chaetodontiformes	Leiognathidae	DD
Pisodonophis boro	Actinopteri	Anguilliformes	Ophichthidae	LC
Planiliza macrolepis	Actinopteri	Mugiliformes	Mugilidae	LC
Planiliza subviridis	Actinopteri	Mugiliformes	Mugilidae	LC
Plicofollis argyropleuron	Actinopteri	Siluriformes	Ariidae	no
Pomadasys hasta	Actinopteri	Lutjaniformes	Haemulidae	LC
Psammogobius biocellatus	Actinopteri	Gobiiformes	Gobiidae	LC
Pseudogobius javanicus	Actinopteri	Gobiiformes	Gobiidae	no
Puntioplites proctozystron	Actinopteri	Cypriniformes	Cyprinidae	LC
Rasbora hobelmani	Actinopteri	Cypriniformes	Danionidae	NA
Rasbora steineri	Actinopteri	Cypriniformes	Cyprinidae	LC
Rastrelliger kanagurta	Actinopteri	Scombriformes	Scombridae	DD
Scatophagus argus	Actinopteri	-	Scatophagidae	LC
Scomber scombrus	Actinopteri	Scombriformes	Scombridae	LC
Selar crumenophthalmus	Actinopteri	Carangiformes	Carangidae	LC
Setipinna melanochir	Actinopteri	Clupeiformes	Engraulidae	DD
Siganus guttatus	Actinopteri	-	Siganidae	LC
Sillago sihama	Actinopteri	-	Sillaginidae	LC
Tetraodon nigroviridis	Actinopteri	Tetraodontiformes	Tetraodontidae	no

Toxotes chatareus	Actinopteri	(vide)	Toxotidae	LC
Trichopodus pectoralis	Actinopteri	Anabantiformes	Osphronemidae	LC
Chaperina fusca	Amphibia	Anura	Microhylidae	LC
Hylarana chalconota	Amphibia	Anura	Ranidae	LC
Hylarana erythraea	Amphibia	Anura	Ranidae	LC
Ingerophrynus divergens	Amphibia	Anura	Bufonidae	LC
Kurixalus appendiculatus	Amphibia	Anura	Rhacophoridae	LC
Limnonectes finchi	Amphibia	Anura	Dicroglossidae	LC
Limnonectes ingeri	Amphibia	Anura	Dicroglossidae	LC
Limnonectes kuhlii species complex	Amphibia	Anura	Dicroglossidae	LC
Polypedates leucomystax	Amphibia	Anura	Rhacophoridae	LC
Acridotheres cristatellus	Aves	Passeriformes	Sturnidae	LC
Aerodramus fuciphagus	Aves	Apodiformes	Apodidae	LC
Amaurornis phoenicurus	Aves	Gruiformes	Rallidae	LC
Anhinga melanogaster	Aves	Pelecaniformes	Anhingidae	LC
Ardea intermedia	Aves	Pelecaniformes	Ardeidae	LC
Ardea purpurea	Aves	Pelecaniformes	Ardeidae	LC
Bubulcus ibis	Aves	Pelecaniformes	Ardeidae	LC
Buceros rhinoceros	Aves	Bucerotiformes	Bucerotidae	VU
Centropus sinensis	Aves	Cuculiformes	Centropidae	LC
Dendrocygna arcuata	Aves	Anseriformes	Anatidae	LC
Excalfactoria chinensis	Aves	Galliformes	Phasianidae	LC
Gallinago stenura	Aves	Charadriiformes	Scolopacidae	LC
Gallirallus striatus	Aves	Gruiformes	Rallidae	LC
Geopelia striata	Aves	Columbiformes	Columbidae	LC
Gorsachius melanolophus	Aves	Pelecaniformes	Ardeidae	LC
Irena cyanogastra	Aves	Passeriformes	Irenidae	NT
Lophura ignita	Aves	Galliformes	Phasianidae	VU
Mixornis gularis	Aves	Passeriformes	Timaliidae	LC
Muscicapa latirostris	Aves	Passeriformes	Muscicapidae	NA
Myophonus caeruleus	Aves	Passeriformes	Muscicapidae	LC
Nycticorax nycticorax	Aves	Pelecaniformes	Ardeidae	LC
Phodilus badius	Aves	Strigiformes	Tytonidae	LC
Serilophus lunatus	Aves	Passeriformes	Eurylaimidae	LC
Todiramphus sanctus vagans	Aves	Coraciiformes	Alcedinidae	LC
Tricholestes criniger	Aves	Passeriformes	Pycnonotidae	LC
Aonyx cinereus	Mammalia	Carnivora	Mustelidae	VU
Callosciurus notatus	Mammalia	Rodentia	Sciuridae	LC
Callosciurus prevostii	Mammalia	Rodentia	Sciuridae	LC
Chironax sp.	Mammalia	Chiroptera	Pteropodidae	LC
Cynogale bennetti	Mammalia	Carnivora	Viverridae	EN
Cynopterus brachyotis	Mammalia	Chiroptera	Pteropodidae	LC
Cynopterus brachyotis	Mammalia	Chiroptera	Pteropodidae	LC
Echinosorex gymnura	Mammalia	Eulipotyphla	Erinaceidae	LC
Elephas maximus	Mammalia	Proboscidea	Elephantidae	EN
Galeopterus variegatus	Mammalia	Dermoptera	Cynocephalidae	LC

Hipposideros galeritus	Mammalia	Chiroptera	Hipposideridae	LC
Hylobates funereus	Mammalia	Primates	Hylobatidae	EN
Kerivoula pellucida	Mammalia	Chiroptera	Vespertilionidae	NT
Kerivoula sp.	Mammalia	Chiroptera	Vespertilionidae	no
Lenothrix canus	Mammalia	Rodentia	Muridae	LC
Lenothrix sp.	Mammalia	Rodentia	Muridae	LC
Lutra sumatrana	Mammalia	Carnivora	Mustelidae	EN
Lutrogale perspicillata	Mammalia	Carnivora	Mustelidae	VU
Macaca fascicularis	Mammalia	Primates	Cercopithecidae	EN
Macaca nemestrina	Mammalia	Primates	Cercopithecidae	EN
Manis culionensis	Mammalia	Pholidota	Manidae	CR
Manis javanica	Mammalia	Pholidota	Manidae	CR
Maxomys whiteheadi	Mammalia	Rodentia	Muridae	VU
Miniopterus fuliginosus	Mammalia	Chiroptera	Vespertilionidae	NA
Murina suilla	Mammalia	Chiroptera	Vespertilionidae	LC
Myotis horsfieldii	Mammalia	Chiroptera	Vespertilionidae	LC
Nasalis larvatus	Mammalia	Primates	Cercopithecidae	EN
Niviventer cremoriventer	Mammalia	Rodentia	Muridae	LC
Nycticebus menagensis	Mammalia	Primates	Lorisidae	VU
Paradoxurus jerdoni	Mammalia	Carnivora	Viverridae	LC
Paradoxurus hermaphroditus	Mammalia	Carnivora	Viverridae	LC
Penthetor lucasi	Mammalia	Chiroptera	Pteropodidae	LC
Pongo pygmaeus	Mammalia	Primates	Hominidae	CR
Potamochoerus	Mammalia	Mammalia	Suidae	no
Presbytis comata comata	Mammalia	Primates	Cercopithecidae	EN
Prionailurus bengalensis	Mammalia	Carnivora	Felidae	LC
Pteropus seychellensis comorensis	Mammalia	Chiroptera	Pteropodidae	LC
Pteropus sp.	Mammalia	Chiroptera	Pteropodidae	EN
Ptilocercus lowii	Mammalia	Scandentia	Tupaiidae	LC
Rattus exulans	Mammalia	Rodentia	Muridae	LC
Rattus tanezumi	Mammalia	Rodentia	Muridae	LC
Rattus tiomanicus	Mammalia	Rodentia	Muridae	LC
Rhinolophus affinis	Mammalia	Chiroptera	Rhinolophidae	LC
Rhinolophus sp.	Mammalia	Chiroptera	Rhinolophidae	no
Sundamys muelleri	Mammalia	Rodentia	Muridae	LC
Trachypithecus cristatus	Mammalia	Primates	Cercopithecidae	VU
Trichys fasciculata	Mammalia	Rodentia	Hystricidae	LC
Tupaia longipes	Mammalia	Scandentia	Tupaiidae	LC
Tupaia tana	Mammalia	Scandentia	Tupaiidae	LC
Cuora amboinensis	Reptilia	Testudines	Geoemydidae	EN
Cyclemys sp.	Reptilia	Testudines	Geoemydidae	NT
Notochelys platynota	Reptilia	Testudines	Geoemydidae	VU
Varanus salvator	Reptilia	Squamata	Varanidae	LC

Figure 31 : List of species

List of sites with location

SiteID	NameSite	X	Y	Water	Habitat
C1	CorridorB1P1	3129783	2015994	stagnant	Corridor
C2	CorridorB1P4A	3128857	2016490	stagnant	Corridor
C3	CorridorB1P5	3129161	2017534	stagnant	Corridor
C4	CorridorB1P6	3130258	2018964	stagnant	Corridor
C5	PlantationB2P5	3129149	2017512	stagnant	Corridor
E1	Estuary	3235002	2035119	flow	Forest
F1	ForestB3P3	3130398	2024063	stagnant	Forest
F10	RIVER MANAGBOL	3167009	2060862	flow	Forest
F11	RIVER TO DANAU PITAS ABAY	3168067	2063249	flow	Forest
F12	River ManagBol	3124393	2005851	flow	Forest
F2	ForestB3P3	3130604	2024069	stagnant	Forest
F3	ForestB3P5	3129214	2014627	stagnant	Forest
F4	Forest - KeruakBehind Bam's house	3129973	2010548	stagnant	Forest
F5	DANAU BACK	3169313	2065450	stagnant	Forest
F6	DANAUX PITAS GAUCHE	3170648	2064695	stagnant	Forest
F7	OXBOW LAKE ENTREE KILINANAP	3118947	1996715	stagnant	Forest
F8	OXBOW LAKE FOND KILINANAP	3120254	1999203	stagnant	Forest
F9	OXBOW LAKE riv KILINANAP	3120549	1997631	flow	Forest
K1	Kinabatangan river	3164286	2065645	flow	Forest
K2	Kinabatangan river	3144434	2034518	flow	Mixte
K2	Kinabatangan river	3144434	2034518	flow	Mixte
K3	Kinabatangan river	3130848	2015798	flow	Forest
K3	Kinabatangan river	3130848	2015798	flow	Forest
K4	Kinabatangan river	3088307	1986732	flow	Mixte
K4	Kinabatangan river	3088307	1986732	flow	Mixte
K5	Kinabatangan river	3051751	1972233	flow	Forest
K5	Kinabatangan river	3051751	1972233	flow	Forest
K6	Kinabatangan river	2996018	1980909	flow	Forest
K6	Kinabatangan river	2996018	1980909	flow	Forest
K7	Kinabatangan river	2968478	1994835	flow	Forest
K7	Kinabatangan river	2968478	1994835	flow	Forest
K8	Kinabatangan river	2931465	1974513	flow	Mixte
K8	Kinabatangan river	2931465	1974513	flow	Mixte
M1	Mangrove	3216732	2016049	flow	Forest
O1	Oxbow lake	3170554	2062676	flow	Forest
O1	Oxbow lake	3170554	2062676	flow	Forest
O2	Oxbow lake	3117977	1998266	flow	Forest
O5	Oxbow lake	3011834	1972526	flow	Forest
P1	AgroforestryBlock A - Forest Native Species	3119863	2045328	stagnant	Plantation
P10	PlantationRiparian MOPP	3122942	2055992	stagnant	Plantation
P11	Agroforestery	3118118	2045070	stagnant	Plantation
P12	Agroforestry Block C	3121215	2044933	stagnant	Plantation

P13	Bridge Jambatan Orchid	3034436	2045814	stagnant	Plantation
P14	Hasbollah DUCK	3119896	2044780	stagnant	Plantation
P15	Small river M B95K	3119651	2051770	flow	Plantation
P2	AgroforestryBlock B - Mixed Native Species	3118411	2045003	stagnant	Plantation
P3	AgroforestryBlock C - Forest Island	3120594	2045384	stagnant	Plantation
P4	PlantationB2P10	3128416	2024751	stagnant	Plantation
P5	PlantationB2P6	3127323	2021854	stagnant	Plantation
P6	PlantationB2P8	3127324	2022949	stagnant	Plantation
P7	PlantationOil Palm MOPP	3120829	2053734	stagnant	Plantation
P8	PlantationOil Palm MOPP	3119826	2053707	stagnant	Plantation
P9	PlantationRiparian MOPP	3122316	2055566	stagnant	Plantation
PO1	Little river	3122697	2055135	flow	Plantation
T1	Little river	3154446	2073646	flow	Forest
T10	Little river	3128553	2015822	flow	Corridor
T11	Little river	3180368	2065346	flow	Forest
T11	Little river	3180368	2065346	flow	Forest
T2	Little river	3116857	1989774	flow	Forest
T2	Little river	3116857	1989774	flow	Forest
T3	Little river	2998786	1967778	flow	Forest
T4	Little river	2991022	2001177	flow	Plantation
T5	Little river	2956375	2002458	flow	Plantation
T6	Little river	2929870	1981208	flow	Forest
T6	Little river	2929870	1981208	flow	Forest
T7	Little river	3018452	1967186	flow	Forest
T8	Little river	3054923	1970132	flow	Forest
T9	Little river	3146876	2022311	flow	Plantation

Figure 32 : List of sites and locations

SiteID	Spygen	RICHESSE SPECIFIQUE	Mammalia & Fish	MAMMALIA	REPTILIA	AVES	FISH	AMPHIBIAN
C1	SPY214361	19	12	7	1	1	5	5
C2	SPY214362	6	4	1	0	0	3	2
C3	SPY214366	8	4	4	0	2	0	2
C4	SPY214365	6	4	2	0	0	2	2
C5	SPY214364	11	7	2	1	2	5	1
E1	SPY193037	11	11	0	0	0	11	0
F1	SPY214369	22	17	17	0	2	0	3
F10	SPY223474	6	3	1	0	2	2	1
F11	SPY223469	6	6	3	0	0	3	0
F12	SPY214374	15	13	8	0	0	5	2
F2	SPY214370	16	11	8	1	2	3	2
F3	SPY214363	18	9	5	1	4	4	4
F4	SPY214372	7	4	4	1	1	0	1
F5	SPY223468	3	3	1	0	0	2	0
F6	SPY223466	2	2	0	0	0	2	0
F7	SPY223473	11	10	2	0	1	8	0
F8	SPY223467	7	6	1	0	1	5	0
F9	SPY223471	10	9	2	0	0	7	1
K1	SPY193021	4	4	1	0	0	3	0
K2	SPY193019	0	0	0	0	0	0	0
K2	SPY193027	2	2	1	0	0	1	0
K3	SPY193020	2	2	1	0	0	1	0
K3	SPY193028	0	0	0	0	0	0	0
K4	SPY193031	2	2	1	0	0	1	0
K4	SPY193048	3	3	1	0	0	2	0
K5	SPY193023	2	2	0	0	0	2	0
K5	SPY193040	5	5	2	0	0	3	0
K6	SPY193036	6	6	2	0	0	4	0
K6	SPY193039	6	6	3	0	0	3	0
K7	SPY193050	6	6	4	0	0	2	0
K7	SPY193054	7	7	3	0	0	4	0
K8	SPY193024	6	6	3	0	0	3	0
K8	SPY193032	9	9	7	0	0	2	0
M1	SPY193042	48	48	4	0	0	44	0
O1	SPY193038	4	4	1	0	0	3	0
O1	SPY193044	4	4	1	0	0	3	0
O2	SPY193043	3	3	1	0	0	2	0
O5	SPY193033	7	7	3	0	0	4	0
P1	SPY214375	7	3	1	0	3	2	1

P10	SPY223461	10	7	6	0	2	1	1
P11	SPY223472	7	4	1	0	2	3	1
P12	SPY223470	8	4	1	1	2	3	1
P13	SPY223464	8	6	3	0	1	3	1
P14	SPY223463	7	6	2	0	0	4	1
P15	SPY223465	21	15	9	1	4	6	1
P2	SPY214373	6	3	1	0	2	2	1
P3	SPY223462	10	5	2	0	4	3	1
P4	SPY214371	11	4	2	1	4	2	2
P5	SPY214367	9	5	3	1	3	2	0
P6	SPY214368	9	3	1	1	2	2	3
P7	SPY214376	8	5	3	0	1	2	2
P8	SPY223460	17	11	8	1	4	3	1
P9	SPY223459	17	7	5	1	6	2	3
PO1	SPY193030	1	1	0	0	0	1	0
T1	SPY193041	8	8	3	0	0	5	0
T10	SPY193025	4	4	2	0	0	2	0
T11	SPY193022	1	1	0	0	0	1	0
T11	SPY193029	1	1	0	0	0	1	0
T2	SPY193053	14	14	5	0	0	9	0
T2	SPY193055	11	11	4	0	0	7	0
T3	SPY193045	15	15	6	0	0	9	0
T4	SPY193052	10	10	2	0	0	8	0
T5	SPY193051	16	16	7	0	0	9	0
T6	SPY193034	13	13	6	0	0	7	0
T6	SPY193046	22	22	13	0	0	9	0
T7	SPY193047	8	8	2	0	0	6	0
T8	SPY193049	16	16	7	0	0	9	0
T9	SPY193026	17	17	7	0	0	10	0

Figure 33 : Biodiversity per sites