Mount Wilhelm summit (4507 m a.s.l.)
(Photo by T. Fayle)

Land module of Our Planet Reviewed - Papua New Guinea: aims, methods and first taxonomical results

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ABSTRACT

Until now the altitudinal factor has not been taken into account to estimate tropical arthropod diversity. The ultimate aim of the terrestrial biodiversity survey "Our Planet Reviewed – Papua New Guinea" was to estimate biological diversity generated by altitudinal turnover of arthropod species. It took place on Mount Wilhelm, Papua New Guinea highest peak (4509 m a.s.l.), and one of the few equatorial mountains outside the Andes left with a continuous undisturbed forest from the sea level all the way to the timber line limit. An unprecedented sampling effort was concentrated over 16 days in 2012 with a semi-simultaneous sampling at eight different elevations (every 500 m from 200 m to 3700 m a.s.l.). Arthropods were collected with various methods: flight interception traps (targeting Coleoptera), Malaise traps (targeting Hymenoptera, Diptera and Hemiptera), Steiner traps (targeting tephritid flies), beating of the understorey vegetation, and insecticide spraying on tree barks (various groups targeted). A botany survey was conducted at each elevation to characterize vegetation. An additional site, Wanang, was sampled according to the same protocol, as replicated lowland site. Our team combined international experts with local postgraduate students, para-ecologists and villagers. Arthropod samples collected during the biotic survey were pre-sorted in Papua New Guinea and forwarded to taxonomists worldwide. The current book presents the first taxonomic results of the biotic survey. Project outputs included not only species discovery, but also direct financial benefits to landowner communities, raised profile of conservation areas, training of paraecologists and postgraduate students, education programmes and, finally, crucial biodiversity information needed for ecological analyses and conservation management.

RÉSUMÉ

Module terrestre de "La Planète Revisitée - Papouasie-Nouvelle-Guinée" : buts, méthodes et premiers résultats taxonomiques.

Jusqu'à présent le facteur altitudinal n'a pas été pris en compte dans les estimations du nombre global d'arthropodes dans les milieux tropicaux. Le but ultime de l'inventaire de biodiversité terrestre "La Planète Revisitée - Papouasie Nouvelle Guinée" est d'estimer la diversité biologique générée par le renouvellement altitudinal des espèces. Cet inventaire a pris place au Mont Wilhelm, le plus haut pic de Papouasie Nouvelle Guinée (4509 m), et l'une des rares montagnes, en dehors des Andes, encore couverte de forêt depuis le niveau de la mer jusqu'à la limite de distribution des arbres. Un effort d'échantillonnage sans précédent a été concentré sur 16 jours en 2012 avec des récoltes semi-simultanées à huit altitudes (tous les 500 m, de 200 à 3700 m). Les arthropodes ont été récoltés par différentes méthodes: des pièges d'interception (visant les coléoptères), des pièges Malaise (pour les hyménoptères, diptères et hémiptères), des pièges Steiner (pour les mouches téphritides), du battage de la végétation de sous-bois et de la fumigation d'insecticide sur les écorces d'arbres (récoltant une multitude de groupes). De plus, un inventaire botanique a été conduit à chaque altitude pour caractériser la végétation. Un site supplémentaire de basse altitude, Wanang, a été également échantillonné selon le même protocole, à titre de réplicat. Notre équipe était composée d'experts internationaux associés à des étudiants, des paraécologistes et des villageois. Les échantillons d'arthropodes récoltés durant l'inventaire de biodiversité ont été pré-triés en Papouasie-Nouvelle-Guinée et envoyés à des taxonomistes dans le monde entier. Le présent ouvrage présente les premiers résultats taxonomiques de l'expédition. Les résultats du projet incluent non seulement la découverte de nouvelles espèces, mais aussi le soutien financier aux communautés locales propriétaires des sites échantillonnés, la mise en valeur des aires protégées, la formation de paraécologistes et d'étudiants, l'éducation du public et, finalement, le rassemblement de données de biodiversité cruciales pour les analyses écologiques et la conservation des milieux.

INTRODUCTION

One of the main aims of the "Our Planet Reviewed" initiative is to document both terrestrial and marine biodiversity in some of the most biodiverse and least explored areas of the planet. This initiative results from the collaboration between a team of marine biologists led by Philippe Bouchet, Muséum national d'Histoire naturelle (MNHN, France), and Olivier Pascal, coordinator of numerous terrestrial expeditions involving the canopy raft ["Radeau des Cimes", an inflatable platform laid down on the top of the forest canopy] and the IBISCA (Investigating the Biodiversity of Soil and Canopy Arthropods) expert network (Basset *et al.* 2007; Leponce *et al.* 2012). Previous expeditions have been conducted in 2006 in Vanuatu (SANTO2006 project, Bouchet *et al*. 2009, 2012; Corbara 2009) and in 2009-2010 in Mozambique/Madagascar (Clarke 2011, Pascal 2011). Typically, these scientific expeditions gather a large number of participants. In SANTO 2006, a total of 233 persons (23 nationalities) were involved, comprising 155 scientists, 20 media participants (journalists, film makers, photographers, observers) and a support staff of 58 persons (managers, technicians, logistics support). In Mozambique/Madagascar, 155 persons (19 nationalities) participated to the project: 109 scientists, 22 media participants and a support staff of 24 persons.

Papua New Guinea (PNG) was an obvious choice for a new project. The island of New Guinea is the largest and highest tropical island. New Guinea is situated within the coral triangle and its marine biodiversity is exceptional (Veron *et al.* 2009). PNG is also the third largest remaining block of tropical forest, after the Amazon and Congo basins. The synergistic actions of equatorial climate, insular situation and complex orogeny have resulted in extremely rich terrestrial fauna and flora (Gressitt 1982; Barthlott *et al.* 2005; Marshall & Beehler 2007; Mutke *et al.* 2011; Toussaint *et al.* 2014). Plant richness is very high, estimated at between 15 and 20 thousand species, over 70% of them endemic (Davis *et al.* 1995). Davis *et al.* (1995) also estimated that there should be 5,000-6,000 plant species within an area of 9000 km^2 around Mt Wilhelm, Papua New Guinea's highest mountain (4509 m a.s.l.).

Apart from its extraordinary biodiversity, Papua New Guinea presented two key advantages for the terrestrial module project. First, PNG is one of the few places left where one can find complete elevational gradients in equatorial forests, from sea level up to the tree line. In many other places lowlands are heavily disturbed by human activities, or the mountains do not reach the tree line. Second, a large-scale study was feasible thanks to the presence of a leading paraecologist/parataxonomist research center, the New Guinea Binatang Research Center (BRC) led by Prof. Vojtech Novotny (Schmiedel *et al.* 2016). Parataxonomists and paraecologists are local technicians, generally hired from local communities but sometimes also new university graduates in biology (Janzen 2004, Basset *et al.* 2004, Schmiedel *et al.*2016). They were trained by professional taxonomists or ecologists. The additional workforce of paraecologists/parataxonomists allowed us to collect more biological samples and process them more efficiently. In PNG, parataxonomist training began in 1994 and led to the collection of major datasets on plant-herbivore food webs (Novotny *et al.* 2002, 2006, 2007, 2010). These datasets were used by Hamilton and colleagues (2010, 2013) to reassess the total number of tropical arthropods to between two and 7 million species. Another dataset collected in Panama by the IBISCA network allowed for the first time to evaluate the local arthropod diversity in a large (6,000 ha) patch of a local rainforest. The resulting estimate of approximately 25,000 species lives in a rainforest of the size of Manhattan (Basset *et al.* 2012). This study also suggested that tree diversity, which is far easier to determine, is a good predictor of the arthropod diversity. However a gap remains between the estimation of local and global arthropod diversity. We know too little about biodiversity at landscape-scale, where species composition changes along environmental gradients. Global estimates are based on lowland rainforests only and do not consider the rapid change in species composition along altitudinal gradients. This is a serious weakness since elevational gradients appear to be among the largest generators of species diversity, particularly in the tropics (Merckx *et al.* 2015).

The ultimate aim of the Our Planet Reviewed terrestrial project in Papua New Guinea was to estimate, for the first time with such intense sampling effort, biological diversity generated by elevational turnover of arthropod species. Our approach was three-fold. First, we aimed to obtain, during an intense biotic survey, a global picture of the distribution of plant and selected arthropod groups along a complete elevational rainforest transect. Second, we studied in full detail the effects of plant diversity and abundance on insect diversity and abundance using a detailed census of plant-insect interactions within 0.2 ha forest plots in primary and secondary forest at 900 m asl. (to be compared with similar data from 100 and 1700 m a.s.l.). Third, using a model plant taxon with a large elevational distribution (*Ficus*, fig trees), we studied how herbivores of a particular plant species change with elevation and how they respond to change in their host plant species composition with elevation.

We focus here on the main biotic survey during which we collected the species described in the next nineteen chapters of this book. We provide descriptions of study sites, sampling protocols, sample processing protocols and perspectives on the project.

STUDY SITES

Mount Wilhelm

Study sites were distributed along a West-East transect on the slopes of Mount Wilhelm (4509 m a.s.l.). This transect partly followed a now defunct Brahmin – Keglsugl road. The transect covered a complete elevational gradient spanning from the lowland floodplains of the Ramu river (200 m a.s.l.) up to the timber line at 3700 m a.s.l. (Figure 1). The transect

comprised eight study sites, regularly spaced with 500 m elevational interval between neighbouring sites. The horizontal planimetric distance between the first and last point of the Mt Wilhelm *Complete Altitudinal Rainforest Transect* (hereafter *CART*) was 30 km whilst adjacent sites were separated by two to nine kilometers (Table 1).

The elevational gradient spanned from "mixed lowland rainforest" up to "upper montane forest" (Johns 1982). The vegetation encountered at 200, 700 and 1200 m fitted the "mixed lowland forest" category of Johns (1982). According to Paijmans' classification (1976) however, the forest at 200 m was a "mixed alluvium forest of plains and fans" (Figure 2), while those at 700 m (Figure 3) and 1200 m (Figure 4) belonged to the "mixed evergreen forest of foothills and mountains". At 1700 m (Figure 5) the forest could be classified either as "lower montane forest" *sensu* Johns (1982) or as "mixed lower montane forest" *sensu* Paijmans (1976) with the presence of Fagaceae, Nothofagaceae, Lauraceae, Cunoniaceae, Myristicaceae, Aquifoliaceae, etc. The "mid montane forest" of Johns (1982), was observed at 2200 m and 2700 m with an abundance of southern beeches, *Nothofagus grandis* Steenis at 2200 m (Figure 6) and *N. resinosa* Steenis at 2700 m (Figure 7), thus corresponding to the "Nothofagus forest" of Paijmans (1976). The "Upper montane forest" found at 3200 m (Figure 8, right pictures) was characterised by *Dacrycarpus*, *Papuacedrus* and *Amaracarpus* trees, with *Myrsine*, *Pittosporum*, *Ascarina*, *Decaspermum,* and *Elaeocarpus* in the understorey. The open areas in the valley, where we established the camp (Figure 8, upper pictures), were very distinctive with a grassland dominated by tree ferns. Finally, at 3700 m (Figure 9) the "subalpine forest" (Johns 1982, Fairbairn *et al.* 2005) also called "small crowned forest with conifers" (Saunders 1993) was dominated by shrubs (*e.g.* Primulaceae, Ericaceae, Asteraceae) and tree-ferns (*e.g. Cyathea*), with a few emerging gymnosperms (Podocarpaceae). The alpine zone with grassland (Smith 1977) appeared above the tree line at ca. 3800 m, and in open places around the lake where we had our camp.

Rainfall data were recorded with four data logging rain gauges (Global Water RG200 rain gauge with TGPR-1201 Tinytag data recorder) installed in open areas at 200, 1200, 2200 and 3200 m a.s.l. between 6th November 2012 and 31st December 2013 (Figure 10). Unfortunately, the rain gauge at 3200 m was lost and those at 1200 and 2200 m experienced some failures. As usual in most years, the months May to September tended to be drier (Hope 1976). The main biotic survey occurred during a relatively dry period, as evidenced by the comparison of November-December 2012 and November-December 2013. Complete recordings were only available for 200 m in 2013 and show a high annual rainfall during that year (4870 mm). No consistent rainfall differences were observed between the three elevations. Rainfall on the slopes of Mt Wilhelm was clearly much higher than the average rainfall of the nearest city with a weather station (Goroka, 1546 m, 2240 mm annual average).

Temperature at five study sites (200, 1200, 2200, 2700, 3700 m) was measured from June 2010 to August 2011 by Katerina Sam prior to the main biotic survey using data loggers (Figure 11). The mean temperature ranged between 8.6°C at 3700 m and 27.4°C at 200 m (Figure 12). The temperature decreased linearly with elevation, dropping 5.4°C per 1000 m of increase in elevation.

TABLE 1

Coordinates of each study site (based on botanical plot A), in decimal degrees, and horizontal distance between successive sites in the table (*e.g.* 8.6 km between Oromongu and Kausi). The vertical interval between Mt Wilhelm sites was of 500 m.

Elevation (m)	Study site	Latitude (°)	Longitude (°)	distance (km)	Forest type (Johns 1982)	Forest Type (Paijmans 1976)
175 m	Wanang (Swire) Research Station	-5.225433	145.0808833	--	Mixed lowland rainforest	Mixed alluvium forest of plains and fans
200 m	Kausi	-5.739897	145.329742	63.2	Mixed lowland forest	Mixed alluvium forest of plains and fans
700 m	Oromongu	-5.731961	145.252165	8.6	Mixed lowland forest	Mixed evergreen forest of foothills and mountains
1200 m	Memeku	-5.720874	145.269465	2.3	Mixed lowland forest	Mixed evergreen forest of foothills and mountains
1700 m	Bananumbo	-5.759269	145.235608	5.7	Lower montane forest	Mixed lower montane forest
2200 m	Sinopas	-5.758978	145.186067	5.5	Mid montane forest	Mixed lower montane forest : "*Nothofagus* forest"
2700 m	Kiangimangi	-5.815272	145.156467	7.0	Mid montane forest	Mixed lower montane forest : "*Nothofagus* forest"
3200 m	Kombunomambuno	-5.806698	145.072923	9.3	Upper montane forest	Upper montane forest
3700 m	Pinde-Yaunde Lake	-5.786142	145.059845	2.7	Sub-alpine forest	Near the limit tree vegetation

Wanang conservation area

The lowland site from the Mt Wilhelm elevational transect (200 m) was replicated at the Wanang (Swire) Research Station, approximately at the same elevation but at a distance of 63 km (Table 1). It was included to investigate species turnover within the mixed lowland rainforest, which is the most extensive forest type in PNG. This is the site of the Wanang Conservation Area, a 10,000 ha of rainforest on the Ramu floodplains protected by indigenous communities (Figures 13A,

FIGURE 1

Geographic location of the project in Papua New Guinea showing the nine study sites. Eight sites were located along Mount Wilhelm, between 3700 and 200 m asl, ending in the floodplains of the Ramu river. One lowland replicate was located at Wanang. The New Guinea Binatang Research Center is located near Madang town along the North Coast. Upper inset: Location of Mount Wilhelm and Wanang (Swire) Research Station. Note the shallow map view (Wanang is not close to the main transect). Source: © Google Earth 2016.


200 m
700 m

13B, 13C) and surrounded by selective logging operations (Novotny 2010; Novotny & Toko 2015). The addition of the Wanang site to the elevational gradient anchored the Mt Wilhelm CART at a permanent study site, where long-term data on plant and insect communities are being collected in a permanent CTFS-ForestGEO plot. CTFS-ForestGEO (*Center for Tropical Forest Science - Forest Global Earth Observatory*) plots form a worldwide network of forest research plots (Condit 1995; Anderson-Teixeira *et al.* 2015). The Wanang CTFS-ForestGEO 50 ha plot was established in 2009. In this plot all woody stems ≥1 cm diameter at breast height (DBH) are censused every five years (Vincent *et al.* 2015). In addition, selected arthropod assemblages have been monitored since 2013 using various techniques: Pollard transects for butterflies, McPhail traps for fruit-flies, Winkler extractors for ground-dwelling ants, transects for termites, and seed rearing for collecting seed predators (Basset *et al.* 2011; Basset 2015; Anderson-Teixeira *et al.* 2015). The study sites (Figure 13D, 13E) were situated around the Wanang (Swire) Research Station (Figure 13F, 13G), near the CTFS-ForestGEO plot, at the elevation between 90 and 190 m a.s.l. The Wanang mean annual rainfall is around 4000 mm and the mean monthly air temperature about 26°C.

FIELD PARTICIPANTS

A total of 63 persons (11 nationalities) were involved, comprising 21 para taxonomists/ecologists, 21 international experts, four students (two local and two international), three journalists (film makers, photographers) and a support staff of 11 persons (coordinators, technicians, logistics and medical support) (Figure 14 and associated Table 2). In addition the project generated local employment by involving over one hundred villagers in sample collecting, camp building and maintenance, and transport of the equipment. Agreements with local communities along Mt Wilhelm and in Wanang were made prior to the beginning of the project. Capacity building was a major component of the project with half of the participants being Papua New Guineans and the other half overseas participants. Paraecologists and parataxonomists collected primary biodiversity information (collection of samples and environmental data, rearing of specimens, implementation of field experiments) and processed the material collected (they sorted, prepared, pre-identified, imaged and databased specimens). The knowledge of the local environment by the paraecologists was an additional benefit.

Very basic field camps (Figures 2-9) were available at each study site and accommodated resident paraecologists, their village assistants and passing international experts. Due to their limited size, camps could only accommodate one patrol at a time, explaining the slight delay between the visit of the entomology and the botany patrols (ten people each, including the medical assistance and the media team) (Table 3). In Wanang, project participants were accommodated at Swire Research Station. All participants spent a few days at Binatang Research Center headquarters during their transit in Madang.

METHODS USED DURING THE MAIN BIOTIC SURVEY

Overview of sampling protocols

The main biotic survey, including international experts, extended from October to December 2012 (Table 3). An overview of the global sampling scheme used at each of the eight study sites along Mt Wilhelm CART and at the replicated lowland site, Wanang, can be found at Figure 15. We followed the IBISCA approach (Basset *et al.* 2007; Leponce *et al.* 2012; url:www.ibisca.net) allowing to quantification of the local diversity and abundance of forest arthropods by relying on a multiscale, multi-taxa and multiprotocol design. All data collected were integrated from the start, with a common coding system and a common database. The basic sampling design focused on the understorey fauna and was replicated vertically at all nine elevations, with individual sampling methods replicated horizontally (at the same elevation) within

FIGURES 2-3

Distant views, views of the camps, views of the forest vegetation and canopy of the study plots located at 200 (**2**) and 700 (**3**) m asl on the slopes of Mount Wilhelm.

TABLE 2

List of participants to Our Planet Reviewed 2012-2013 land module at Mt Wilhelm (MW), Wanang Conservation Area (WAN) or Binatang Research Center (BRC). Abbreviations: A: Advisor, B: Botanist, E: Entomologist, L: Logistician, M: Manager, O: Observer, P: Pedologist, PT: Para taxonomist/ecologist, PTT: Para taxonomist/ecologist training, SC: Scientific coordinator, ST: Student, T: Technician. (*): Taxonomic Working Group leader, [1]: Coleoptera sorting team 1, [2]: Coleoptera sorting team 2.

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4	Auga	John	PT	WAN	Binatang Research Center	Papua New Guinea
5	Baiben	Noui	Tree climber	MW		France
6	Basset	Yves	E, PTT	WAN	Smithsonian Tropical Research Institute	Switzerland
7	Bickel	Daniel	E*, PTT	WAN	Australian Museum Australia	Australia
8	Cambanis	Leonidas	O	MW		Greece
9	Chevalier	Cyril	Doctor	MW		New Caledonia
10	Cleyet-Marrel	Dany	Pilot	WAN	Opération Canopée	France
11	Colwell	Robert	A	MW	University of Connecticut	U.S.A.
12	Croizer	Régis	Media	MW	Cargo Culte Productions	France
13	Dahl	Chris	PT	MW+WAN	Binatang Research Center	Papua New Guinea
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16	Desmier	Xavier	Media	MW+WAN		France
17	Dilu	Mary	PT	WAN	Binatang Research Center	Papua New Guinea
18	Dumoulin	David	Sociology	WAN	Université Paris 3 - Sorbonne Nouvelle	France
19	Fayle	Tom	E	MW	Imperial College London	U.K.
20	Fourcaud	Roland	L	MW		France
21	Gagul	Janet	B, L		University of Papua New Guinea	Papua New Guinea
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27	Koane	Bonny	PT	MW+WAN	Binatang Research Center	Papua New Guinea
28	Kua	Joseph	PT [1]	MW+WAN	Binatang Research Center	Papua New Guinea
29	Kumba	Thomas	PT	WAN	Binatang Research Center	Papua New Guinea
30	Le Gouil	Gwenlaouen	Media	MW	Cargo Culte Productions	France
31	Legendre	Frédéric	E	MW	Muséum national d'Histoire naturelle, Paris	France
32	Legi	Sam	E	MW	Binatang Research Center	Papua New Guinea
33	Leponce	Maurice	E, SC, PTT	MW+WAN	Royal Belgian Institute of Natural Sciences	Belgium
34	Lilip	Roll	PT	WAN	Binatang Research Center	Papua New Guinea
35	Mansa	Albert	PT	WAN	Binatang Research Center	Papua New Guinea
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37	Maspain	Dolores	T	WAN	Binatang Research Center	Papua New Guinea
38	Mogia	Martin	PT [2]	MW+WAN	Binatang Research Center	Papua New Guinea
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44	Novotny	Vojtech	E, SC, PTT	BRC	University of South Bohemia	Czech Republic
45	Nowatuo	Hans	PT	MW	Binatang Research Center	Papua New Guinea
46	Ødegaard	Frode	E*, PTT	WAN	Norwegian Institute for Nature Research – NINA	Norway
47	Orivel	Jérôme	E	MW	Ecologie des Forêts de Guyane	France

no	Family name	Surname	Role	Field	Institution	Country
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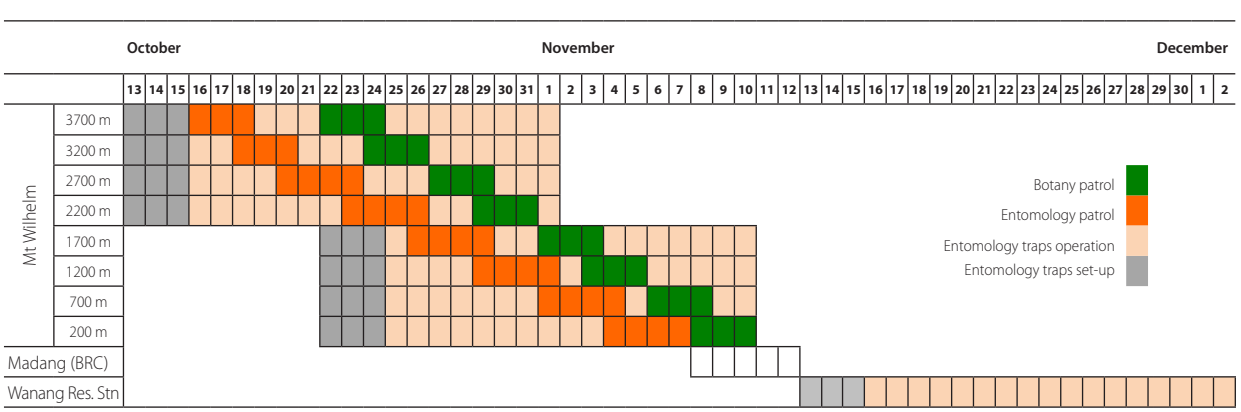
49	Philip	Frank	PT	WAN	Binatang Research Center	Papua New Guinea
50	Pierron	Laurent	Tree climber	MW		France
51	Pintaud	Jean-Christophe	B	MW	Institut de Recherche pour le Développement	France
52	Robillard	Tony	E*, PTT	MW+WAN	Muséum national d'Histoire naturelle, Paris	France
53	Roisin	Yves	E*, PTT	MW	Université Libre de Bruxelles	Belgium
54	Sabagai	Kui	T	MW+WAN	Binatang Research Center	Papua New Guinea
55	Siki	Byron	PT	MW	Binatang Research Center	Papua New Guinea
56	Soldati	Laurent	E, PTT [1]	WAN	CBGP, INRA	France
57	Soulier-Perkins	Adeline	E*, PTT	WAN	Muséum national d'Histoire naturelle, Paris	France
58	Sui	Sean	PT [2]	WAN	Binatang Research Center	Papua New Guinea
59	Tulai	Salape	PT [2]	MW+WAN	Binatang Research Center	Papua New Guinea
60	Uma	Collin	PT	WAN	Binatang Research Center	Papua New Guinea
61	Villemant	Claire	E*, PTT	WAN	Muséum national d'Histoire naturelle, Paris	France
62	Winckler	Amandine	ST	WAN	Université de Nouvelle-Calédonie	New Caledonia
63	Yalang	Joachim	PT	WAN	Binatang Research Center	Papua New Guinea

a sampling extent of 1 km (Figures 15A, 15B). The cumulative length of the Mt Wilhelm transect segments between successive localities was around 40 km and the distance between the two lowland sites (Wanang 175 m and Mt Wilhelm 200 m) around 60 km (Table 1).

Twenty four botany plots (n = 3 plots/elevation x 8 elevations) were setup along the CART, before the beginning of the main biotic survey, from May to August 2012, by a Binatang Research Center paraecologist team led by Kenneth Molem. Botany plot size (20x20 m) was the standard IBISCA plot size as well as the standard CTFS-ForestGEO subplot size (Condit 1995; Vincent *et al.* 2015). All trees with a minimum diameter at breast height (DBH) of 5 cm were measured (DBH), tagged and pre-identified. During the main survey, between the 22nd of October and the 10th of November 2012 (20 days, see Table 3), a botany patrol composed of Kipiro Damas (PNG Forest Research Institute), Kenneth Molem (BRC), Jérome Munzinger (IRD), Jean-François Molino (IRD) and Jean-Christophe Pintaud (IRD) was in charge of validating species identifications and collecting more voucher material. With the help of two professional tree climbers (Laurent Pierron and Noui Baiben) vouchers of fruits and flowers were collected at the top of trees. At least one voucher per species

TABLE 3

Time schedule for the main entomology and botany surveys that occurred from October to December 2012. Entomology traps were operated during 16 full days (but extended on 17 days, being started and ended in the morning), after three days of sampling site selection and trap set-up. For logistical reasons (end of the botany patrol), traps at the four lowest localities were started nine days after the highest ones. Due to limited camp capacities in terms of infrastructure, the entomology and botany patrols did not overlap. No botany patrol was organized in Wanang since the vegetation was already monitored during the first survey of the CTFS-ForestGEO 50 ha plot.



and per elevation was collected. Leaves were also collected, and preserved in silica gel for further phylogenetic studies or identification using molecular tools. The results of this botany survey will be published elsewhere. No botany survey was conducted in Wanang since data were already available from the 50 ha CTFS-ForestGEO plot first inventory (Vincent *et al.* 2015; Anderson-Teixeira *et al.* 2015).

We used a combination of five mass sampling techniques to collect a variety of arthropods representing major Orders (Coleoptera, Hymenoptera, Diptera, Hemiptera, Orthopteroids, Araneae) covering a wide array of functions in the ecosystem (predators, scavengers, decomposers, leaf-chewers, sap-suckers, pollinators) (Table 4). The largest effort (180 traps running part of the time simultaneously, 2880 trap-days) (Table 3) was put in collecting flying beetles with flight interception traps (Table 4). Such a huge effort represents an attempt to obtain a representative sample size allowing us to differentiate inter-elevation from intra-elevation turnover of species. The second mass collection method was Malaise traps (576 trap-days). Steiner traps for collecting fruit-flies summed 720 trap-days with 3 different types of baits - Cue lure, Methyl eugenol, and Vanillyl acetone - representing 432, 144 and 144 trap-days, respectively. Beating of the vegetation was conducted in 45 plots and the bark of 324 trees was sprayed with insecticide (total sampling extent: 648 m^2 of bark). In all, 2970 arthropod samples were collected in October-November 2012. Details of the protocols are provided below.

In addition to the mass sampling protocols (including Malaise, flight interception traps, beating of vegetation, barkspray and Steiner traps), individual research projects were conducted by international participants along the Mt Wilhelm elevational gradient and/or in Wanang Conservation Area (Table 5). These projects concern the distribution of Orthopteroids (caught mainly at night; see Robillard *et al*. 2016; Dong & Robillard 2016, this volume), Tenebrionid beetles (see Soldati *et al*. 2016, this volume), brentid beetles, deadwood insects (*e.g.*, termites and beetles) and ants.

ARTHROPOD MASS SAMPLING

The five mass collection methods (Table 4) were operated during 16 days at each site. A unique feature of this project is that, thanks to the workforce of paraecologists, assisted by villagers and supervised by senior researchers, it was possible to sample simultaneously at all elevations of the CART during seven days! For logistical reasons, lower elevation traps (200-1700 m) were started nine days after upper elevations ones. In Wanang, entomology traps were started three weeks later.

LABELLING OF SAMPLES AND SPECIMENS, TRACKING OF SPECIMENS

Prior to field work, two series of solvent-resistant polyester labels were printed with unique codes. A first series concerned samples (specimens generally originating from an insect trap and stored in whirl-paks). Each sample had a short code starting with "P" (referring to "Papua New Guinea") and a unique four digit number (*e.g.* P1040, Figure 16). It was followed by a longer code which summarized sample details: *sampling method – site - sample number/total number of samples for this trap - day of collection* (*e.g.* MAL-MW0200C-11/16-d11, for Malaise, Mt Wilhelm 200 m sampling point C, 11th sample out of 16 for this trap, day 11). In addition collector names and the GPS coordinates were indicated. These labels were put in the field in the whirl-pak used for storing specimens. During the processing of the material collected, duplicates of these labels were printed to accompany the specimens stemming from the same trap and stored in different vials (see section below dedicated to sample processing).

A second series of labels concerned vials. These labels were sequential numbers from 00001 to 99999. They were unique codes (no duplicates printed). Sheets of labels were distributed to participants during the project. A few of these labels were used in the field during hand collection. However most of them were used during sample processing. Specimens stemming from the same trap were stored in vials with two labels: one with the sample code and another with the vial

FIGURES 4-5

Distant views, views of the camps, views of the forest vegetation and canopy of the study plots located at 1200 (**4**) and 1700 (**5**) m asl on the slopes of Mount Wilhelm.


1200 m
1700 m


2200 m
2700 m

code (hypothetical example from Figure 16: the content of trap P1040 was transferred to 3 vials: 05881, 05882, 05883). During specimen identification, when the content of a vial was divided between several vials, a suffix was added to the original vial number (*e.g.* 05883 split into 05883-1 and 05883-2, Figure 16). This allowed to easily track the origin of specimens during the sample processing.

Flight interception traps

Flight interception traps (FITs) are one of the best tools in collecting and sampling small flying insects in forest understorey, beetles in particular, because they drop down after flying into an obstacle (Peck & Davies 1980, Carlton *et al.* 2004). Twenty FITs were installed at each elevation at sampling points A to T and separated by at least 50 m (see Figure 15). Care was taken not to locate FITs and Malaise traps near and behind each other. All FITs had their black wall parallel to contour lines. Flight interception traps consisted in a barrier made of black plastic mosquito mesh (h: 120 cm x L: 200 cm = 2.4 m2) (Figure 17A). Three large aluminium baking trays (65 x 45 cm) were used as collectors and installed 2 cm under the mesh on relatively flat terrain, levelled as needed prior to trap installation (Figures 17A, 17B). One corner of the tray was cut to pour more easily the content in a strainer to transfer them into a 13 oz whirl-pak filled with pure ethanol (Figure 17C). Each tray was filled with water, salt (about 150 g per tray) and liquid detergent (4 drops per tray) and the material collected in a two-day cycle (the first ten traps A-J on even days and the last ten traps K-T on odd days). A series of small holes was drilled in the middle height of each side of the trays, to avoid overflow during strong rains. A roof erected over the FIT made of clear plastic (l: 100 x L: 300 cm) prevented the trays from rain. The FIT mesh was stretched, but not too tight, between two wooden sticks to allow movement during windy weather.

The total number of samples collected was 1440 (20 sampling points x 8 samples/point=160 samples/elevation x 9 sites).

Malaise traps

Malaise traps are tent-like structures (Figure 18A) that are particularly efficient in capturing flying insects such as Diptera, Hymenoptera or Hemiptera. The Entosphinx model (height: 120 cm x breadth: 100 cm x length: 150 cm), made of polyamide fabric with white roof and black wall was used. The collecting jar was emptied every day (Figure 18B) and its content stored in a 13 oz whirl-pak filled with pure ethanol and containing a sample code label (Figure 18C). Lepidoptera that are damaged by ethanol were discarded during the sorting (Figure 23B). It should be noted that our aim was to evaluate the average density of flying insects in the forest, therefore trap placement was not optimized (as is usually done) by putting Malaise traps below gaps in the canopy or in flight corridors, such as trails or streams. A common annoyance in lowland forests were ants, especially the weaver ant *Oecophylla smaragdina*, which preyed on insects captured by the Malaise traps, and even waited in a ring around the collecting jar entrance to capture live specimens (Figure 18D). This problem was not anticipated and we had to resample again with the Malaise traps in 2013, between 11 and 27 May at 200 m and between 13 and 29 May at 700 m and 1200 m. This time, to prevent the ants from interfering, a Tanglefoot barrier was put on the suspension ropes (Figure 18E, 18F).

A total of 576 samples were obtained in 2012 (16 samples/plot x 4 plots/elevation x 9 elevations) and 192 samples in 2013 (3 elevations).

Insecticidal bark spray

A wide range of arthropods are found on tree bark. They constitute a specific assemblage that was collected by spraying insecticide on the bark. In an area centred on each botany plot (plots A-C, Figure 15), the twelve trees with the highest diameter (≥ 25 cm) were selected and labelled (Figure 19F). Trees with a lot of climbers were excluded. Bark spraying was

FIGURES 6-7

Distant views, views of the camps, views of the forest vegetation and canopy of the study plots located at 2200 (**6**) and 2700 (**7**) m a.s.l on the slopes of Mount Wilhelm.

performed in the morning during dry weather. A bark spray kit (available from Bioform entomology) was provided to each paraecologist (Figure 19H). An area 2 m high and up to 1 m wide was delimited on the most inclined, overhanging, side of the tree (Figure 19B) and sprayed with a non-sticky insecticide (Mortein) (Figure 19C). After 15 minutes, all dead arthropods fallen onto a yellow plastic sheet at the bottom of the sprayed area were gently collected with a camel brush and forceps (Figures 19A, 19D) and stored in a 7 oz whirl-pak containing a preprinted label and 25 ml of DNA grade ethanol (Figure 19E). Collection date was noted, and botany plot labels on trees allowed tree identification.

A total of 324 samples were obtained (12 samples/plot x 3 plots/elevation x 9 elevations).

TABLE 4

Sampling effort for each collection technique and arthropod taxa targeted.

Method	Traps	Samples	Trap-days	Focal taxa
Flight interception traps	180	1440	2880	Coleoptera (Curculionidae, Scarabaeidae, Scolytinae/Platypodinae, all others families except Staphylinidae).
Malaise traps	36	576	576	Hymenoptera, Diptera, Hemiptera, Orthopteroids, Coleoptera
Beating of vegetation		450		Coleoptera (all), Araneae, Formicidae, Orthopteroids
Insecticidal spray on bark	324 trees	324		All major arthropod taxa found
Steiner traps (3 bait types)	45	180	720	Tephritids (Diptera)
		2970	4176	

TABLE 5

Individual research projects conducted along Mt Wilhelm CART and/or in Wanang Conservation Area.

Protocol	Locality	Leader	Collaborators
Ant functional groups	Mt Wilhelm	J. Orivel	P. Klimes (Univ South Bohemia)
Ant nutrient removal assays, "cafeteria" experiments, pitfall trapping, tuna baiting on tree trunks, hand sampling understory and leaf litter.	Mt Wilhelm	T. Fayle	J. Moses, N. Plowman (Univ South Bohemia), P. Klimes
Arboreal-dwelling ants, epiphytic myrmecophytes and isotopic analyzes	Mt Wilhelm & Wanang	M. Leponce	J. Jacquemin (RBINS), P. Klimes
Tenebrionidae & Brentidae	Wanang	L. Soldati & A. Mantilleri	
Dead wood insects	Mt Wilhelm	Y. Roisin	
Orthopteroids	Mt Wilhelm & Wanang	T. Robillard & F. Legendre	

BEATING OF VEGETATION AND DEAD BRANCHES

Beating is an effective method to collect beetles, spiders, ants and other arthropods on the foliage. Beating was conducted in five plots per elevation (A-E, Figure 15), in the morning, during dry weather. It was performed by a team of three people comprising two assistants, the "*beater*" and the "*collector*", and a paraecologist, the "*timer*" (Figure 20). The *beater* stroked or shook the branches with a 1.5 m long strong stick. Insects falling from the plant landed on a white cloth stretched out on a square frame of 1 m^2 (Bioquip Ripstop Beating Sheet). These were then picked up using soft forceps or aspirator by the *collector*. The *collector* also removed large debris from the tray from time to time so that insects could be seen. After 5 minutes, the *timer* stopped all the beating and everyone looked closely onto the beating tray to collect small insects with the aspirator (or with forceps or a large vial). All insects in the aspirator were then transferred into a 24 oz whirl-pak. The whirl-pak contained a pre-printed label and DNA-grade ethanol. All debris were then removed from the tray and the *beater* started a new sample. The *timer* was also responsible to ensure that the total of ten samples, each during five minutes, were collected from all over the 400 m^2 plot. The team walked along five parallel 20 m long transects with 4 m spacing between adjacent transects, subdividing the plot into subplots 4 m wide and 10 m long. The beating survey was replicated between 200 and 2200 m in May-June 2014, to obtain additional understorey ants and other arthropods.

A total of 450 samples were obtained in 2012 (10 samples/plot x 5 plots/elevation x 9 elevations) and 250 in 2013.

Steiner traps for collecting fruit flies

Five Steiner traps (Figure 21) were used at each elevation (in plots A-D, Figure 15). Fruit flies (Tephritids) were attracted by a male parapheromone lure. Three different lures were used: Cue lure (in plots A, B, C of Figure 15), Methyl eugenol (in plot D, at 120 steps from plot C) and Vanillyl acetone (in plot E, at 120 steps from plot D). The insecticide was Belltek Bifenthrin 1% EC, a synthetic Pyrethroid insecticide with Bifenthrin as active ingredient. Lures were put near the Malaise and FIT traps, 1.5 m above ground, hanged to a branch without touching any leaf or branch (Figure 21A). A bit of Tanglefoot was put on the rope (Figure 21D) to prevent ants from capturing the flies. Wicks were manipulated with their wire ring, not with fingers to avoid contamination of other traps with the bait. Cotton balls impregnated with insecticide were put on the trap floor using large forceps (to prevent touching the insecticide) (Figure 21E). Traps were surveyed every day. Dead flies were collected gently with a brush or soft forceps and put into a collecting vial containing a label with the trap code. If condensation occurred in the trap it was wiped dry with towel paper. All flies were conserved dry, not in ethanol. Flies were stored in carton boxes. The catches of four days were pooled together in the same carton box. Carton boxes were stored in a waterproof bucket lined with 2 kg of silica gel.

The total number of samples collected was 180 (4 samples per plot x 5 plots/elevation x 9 elevations).

Processing of material in Wanang (Swire) research center

Eight scientists supervising 23 parataxonomists and two students processed half a million specimens during three weeks at the Swire Research Station in the Wanang Conservation Area (Figure 13F & Figure 13G), between November and December 2012 (Table 2 & Table 3). Taxonomic Working Groups (Table 6) have been established to organize the complex processing of the material collected around major taxonomic groups (*e.g.*, arthropod orders) or methods (Table 7). In Papua New Guinea, the responsibility of TWIG leaders was to organize the sorting of the material collected to higher categories (Orders or Families) and to isolate focal taxa (Table 4). The rest of the specimens collected was considered as residue.

TABLE 6

Taxonomical working groups (TWIGs) with leader names, affiliation and number of associated taxonomic authorities.

Taxa	TWIG leader	Institution	Taxonomists
Arachnids	D. De Bakker	Royal Belgian Institute of Natural Sciences	37
Coleoptera	C. Wardhaugh & J. Schmidl	University of South Bohemia, Czech Republic & Universität Erlangen-Nürnberg, Germany	52
Diptera	D. Bickel	Australian Museum	13
Hemiptera	A. Soulier-Perkins	Muséum national d'Histoire naturelle, Paris,	4
Hymenoptera	C. Villemant	Muséum national d'Histoire naturelle, Paris	40
Orthopteroids	T. Robillard & F. Legendre	Muséum national d'Histoire naturelle, Paris	9
Non-focal taxa (residues)	M. Leponce	Royal Belgian Institute of Natural Sciences	3
Plants	J. Munzinger	Institut de Recherche pour le Développement, France	17
Total			**175**

Processing of flight interception traps samples

Pre-sorting of the 1440 FIT samples within 16 days required some organization. At least 90 samples per day had to be sorted, requiring around 2 days to sort all the samples coming from a single elevation. Two teams of four parataxonomists supervised by two senior coleopterists were formed (Coleoptera sorting teams 1 & 2 see Table 2). Samples from one elevation at a time were sorted, starting from the lowest elevations (which were the richest). The first step was to select a sample to study and to complement it with 12 copies of the sample code label and a "quality check" label (Figures 22A, 22B). Each sample was opened and its content poured into a large white plate. Curculionidae, Scarabaeidae, Scolytinae/Platypodinae, other Coleoptera (except Staphylinidae, too numerous and difficult to identify) were separated in a Petri dish (Figures 22C, 22D). Vegetal debris and Lepidoptera were discarded. Orthopteroids were further processed by the senior expert of this group (TR, Figure 22K) who added a vial code to the vial (Figure 22L). All other arthropods were put back in the whirl-pak (Figures 22E, 22F). At the end of the process, the senior expert verified under the microscope that the specimens in the Petri dish were correctly separated into families, that the whirl-pak with residues did not contain any focal taxa and, in this case, validated the quality check label

indicating that all target Coleoptera and Orthopteroids were removed (Figures 22H, 22I). He/she then put the focal families into separate vials and wrote down on a pre-printed datasheet the vial codes corresponding to the different Coleoptera groups targeted (Figure 22J). A label with the corresponding sample code was added to each vial, together with the vial code.

TABLE 7

Methodology working groups.

Method	leader	Institution
Malaise traps	C. Villemant & D. Bickel	Muséum national d'Histoire naturelle, Paris & Australian Museum
Flight Intercept traps	A. Tishechkin	USDA Systematic Entomology Lab, USA
Beating	F. Ødegaard	Norwegian Institute for Nature Research
Barkspray	J. Schmidl	Universität Erlangen-Nürnberg, Germany
Steiner traps	R. Drew	Griffith University, Australia
Common database	M. Leponce	Royal Belgian Institute of Natural Sciences

PROCESSING OF MALAISE TRAPS SAMPLES

The sorting of Malaise samples (Figure 23A) was more complex than the processing of FIT samples because five higher taxa had to be extracted: (Figure 23B), Orthopteroids (Figure 23C), Coleoptera (Figure 23D), Hymenoptera (Figure 23F), selected families of Diptera (Figure 23G) and Hemiptera (Figure 23H). Remaining arthropods (except Lepidoptera that were discarded because damaged by ethanol), formed the residue and were put back in their original whirl-pak. The first step was to prepare the sample: transfer the specimens to a Petri dish, discard Lepidoptera, remove Coleoptera, remove Orthopteroids, add 20 copies of the sample code label. Afterwards, to allow the circulation of samples between sorters, a "sorting pipeline" was set-up with different segments (Figure 23E). The first segment contained samples (transferred from whirl-pak to Petri dishes) without Lepidoptera, Coleoptera and Orthopteroids. Each time a new higher taxon was removed from the samples, the sample could move to the next segment of the pipeline. For example, once Hymenoptera were removed the sample was transferred from the first segment to the segment "-1 Higher Taxa". After removing Diptera from this samples it was transferred to the segment "-2 Higher Taxa" and so on. A label with multiple check boxes (Hymenoptera, Diptera, Hemiptera, Orthopteroids, Coleoptera) allowed to keep track of which Orders were already removed (see labels on Figures 23F, 23G, 23H). All vials containing the sorted specimens originating from a single sample included a copy of the sample code label and a unique vial number. The replacement lowland Malaise samples collected in 2013 (to replace the original 700 m and 1200 m collections that had been damaged by weaver ants) were processed in October 2013 at Binatang Research Center, Madang, PNG, under the supervision of Dan Bickel.

DATABASING

Datasheets filled manually during the sorting (see Figure 22J) were encoded in a global database which produced a list of specimens (pre-identified and counted) for export. Part of the specimens were directly brought back home by TWIG leaders in December 2012, while the rest were shipped in a large container to Paris and arrived in June 2013.

CANOPY SAMPLING

Canopy sampling with a hot-air balloon propelled by an electric motor (Dany Cleyet-Marrel's *Cinébulle*) was conducted in April-May 2013. The aim was to collect arthropods living or flying in the forest canopy, in complement to the other samples collected during the main biotic survey, which were mainly focused on the understorey. The balloon was used to install insect traps in the canopy and to collect arboreal-dwelling ants, especially those inhabiting epiphytic myrmecophytes (Leponce 2016).

FIGURES 8-9

Distant views, views of the camps, views of the forest vegetation and canopy of the study plots located at 3200 (**8**) and 3700 (**9**) m a.s.l on the slopes of Mount Wilhelm.


3200 m
3700 m

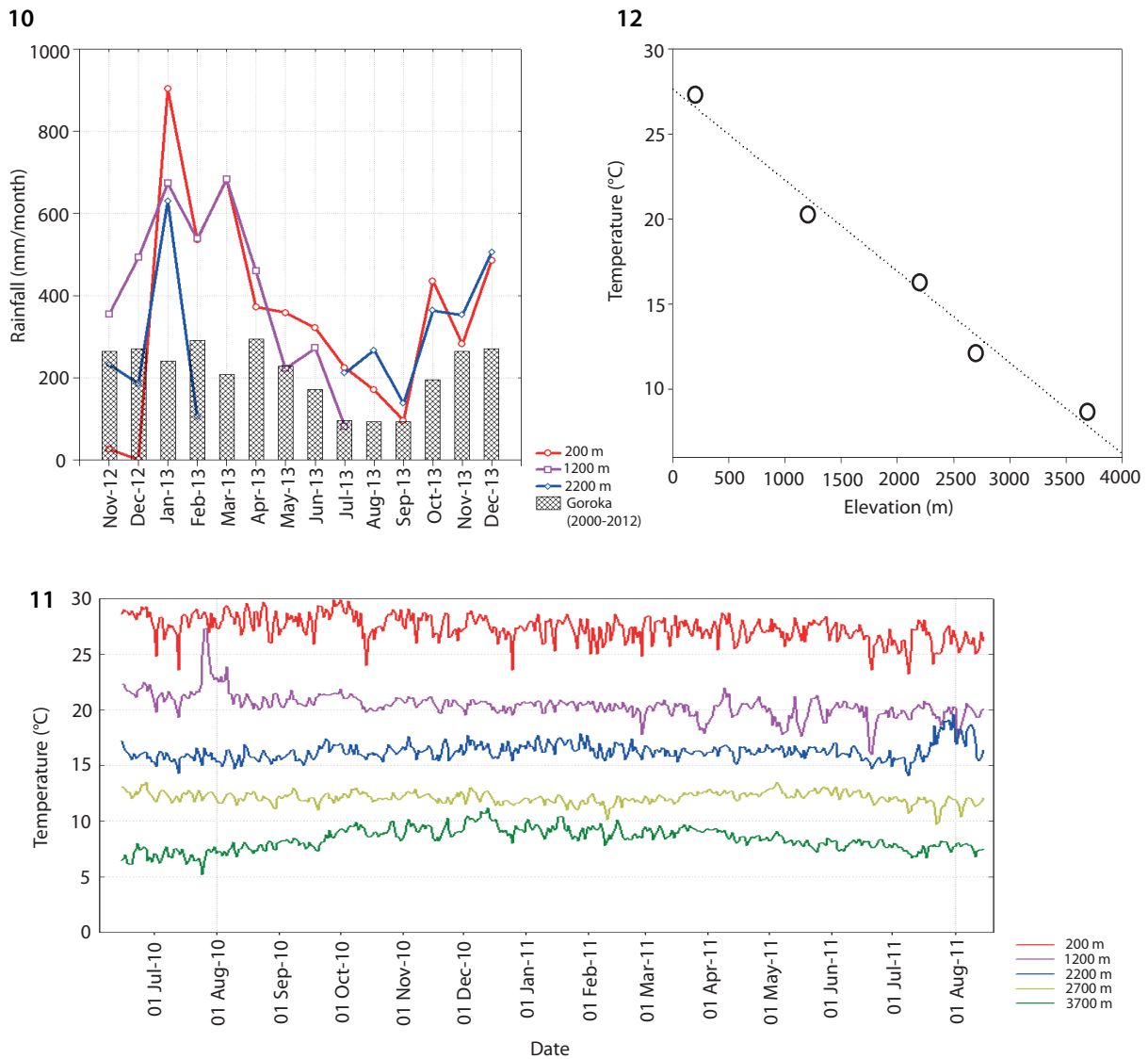


FIGURE 10-12

(**10**) Monthly rainfall measured from 6 November 2012 to 31 December 2013 at study sites from 200, 1200 and 2200 m asl. Part of the data is missing due to malfunctions of the rainfall gauges. Bars represent the average rainfall in the city of Goroka (1546m a.s.l.), distant of about 60 km from Mt Wilhelm summit (source: http://www.worldweatheronline.com/goroka-weather-averages 6 June 2016). (**11**) Daily average temperature at 5 out of the 8 study sites along Mt Wilhelm recorded between 15 June 2010 and 15 August 2011. (**12**) Correlation between average mean temperature (measured from 31 July 2010 and 1 August 2011) and elevation.

FIGURE 13

Wanang Conservation area. **A**, Wanang village. **B**, Wanang school. **C**, Traditional welcome party for the participants of the project in November 2012. **D**, Aerial view of the forest and river. **E**, Large *Ficus* tree. **F**, Wanang (Swire) Research Station. **G**, One of the laboratories of Wanang Research Station where project participants sorted, during November-December 2012, the material collected along Mount Wilhelm in October-November 2012.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C
D
E
F
G

FIGURE 14

Participants to the field expedition. See Table 2 for names and role in the project.


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DETAILED STUDY OF PLANT-HERBIVORE FOOD WEBS AT 900 M A.S.L.

This was a unique study which took advantage o the traditional practice of slash-and-burn agriculture by PNG villagers, during which a patch of rainforest is cut down and the land planted by crops. An agreement was made with landowners in the village of Numba that their forest felling within 0.2 ha (45 x 45 m square) of primary forest would be done in collaboration with our team. This provided an opportunity to record all vegetation, including lianas, and sample main groups of non-flying arthropods from the felled trees (free feeding, mining and galling herbivorous larvae, ants, spiders) (Whitfeld *et al.* 2012, Klimes *et al.* 2012). In this way we were able to obtain a comprehensive 3-dimensional survey of plants and focal insect groups in the tropical forest. The results will be compared with similar data sets already obtained from 200 m (Wanang) and 1700 m a.s.l. (Mt Finisterres), obtaining thus a sequence of forest plots along elevational gradient.

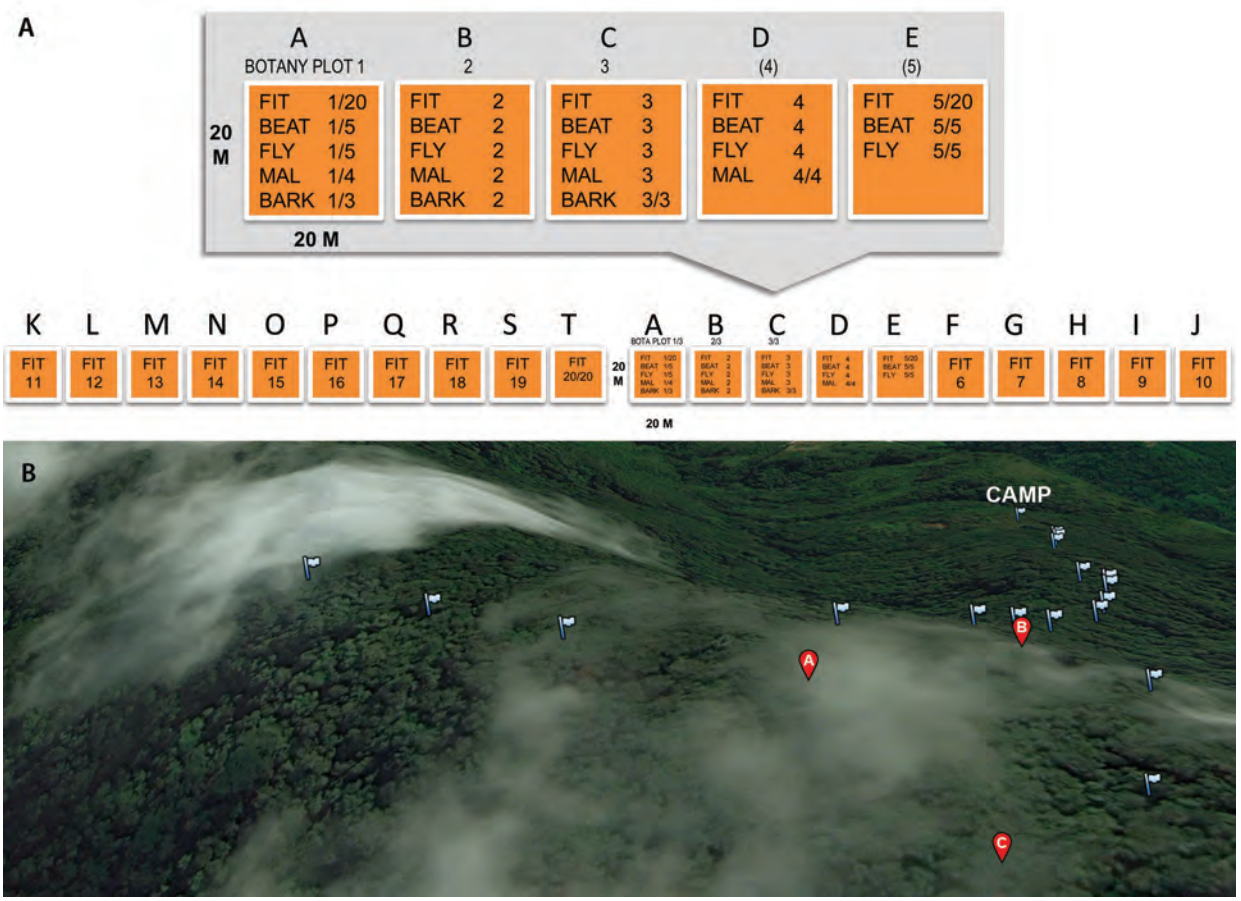


FIGURE 15

A, theoretical sampling scheme followed at each elevation. Twenty sampling points (A-K) each distant of at least 50 m were delimited in each locality. Points A to D are 20x20 m plots. Botany plots (A-C) were installed more or less at the center of the set up. A botany inventory and insecticide spraying on the bark (method abbreviated "BARK") of 12 of the largest trees took place in plots A to C. Malaise traps ("MAL") were set up in plots A to D. Beating of the vegetation ("BEAT") was conducted in plots A to E, where Steiner traps ("FLY") to collect fruit-flies were also installed. Flight interception traps ("FIT") were installed at all sampling points (A-T). **B**, Pragmatic sampling scheme in the field exemplified by the actual sampling that occurred at 1700 m. The 20 sampling points followed the crest line at an elevation of 1700 ± 50 m. The three botany plots (A-C) are shown in red. Flags indicate the location of the other sampling points (D-T) and of the camp further down (source Google Earth ©2016).

These "felling" data capture both the change in the composition of vegetation and its associated herbivores for an entire patch of the forest. This allows us to measure directly changes in insect diversity with elevation as they are determined by simultaneous changes in (i) plant species diversity, (ii) plant abundance, and (iii) diversity and abundance of herbivores per unit of biomass of a particular plant species. In a forest plot, more common plants tend to have more herbivore individuals and species than rare plant species so it is important to capture differences in abundance among plants and their effect on insect diversity. Further, most plant species are rare in tropical forests. Sampling rare plant species is important for the overall assessment of herbivore diversity because even with a few herbivore species per each rare plant species, the combined diversity of herbivores supported by rare plants can be substantial. This "felling" experiment started on the 1st May 2013 and the field work was completed on 5th September 2013.

ELEVATIONAL VARIATION IN PLANT-HERBIVORE INTERACTIONS INVOLVING FICUS TREES

The aims were to explore how (i) herbivores on a particular plant species change with elevation, (ii) herbivores respond to change of their host plant species composition with elevation. It is possible that the same plant species has different herbivore species at different elevations, but also that a change in plant species with elevation does not lead to corresponding change in herbivore species. The relative importance of species turnover with elevation in plants and their herbivores is crucial for our analysis of the effect of elevation on the global diversity of insects. We know from previous research how many insect species feed in the lowlands on an average tree species, and also know how many tree species are there, both for *Ficus* trees (Basset *et al.* 1997, Basset & Novotny 1999) and in general (Novotny *et al.* 2002). The present research will allow us to correct the estimate for changes in tree and insect diversity with elevation, which is the most important environmental gradient for tropical diversity. The *Ficus* project was logistically demanding as it included long-term sampling and rearing of insects along the Mt Wilhelm elevational gradient, at six stations from 200 to 2700 m a.s.l. (which is the range of *Ficus* distribution). The project included, at each elevation (200, 700, 1200, 1700, 2200 and 2700 m a.s.l.) the following stages: (i) local survey, mapping, tagging and identification of all stems of *Ficus* trees with the diameter above 5 cm within 10 rainforest transects, each 500 x 10 m (*i.e.* from the total area of 5 ha), (ii) sampling of all herbivorous insects (caterpillars, miners, gallers, adult beetles, grasshoppers, and stick insects) from the foliage, sampling one transect per day, and sampling each transect at 10 different sampling days at 10-day intervals (*i.e.*, 100 sampling days total per elevation), and (iii) rearing insect larvae to adults and testing adults for their feeding preferences on *Ficus* trees in field conditions. Further, the insect specimens were brought to the BRC main laboratory for the stage (iv) which included sorting to species, databasing, labelling, photography and export overseas for further taxonomic analysis. This study extended from May to October 2013. The survey was followed by experimental transplantation of ~1,000 Ficus samplings from several species to the study sites 500 m above or below their natural elevational limits, and sampling newly formed herbivore communities from these saplings in 2014-2016.

SIGNIFICANCE AND PERSPECTIVES

This "Our Planet Reviewed: Papua New Guinea" project complements previous studies along the CART related to butterflies (Sam 2011, Colwell *et al.* 2016), geometrid moths (Toko 2011), leafhoppers (Dem 2011), bark beetles (K. Zimova, unpubl.data), frogs (Dahl *et al.* 2012), birds (Tvardikova 2013, Sam *et al.* 2015, Colwell *et al.* 2016), bats (P. Amick, unpubl. data), *Ficus* trees (S. Segar, unpubl. data) and their herbivores (L. Sam, unpubl. data), and ferns (Colwell *et al.* 2016) (Novotny & Toko 2015). With all these data combined, one can expect that Mt Wilhelm will become one of the best studied CART in the Tropics.

The "Our Planet Reviewed: Papua New Guinea" project, composed of a marine and a terrestrial module, was made possible thanks to the collaboration between Paris and Brussels Natural History Museums (MNHN and RBINS), the NGO Pro-Natura International, the Institut de Recherche pour le Développement (IRD, France), the New Guinea Binatang Research Center, the University of Papua New Guinea and the Divine Word University of Madang. It mobilized 222

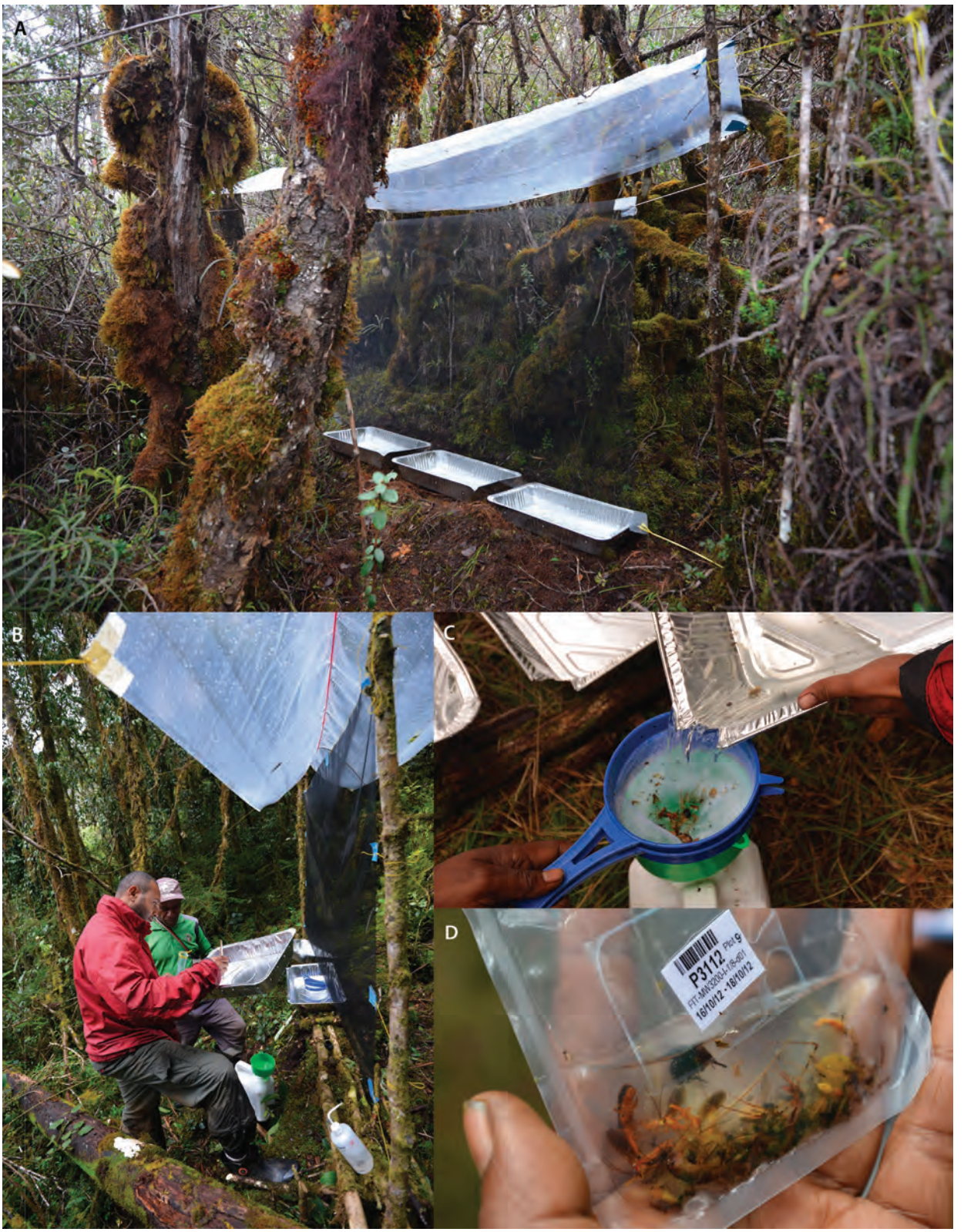
participants of 22 nationalities (63 participants and 11 nationalities for the terrestrial component alone). To this number one can add approximately 300 taxonomic experts working on the specimens collected as well as a number of other persons, difficult to estimate, working on the communication and education aspects of the project and coordinated by MNHN Education service. Altogether one can estimate that about 550 people who were involved directly or indirectly in the project. The project budget, around 1.8 million euros (one third dedicated to the terrestrial project), was funded by a combination of private funds (Prince Albert II of Monaco Foundation, Stavros Niarchos Foundation, Total Foundation, Fondation d'entreprise EDF, Spiecapag, Entrepose Contracting, Reef Foundation) and public funds (IRD, Fonds Pacifique, New-Caledonia Government, the Belgian National Science Foundation and the Belgian National Lottery). The terrestrial module was innovative in collecting arthropods virtually at eight elevations along a particularly long elevational tropical gradient, by combining community surveys with food web studies, and by combining large contingents of overseas and local partners.

FIGURE 16

Two series of labels were printed before field work. One concerns the samples, with a short alphanumeric code starting with "P", a longer code with the sampling method, the site, the order in the series of collecting events linked to the trap and finally full information on the collecting event. The second series concerns vial labels with unique numeric codes. By convention when the content of a vial is split into several vials during specimen identification, a suffix is added to the original vial number.

FIGURE 17

Collection of insects with flight interception traps. **A**, Three trays partly filled with water, salt and detergent were used to collect flying insects. **B-C**, Trays were emptied every two days. **D**, Specimens caught were stored in a whirl-pak filled with pure ethanol and containing a pre-printed polyester label.


A
B
C
D
P3112
Plot 9
FIT-MN-0000-TR-001
16/10/12 - 16/10/12

The key achievements of the terrestrial project were:

(1) The collection of detailed and comprehensive information on tropical forest biodiversity distribution along a complete elevational rainforest gradient in the tropics, which is important for global biodiversity estimates, conservation and climate change monitoring. Distribution data on plants, insects, vertebrates and their interactions were collected along one of a few complete elevational rainforest gradients in the world, as a baseline for conservation decisions and monitoring and modelling of biodiversity response to climate change. Data on plant-insect interactions will be used to refine the latest Hamilton *et al.* (2010, 2013) estimates of global species richness by including elevational variation in species diversity in the equation, which has, until now, been largely reliant on data from lowland rainforests. In particular, species composition, diversity and host specificity of insects on a particular plant species can change with elevation (Novotny *et al.* 2005), and these shifts can have important, previously neglected effects on overall biodiversity estimates. Furthermore, scenarios of future climate change predict important shifts in elevational distribution of biodiversity (Ashton *et al.* 2016). In particular, global warming can facilitate the expansion of lowland species to higher elevations, as well as disappearance of cold-adapted, high-elevation ecosystems from the tropics. The altitudinal shifts in species distribution have already been documented in the temperate zone (Warren *et al.* 2001) and, also in the tropics, on the island of Borneo (Chen *et al.* 2009). These changes in species distribution are particularly important in New Guinea, one of the few areas in the humid tropics with a complete elevational range, including a well-developed alpine zone (Hope 2014). Our data set is one of the first base-line quantitative data sets for insect distribution along an elevational gradient in New Guinea, and one of the first detailed data sets from the tropics. We will use it to simulate effects of different climate scenarios on biodiversity, including upward shifts in elevational distributions, of 600 m estimated for 3.2oC warming scenario over a century (Colwell *et al.* 2008). These simulations will assess how many species will have reduced elevational ranges, including those reduced them to zero and thus driven to extinction, or gaps between their present distribution and the one expected due to global warming. We will also include the effect of reduced land area available to each species as they shift to higher elevations. In collaboration with a team of geographers led by P. Shearman (University of PNG) we have already obtained land area measurements for different elevations in New Guinea. Finally, we will also include the effect of habitat destruction as some of the land areas are deforested and have to be discounted as potential refugia for rainforest species. We have state of the art habitat assessment for PNG based on satellite photos (Shearman *et al.* 2009, Bryan & Shearman 2015).

(2) The engagement of local communities in the collection of research data and strenghtening their interest in rainforest conservation. The project worked with rainforest-dwelling indigenous communities that established the Wanang Conservation Area, and also with the communities living adjacent to the Mt Wilhelm National Park. In Wanang, eight clans that opted for conservation instead of logging are actively looking for alternative income from conservation, as well as technical assistance and moral support for sustaining their conservation effort in the face of widespread logging. The present project provided such technical help, including training and employing paraecologists from Wanang community, biodiversity data useful for conservation management as well as ecotourism, and, last but not least, increased visibility and sense of importance for the community and the Conservation Area coming from the attention to their forests from such large international study. The project provided crucial support for the choice of this community to pursue conservation rather than deforestation. Recently, the Wanang community received United Nations Development Program's Equator Prize 2015 for "innovative approaches to conservation". The communities along the elevational transect at Mt Wilhelm include landowners from within the Mt Wilhelm National Park (sites at 3200 and 3700 m a.s.l.) and communities with rainforests outside this park, that however comprise most of the local biodiversity. The project stimulated interest of these

FIGURE 18

Collection of insects with a Malaise trap. **A**, In thick forests, here at 3700 m a.s.l., the ground vegetation was cleared to allow the installation of the trap. **B**, Collecting bottles were filled with pure ethanol and emptied every day. **C**, The content of the bottle was put in a whirl-pak with pure ethanol and a pre-printed label. **D**, At low elevations, weaver ants (*Oecophylla smaragdina*), sometimes invaded the trap. **E-F**, To prevent the arrival of ants, a Tanglefoot barrier was put on the suspension ropes.


A
B
C
D
E
F


A
B
C
POLICE
D
E
P3409
P3408
F
00308
G
H

FIGURE 20

Team of three people conducting the vegetation beating and composed of one paraecologist and two villagers. The paraecologist supervises the arthropod collection and keeps track of the time. Each beating session, corresponding to one sample, lasts five minutes. Ten sessions of five minutes are performed all over the 20x20 m botany plot. The plot here is at 3200 m a.s.l. A villager is responsible of stroking the low vegetation with a strong stick, another one uses an aspirator to collect the fallen arthropods onto the sheet. Please note that on this image, the umbrella is upside down, the PVC frame is better held when above the white sheet. A Steiner trap is hanging at the upper right corner of the picture.

FIGURE 19

A, A 60x100 cm plastic sheet was pinned at the bottom of a large tree, on the side which was the most suitable to collect falling insects. The sheet formed a bowl with its deepest point in the middle. **B**, An area 2m high and up to 1m wide was delimited (see above). **C**, The area was sprayed twice and only during dry weather (the bark had to be dry). **D**, After 15 minutes, arthropods fallen in the plastic sheet were collected with a small brush. Special care was taken not to damage the fragile specimens and not to miss the tiniest ones (mites and springtails). Another plastic sheet was put under the collecting sheet to avoid specimens drop on the floor by accident. **E**, The arthropods were stored in pure ethanol in a whirl-pak containing a pre-printed label with the sample code. **F**, Tree numbers were recorded. **G**, The diameter at breast height was measured. **H**, A bark-spray kit was provided to each paraecologist team and contained a plastic box which could be used as a tray, whirl-paks, a wash-bottle with ethanol, a tape meter, a brush, a pen, pins and pegs, pre-printed labels, a listing of sample codes and a protocol.


A
B
C
D
E

FIGURE 22

Sorting process for Flight Intercept Trap samples. **A**, A team of parataxonomists was supervized by a senior Coleoptera expert. **B**, Each sample was accompanied by copies of the sample code label and a quality-check label. **C-D**, Each parataxonomist extracted the focal taxa (Coleoptera and Orthopteroids) which were placed in Petri dishes. **E-F**, Residues were put back in the whirl-pak. Care was taken to remove the air from the whirl-pak before to roll it several times. **K-L**, Orthopteroids were transferred to the senior expert of this group (Tony Robillard). **G-J**, Beetles focal taxa and samples residues were transmitted for verification to the senior taxonomist (Laurent Soldati) who noted the corresponding information in a datasheet. For details see text.

FIGURE 21

Steiner traps used to attract fruit flies. **A**, They were suspended below a tree branch, at 1.5 m height. **B**, They contained a male specific parapheromone lure impregnating cotton wicks suspended from the center of the trap. **C**, Close-up of a Tephritid fly. **D**, Tanglefoot is added to the suspension rope to prevent the arrival of ants (on this picture, too much glue was used, it should not go down on the trap surface as it may glue some flies). **E**, A cotton wool at the bottom of the container diffuses an insecticide (Bifenthrin). Flies were collected daily.

communities to establish a conservation area similar to Wanang, as they could see the financial and reputational benefits of biodiversity research on their lands. Such a result would be a major achievement since the diversity along the Mt Wilhelm transect is extraordinary and includes 15 – 51% of all PNG species for various plant and animal taxa (Novotny & Toko 2015).

(3) The training of para-taxonomists/ecologists and students. The project included 21 para-taxonomists/ecologists from BRC, which is one of the two leading institutions for paraecologist training worldwide (Schmiedel 2016). The project allowed them to increase their training in state-of-art collection and identification techniques. The project included dissertation research by two MSc students registered at the country's premier university, the University of Papua New Guinea (UPNG) and resident at BRC and one PNG PhD student at the Griffith University (Australia). Postgraduate student training was successful as there were many synergies between the para-ecologists/taxonomists, the international experts and the two local MSc students. The student training further contributed to the capacity-building in PNG and resulted in two MSc thesis and a Bachelor thesis (Yombai 2014, Moses 2015). In addition, a Papua New Guinean scientist (SA) benefitted from a grant to continue her training during one month at Claire Villemant's lab in Paris Museum. Another one (JM) received a PhD grant to continue his work on the Mt Wilhelm ant dataset.

(4) The involvement of media attention and education of the public on the themes of biodiversity exploration, species discovery, sustainable development, capacity-building and conservation in Papua New Guinea. Between 2012 and 2013, the project was mentioned more than 258 times in the media (radio, television, magazines, internet), including National Geographic France.

(5) The enrichment of natural history collections with PNG plants and arthropods. These reference collections, identified by expert taxonomists will be deposited in Papua New Guinea, at MNHN and in other major Museums. Sample residues, containing non-focal taxa, are temporarily stored in Brussels at the Royal Belgian Institute for Natural Sciences (RBINS) where their study is encouraged.

The current book represents a first step towards the description of numerous new species collected during the project. Apart from this introductory chapter, the present volume comprises nineteen contributions from 32 authors belonging to 14 countries, including (in alphabetical order): Australia, Belgium, Brazil, Canada, China, Colombia, France, Italy, Papua New Guinea, Romania, Russia, Singapore, Thailand and USA. Most papers are purely taxonomic studies of some major insect orders sampled during the main biotic survey: Coleoptera (1 paper), Diptera (1), Heteroptera (1), Blattodae (1), Orthoptera (3) and Hymenoptera (12). Less than four years after the survey, this volume should be seen as the first trees of a forthcoming forest of new findings. Many taxonomical outcomes are still expected for all focal taxa sampled. Contributing authors of this book described no less than 144 new species and six new genera. They revised many other species descriptions, completed them with new localities where found, which resulted in new or updated identification keys and species checklists. The survey also allowed us to collect novel data about species sampled in the region of Madang, such as information about their habitats and behaviors (Dong & Robillard, Robillard *et al.* this volume). Some papers are more synthetic and include both taxonomic work and phylogenetic information about the taxa (Soldati *et al.*, Villemant *et al*. this volume), while others discuss the taxonomic distinctiveness along the elevational gradient (Bickel & Martin, Colinet *et al.* this volume).

FIGURE 23

Sorting process for Malaise traps. **A**, The whirl-pak content is poured into a Petri dish. **B**, Lepidoptera are discarded; **C**, Orthopteroids are separated and further processed by an expert (Tony Robillard). **D**, Coleoptera are separated and further processed by an expert (Antoine Mantilleri). **E**, the Petri dish is then closed and put inside a whirl-pak together with 20 copies of the sample code label and one label indicating which insect orders are already removed. Whirl-paks are temporarily stored in the first segment of the "sorting pipeline". **F**, The Hymenoptera specialist (Claire Villemant) and her assistant (Sharon Agovaua) remove all the specimens from this order from the Petri dish which is put back in the second segment of the sorting pipeline. **G**, Then Diptera are removed by the expert for this group (Dan Bickel). **H**, followed by Hemiptera (Adeline Soulier-Perkins and her assistant, Amandine Winckler).


A
B
LEPIDO
ORTHOPTEROIDS
COLEOPTERA
C
D
E
MALAISE
1 HIGHER TAXA
2 HIGHER TAXA
F
G
H
P1790
MALAISE 1200M
HYMENOPTERA
DIPTERA
HEMIPTERA
ORTHOPTEROIDS
COLEOPTERA

PHOTO CREDIT

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