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Using field-based entomological research to promote awareness about forest ecosystem conservation

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Abstract

Interactions between plants, insect herbivores and associated predators represent the majority of terrestrial biodiversity. Insects are vital food sources for many other organisms and provide important ecosystem functions and services including pollination, waste removal and biological control. We propose a complete and reproducible education programme to guide students to understand the importance of managing and conserving forest ecosystems in their region through the study of insect ecology and natural history. Our programme involved lectures, workshops and field surveys of insects with a group of 60 high school students in Eastern Africa (Ethiopia). It addresses the key stages of an entomological research project including: 1) general entomological knowledge and understanding the role of insects in terrestrial diversity and in ecosystem functioning and services; (2) the proposal of simple research questions including hypothesis development and evaluation using scientific literature, 3) fieldwork using different types of light traps; 4) sorting and identification of the insect orders using simple diagnostic keys and illustrated plates; 5) analysing and interpreting the results and 6) demonstrating findings to peers and a public audience. Identifying insects, exploring their natural history and understanding their functions in the field bring the students towards a better understanding and awareness of the importance of forest ecosystem conservation.

Keywords
Conservation awareness, forest ecosystem, Ethiopia, biological education, Des Insectes et des Hommes, public outreach

Introduction

Insects and plants have undergone a co-evolutionary arms race for over 200 million years (Labandeira et al. 1994; Van Eldijk et al. 2018). Plant-insect interactions represent almost 75% of terrestrial biodiversity composed of host plants, herbivore insects and their predators (Price 2002), which are mostly other arthropods (May 2010). Insects are central components of terrestrial biodiversity. It is therefore essential that the public is educated to understand and appreciate the multiple roles of insects in ecosystem functioning and services. Given the diversity of insects and complex nature of ecosystem functioning, however, this appreciation can be seen as an abstract notion to comprehend for many public audiences.

The importance of insects and the ecosystem functions they provide are best-illustrated by their fascinating natural history. This facilitates the use of insects as a model for an introduction to ecology and public outreach towards ecosystem conservation and management. For example, insects are soil engineers. Excluding decomposer and detritivorous insects from a forest ecosystem leads to the accumulation of unrecycled organic matter (Beynon et al. 2015). Such a build-up of organic matter can have severe consequences for nutrient cycling and other ecosystem functions. The interactions between herbivore insects and their host plants, which are under constant selective pressure, are one of the main forces driving plant species coexistence in hyperdiverse tropical rainforests (Fine et al. 2004; Lamarre et al. 2012a). The role of insects in pollination is also crucial for structuring plant species coexistence and this biotic interplay allowed many flowering plants to evolve bright colours and incredible shapes as reproductive strategies to attract insects. Some insects, such as wild bees, are beneficial to food production, as they pollinate the large majority of crops (Picanço et al. 2017), while others are agricultural pests. At the top of the food web, insect predators and parasitoids regulate populations of herbivores and other agricultural pests. This makes understanding and maintaining insect diversity vital to global food security. Our agricultural practices are expected to evolve towards agroecology which promotes natural populations of beneficial insects such as pollinators and pest controlling predators and parasitoids (FAO 2014). A better understanding of insects and their functions allow us to realise sustainable practices for our agroecosystems adapted for fluctuating climates.

Despite its global importance, entomology as a discipline has been slowly disappearing along with a lack of formal training and the rarity of insect taxonomists in universities (Leather 2009, Wilson 2017) and in conservation studies (Clark and May 2002). Leather (2009) pointed out that:

> "*Entomologists are like endangered mammals such as tigers and polar bears in that they and their habitats are on the verge of extinction and this is likely to have a profound negative effect on science in general*".

The statement is generally shared amongst the scientific communities where basic biodiversity research is being neglected (Leather and Quicke 2009, Leather 2015; Wilson 2017 and references therein). Advances in entomological knowledge will be crucial for tackling future challenges such as climate changes and other global-scale anthropogenic disturbances leading to the loss of biodiversity and associated ecosystem functions. A large-scale loss of insect diversity has been reported by Hallmann and colleagues (2017) who showed a decline of over 75% in flying insect biomass within protected areas of Germany. Ongoing disturbances such as climate change are predicted to increase the impacts of insect pests and vectors on food production, human livelihoods and health (DeLucia et al. 2008; Jeffs and Lewis 2013). Such observations stimulated numerous media reactions, but, due to a lack of information and education on biodiversity and insect taxonomy, the issues behind these findings remain difficult to fully apprehend.

Here we recommend the use of insects and field study in biological education programmes to increase the understanding of the value of biodiversity. In our field study, the action of observing and inspecting live insects, in the middle of the forest at night for the first time, is unique in creating a memorable experience of nature (Borsos et al. 2018). Our education initiative utilises similar teaching methods to the British Bioblitz programme – i.e. a complete field course on insects that are easy to observe and collect in their natural habitat. We report the feasibility of the novel "Des Insectes et des Hommes" ("Insects and Humans") education programme in Ethiopia (Eastern Africa) as a case in point. To our knowledge, no biological education programme has been yet proposed using a scientific framework in the study of insect communities in the French education system.

The programme addresses every step of entomological research projects and is comparable to a typical undergraduate entomology programme. These activities include: (1) acquisition of general entomological knowledge and understanding the role of insects in terrestrial ecosystem functioning and services; (2) proposal for research questions including hypothesis development and evaluation using scientific literature; (3) fieldwork using light traps as the main collecting technique; (4) sorting and the identification of the 10 main orders of insects using illustrated plates and entomological supports; (5) database preparation, data collection and analysis and interpretation of the results; (6) communicating their findings to the public audience via oral presentation and written reports.

The general philosophy of our field course is governed by the need for investigating the identity (taxonomy), exploring natural history and understanding the functions (ecology) of insects in an observable way in the field. We envisage that this process will develop behavioural changes in the participants and presentation audiences, such as greater curiosity towards insects and their habitats and a motivation to protect them (conservation). The proposed educational programme also provides a basic understanding of natural forest ecosystems at both global and local scales, fostering local community awareness of forest habitat disturbances and the need for conservation in their region.

Methods

Study site and target participants

The French High school Guebre-Mariam in Addis-Abeba (Ethiopia) hosted the project and provided facilities for the lectures, the lab work and the student oral presentations. The target groups are primarily high school students, but this does not exclude the course being applied to other lower and higher education students as well as the wider public (Matthews and Flage 1997). We encouraged the targeting of those who did not take entomological or ecological courses. Here the case study consisted of two classes of students aged between 15 and 19 (mean age of 16.4 years) corresponding to the first year of high school in the French education system (i.e. "Seconde" in French, year 11 in UK and 10th grade in USA). Our programme was fully integrated into the biology major programme ("Sciences et Vie et de la Terre"). A total of 57 students from the two classes (3 were absent) representing 10 different nationalities were randomly allocated to six groups prior to the initiation of this programme (3 groups per class). We decided that an average of nine students per group was an adequate size for efficient interactions amongst students and teachers.

Fieldwork occurred in the Oromiya region within the Menagesha National Park, located at Suba village, 50 km east from Addis-Abeba. The protected forest represents nearly 10000 ha of altitudinal subtropical forests including 2500 ha of pristine forest and 1000 ha of plantations in the surroundings (Demissew 1988). The natural forest is dominated by endemic trees characteristic of the altitudinal highlands of Ethiopia such as the native African juniper (*Juniperus procera*), the Kousso tree (*Hagenia abyssinica*) and the endangered fern pine (*Podocarpus falcatus*). The protected area is part of an old and complex geological formation on the southwest facing slopes of the extinct Wechecha volcano (3,385 m). The project site received almost 1100 mm of precipitation from June to September with an average temperature of 11 °C. This pristine mountain forest remnant also hosts many native and endemic fauna and is thus an important refugia for endangered species, such as the two endemic mammals, the Menelik Bushbuck (*Tragelaphus scriptus meneliki*) and the White-footed mouse (*Stenocephalemys albipes*). Few participants in our course had previously visited this exceptional national park even though it is the last native primary rainforest in the vicinity of Addis-Abeba.

Implementation procedure

We led a complete and reproducible education programme using the study of insect to guide the students towards understanding the importance of conserving and managing forest ecosystems in their region. The programme ran for one entire school week with approximately 8 hours of activities per day (Monday to Friday, 18–22 April 2016) which included a total of 5–6 hours fieldwork at night. Five sequences are presented chronologically below to describe the programme activities. Finally, we discussed the education implications of our course by summarising feedback from the students and teachers 18 months after the programme was concluded.

Sequence #1: Introduction to insect ecology (Day 1, lectures ~ 4h). The first sequence consisted of a general introduction to insect diversity and ecology (Figure 1). Two lectures of 2 hours were given by GPAL in an amphitheatre and served to introduce insects as key components of terrestrial biodiversity, focusing on their extreme abundance and species richness. The lecturer also addressed the importance of insects in providing ecosystem functions and services. We explained the principles of co-evolutionary theory with some examples of anti-herbivore traits such as trichomes on the leaves of plants easily visible in the field. We also taught that herbivorous insects tend to be specialised to feeding on a few evolutionary related host plant species (Novotny and Basset 2005). We discussed the ecological and evolutionary factors that determine the degree to which a herbivore is associated with one or multiple plants. Specialisation is a crucial notion to comprehend because it is related to patterns of association, coexistence and diversification of insect and plant assemblages. GPAL introduced the most dominant insect orders likely to be collected by the students and their range of microhabitats in the forest (Figure 1). Prior to identification of insects to order level (Seq: #3 and #4), the lecture also highlighted the ecological functions of insects in forest ecosystems (e.g. pollinators, scavengers, decomposers, predators). In conjunction with their fascinating natural histories, this context was needed to understand the importance of studying insect functional diversity (see Lamarre et al. 2016).

Finally, we presented the daily schedule of the programme to all participants and formed the field groups before organising the equipment. The participants were encouraged by teachers to ask practical as well as scientific questions about the programme. As a mandatory step prior to any scientific project, we recommended a literature review. In our case, students reviewed online biodiversity studies pertinent to Ethiopian forest ecosystems. We introduced students to an online scientific literature search engine, in this case Google Scholar, which was previously unknown to most students. However, we found neither a local insect list nor any entomofaunal knowledge for our study region (with the exception of information associated with human related vector mosquitoes and flies, but see Rougeot 1977). Such an education project therefore has the potential to produce a basic insect species list (e.g. an inventory) and is an effective form of citizen science (Campanaro et al. 2017, Scheuch et al. 2018) similar to the Bioblitz project in the UK. Detailed inventories, generated from our field course, can serve as a baseline study on the insect communities found in Menagesha National Park.

Sequence #2: Workshop for building research questions (day 1, lab activities ~2h). We allocated student groups to two classrooms to keep the number of students manageable during the workshop. Instructors, GPAL and YJ, led the workshop discussion. In each class, in concert with the students that reached some specific interests

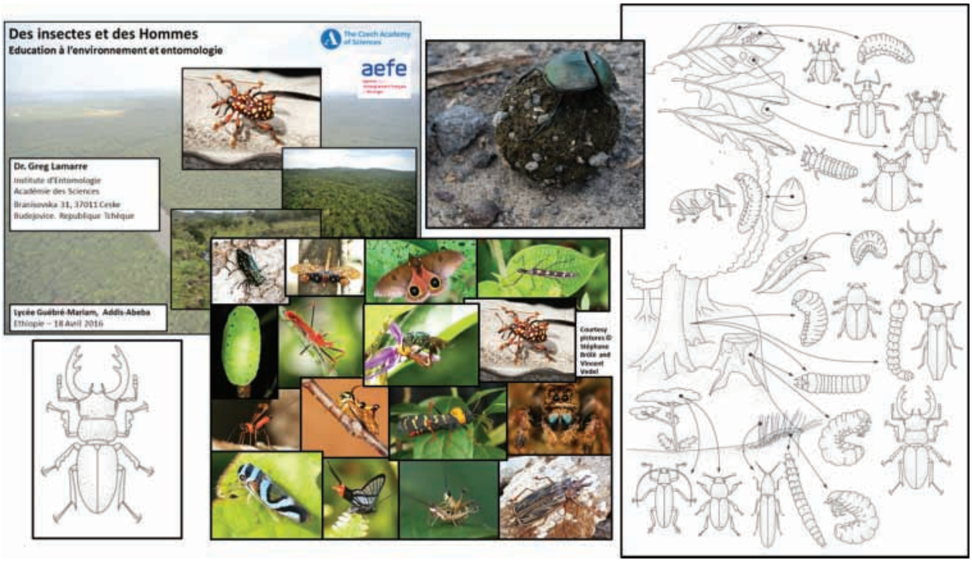

Figure 1. Slide, plates and pictures used for the teaching of the role of insect in global diversity and ecosystem functioning (Seq#1). It includes the PowerPoint presentation for lectures; an illustration of a dung beetle to present their crucial role as soil engineers; an illustrated plate of the multiple arthropods observed in tropical rainforests and finally the myriad insects inhabiting one unique tree associated with different niches (Evans, 1977).

in particular insect group, we proposed a series of simple research questions on insect community composition and structure (community ecology). These questions were related to the previous lectures and were feasible to investigate within the duration of the fieldwork (i.e. generating a sufficient dataset) and the timeline of the project (Table 1). Instructors needed to prepare a list of questions prior to the workshop to facilitate discussion and, if necessary, modify questions in the context of the local area, forest structure, compositions and weather conditions.

During this workshop, one group decided to investigate the three most dominant insect orders found in the national park to generate an illustrated leaflet detailing the charismatic and dominant insects for future visitors. GPAL briefly lectured in Sequence #1 about other insect sampling techniques that might be employed in forest ecosystems and the importance of trap choice in targeting specific insect functional groups (Lamarre et al. 2012b). We introduced two different types of light traps in order to study and compare the number of collected individuals and assemblage composition of the target insect orders. Students from two groups compared the differences in efficiency between the two light trap techniques amongst different groups of insects, allowing them to understand the insect flight activity and seasonality. We discussed the origin and differences in attraction of insect groups to lights (phototactic responses). Sampling efficiency was compared in terms of capturing the dominant, representative species of the local habitats and in terms of capturing species of the target group (e.g. moths). We discussed with the students how to structure a dataset (order × sample × trap) we will generate from the light trapping (Table 1). For some groups, we devel-

Table 1. Scientific questions proposed and examined by each of the six groups during the programme Des Insectes et des Hommes with the themes and topics relevant to the questions.

Groups	No students	Questions (FR)	Questions (ENG)	Themes and relevant topics related to lectures	Proposed by
Group 1	12	Quels sont les différents types de pièges utilisés pour réaliser un échantillonnage standardisé d'une communauté d'insecte?	Which insect traps do we use to sample a standardised insect community?	Methodology (Insect sampling), complementarity of traps for distinct taxonomic and/or functional groups, Inventory and monitoring techniques (day-night)	Instructors
Group 2	10	Comment, après la collecte, trier les insectes?	How, after sampling, do entomologists sort their insect collection?	Methodology (procedure after sampling), entomology (sorting, organising, labelling, identification), museum (conditioning and transport, fate in collection)	Students
Group 3	10	Quelles sont les différences de captures d'insectes entre les deux types de pièges lumineux?	What are the differences in insect community structure (abundance-based per order) between the two different light traps?	Physiology (contrasting responses to light intensity, phototaxis), range of light attraction amongst forest habitats (spatial independence between traps), ecology (insect diversity of Ethiopian forest)	Instructors
Group 4	8	Quels sont les trois ordres dominants d'insectes de la forêt de Menagesha?	What are the three most dominant insect orders in the Menagesha National Park?	Conservation biology, biodiversity study (species list, field inventory for protected area), ecology, (community structure and composition in subtropical altitudinal forest)	Students
Group 5	8	Par quel type de piège lumineux les lépidoptères sont-ils le plus attirés ?	What is the most efficient light trapping technique to capture a moth community?	Conservation biology (biological indicator), methodology (efficiency), long-term monitoring (umbrella species, Lepidoptera), sampling bias	Instructors
Group 6	9	Quelles sont les différences d'abondance de capture de Coléoptères et de Lépidoptères entre le 19 avril et le 20 avril ?	What is the relative abundance in Lepidoptera and Coleoptera before and after rainy events?	Ecology, climate change (responses of contrasting functional groups under rainy event), plant-insect interactions (food sources for herbivore insects with host-plant producing new leaves early rainy season)	Instructors/ students
Overall	57				

oped a posteriori research question during the fieldwork. For instance, a couple of hours of rainfall during the second night of trapping created the opportunity to study the effect of weather variations on insect activities and, ultimately, the assemblage of captured insects. Students also studied the differences in abundance of Coleoptera (beetles) and Lepidoptera (moths), the two most dominant taxa, between clear and rainy nights. This, however, relies on a random event (rainfall) and was therefore not reproducible. Additional questions would have also been possible on butterfly species in the genus *Papilio* and *Graphium*, for example, to investigate the feeding behaviour of these two genera and identify the plants which they visited for pollen (see Jemal and

Getu 2018). Butterflies are excellent models for exploring and to disseminating ideas on feeding ecology, trophic interactions and food webs, especially in species-specific assemblages of plants in threatened montane forests. We need to acknowledge, however, that the choice of habitats, their diversity and the extent to which students will sample with sufficient intensity are not reproducible. Finally, we recommended the educators to remain flexible in terms of questions or objectives proposed to the students and to consider simple "scientifically safe" questions related to lectures (Seq#1) relevant to the topics (entomology, ecology and conservation) and feasible during a short programme.

Sequence #3: Fieldwork using light traps (first class, day 2; and second class, day 3). Prior to the students' arrival, we first explained the survey protocols (including the safety procedures) to the national park service and rangers. Each student from the two classes performed one entire day and a part of the night in the field. We set up two types of light traps in the forest understorey for two nights at around 1 km from the camp in the afternoon (~2 hours taken for trap installation, day 2). The first light trap consisted of a 2.5 m × 1.5 m white sheet attached between two tree trunks using ropes. We suspended one 250 W mercury vapour bulb, powered by a generator, in the upper centre of the white sheet to attract nocturnal flying insects (Figure 2). A small camp (with a few students) was established near the trap to protect the equipment from water damage. At least 500 m from the first light-trap, we set up a portable light trapping device. This second light trap illuminated an 80 cm cylindrical white sheet using a 30 cm actinic tube of 12 W black light (Figure 2). This type of actinic lamp powered by a small-sized battery could also be used alone for the programme, as mercury vapour lamps, ballasts and generators are not always accessible.

During the day, we also introduced the use of aerial fruit traps and pitfall traps for collecting the butterflies, wasps, ants, beetles and spiders commonly found in the understorey and in the canopy (Suppl. material 1: Figure S1). The students, however, ultimately only collected data from the light-traps, as this technique yielded the highest abundance and diversity of insects in the limited sampling period available. Light trapping has a unique advantage amongst other sampling techniques, as this allowed students to observe closely the behaviour of live insects as well as interesting interactions, such as predation and competition. Light trapping also provides a unique opportunity to introduce some morphological traits characterising a distinct insect order and their ecology (but insects need to be immobile on the sheet). For example, the scaled wings are a diagnostic feature of adult Lepidoptera and the proboscis is related to the function of the organism in the ecosystem (pollination).

Fieldwork is often considered as the exciting and adventurous part for field biologists. We shared our experiences of working in tropical countries with the students before dinner (1800 h) and prepared to reach the light trapping sites with headlamps. Before commencing night-time fieldwork, the instructors conducted the safety briefing (e.g. with regards to venomous insects, generator cables and cold weather), explained the schedule and, with students, organised the equipment such as collecting and killing jars (for safety reasons, we used nail polish instead of cyanides), forceps and sample labels. When arriving at light traps, most participants were quick to show an interest in

Figure 2. Pictures from the light-trapping session with two classes of the French High school Guebre-Mariam of Addis- Abeba (Seq#3). The students developed specific entomological skills from the different methods and recognised the choice of the trap needed to target a given insect. The students worked at night and respected safety procedure with toxic products (see killing jars) and finally were able to collect live insects manually. The second light trap technique (i.e. actinic lamp) is shown on the two left pictures while the manual light trap is shown on the four right-side pictures.

knowing the names of collected insect specimens. The illustrated plates (Figure 3), used for identifying the insects, were first presented prior to the collection and used while sampling. Once the groups were fully prepared, GPAL demonstrated how to sample the insects on the sheet to individual students. Students then captured insects on the sheet directly using plastic jars or forceps (Figure 2). At least one instructor supervised one light trap during the entire duration of the fieldwork. The instructors ensured that each group collected arthropods representing the majority of the focal taxonomic groups found on the white sheet, reported the time, date, type of light trapping and weather conditions in their notebook before switching to the second light trap. The instructors also ensured that each group collected insect samples at least twice from each of the two light traps. Between light trapping events, one out of the three groups moved towards the camp in order to start sorting, labelling and organising the insect specimens. We sampled insects until 2300 h or 2400 h. Instructors and some volunteering students then organised and transported the equipment back to the camp and cleaned the site.

Sequence #4: Sorting and identification of the main orders of insects (day 4, lab activities ~6h). One of the objectives of the programme was for the students to be able to identify the major insect orders observed in situ and to take a closer look at insect morphological and functional traits under the microscope. For this purpose, we created coloured plates illustrating examples of insects belonging to each order and simple taxonomic identification keys (Figure 3), which helped students recognise diagnostic

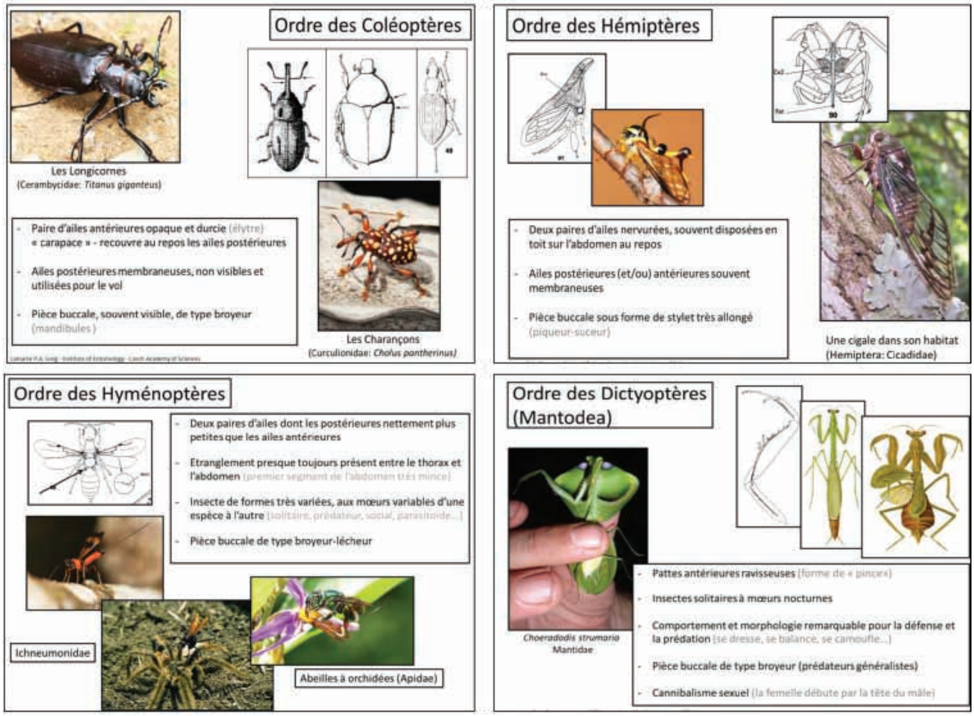

Figure 3. Illustrated plates of some insect orders created for the programme, used to provide the scientific terminology and enabled students to apply and use knowledge connected to the taxonomy of a given insect (Seq#3, #4). Plates are available upon request to the corresponding author.

features of each insect order (see Delvare and Aberlenc 1989). By using these plates, most student groups were able to count and identify their specimens on a petri dish to order (Figure 4). We validated the students' insect identifications and asked them to explain which morphological features were used to identify and sort insects (whilst relating insect traits to an ecosystem function). They finally put individuals belonging to the same order into the same falcon tubes (50 ml) with 70% ethanol to preserve them along with a corresponding label (order, type of trap, location and date). For moth specimens, we explained how to preserve the specimens in a glassine envelope.

All individual specimens from light trapping were counted and identified to order level. Collected specimens included Lepidoptera (moths), Coleoptera (beetles), Hemiptera (true bugs), Orthoptera (grasshoppers), Hymenoptera (bees, wasps, ants), Diptera (flies, mosquitoes), Mantodea (praying-mantises), Phasmatodea (stick insects) and also other arthropods (e.g. spiders). We observed that most of the difficulties in identification were in distinguishing Diptera from Hymenoptera, in some cases one pair of wings was detached or absent. Instructors were able to work interactively with the students to resolve their identification problems and pointed out additional useful morphological traits (e.g. buccal appendices in addition to wing pattern). The use of drawings in notebooks coupled with a microscope camera helped students to learn

Figure 4. Pictures of the laboratory activities including the organisation, sorting and counting of the collected specimen using a systematic procedure under microscope (Seq#4).

the diagnostic characteristics effectively. We also recommended the use of a projector, which offers a direct visualisation of the differences in insect morphology illustrated by high-resolution pictures or diagrams. Lepidoptera, Coleoptera and Hemiptera were the most successfully identified taxa. Some large-sized Hemiptera in Coreidae, Reduviidae and Pentatomidae families were sometimes confused with beetles. Mantodea and Phasmatodea were well distinguished from other orders after the first observation. Separating the different orders in the field (after observation and collection) and the lab (under microscope) received positive feedback by the students and was generally perceived as less challenging than the identification of specimens at higher taxonomic level (family or genus). However, confirmation of students' identifications by instructors was needed. This often generated valuable discussions within a small group of students on the process of discriminating key morphological features amongst insect orders and on functional attributes related to ecosystem services (e.g. pollen-carrying apparatus in bees).

Sequence #5, #6: How to present your data and report your findings? (day 5, lab activities ~5h). We introduced Microsoft Excel software and gave instructions on correct data formatting procedures (Excel was projected on a screen from the teacher's computer). First, one student per group volunteered to enter the insect data. It consisted of the abundances (the number of individuals) of insect orders, the abundances per sampling nights for each insect order or, for some student groups, the abundances associated with the total number of individuals of each order collected between rainy and dry nights from the two type of traps. Each group composed one Excel spreadsheet. Second, GPAL and YJ visited each group to show students how to generate graphical diagrams of their data in Excel. Most of the students chose either bar plots or Venn diagrams to present their results (Figure 4). Using a projector in the classroom, GPAL presented the procedure of constructing a statistical linear model illustrated by a simple correlation plot. Students were asked to think collectively on the interpretation and the presentation of their results and discussion. Instructors ensured that each group work towards their previously devised research objectives when preparing their presentations. If research questions were not sufficiently addressed with their data, instructors provided more guidance and support. Each group worked on a Microsoft Power Point presentation that consisted of 8–10 slides with simple graphics and fieldwork pictures, sufficient for a 5–10 min oral presentation (Figure 5). Students were encouraged to present any findings relevant to the topics covered during the lectures, lab and fieldwork, which may increase scientific knowledge of the site (Table 1). We also emphasised the potential use and application of their findings to local forest conservation.

This biological education programme not only taught scientific procedure and methods, but also trained the students to present to the public audience, sometimes for the first time. This last step was mandatory as it is a common method of communicating the results of any scientific project and is a valuable transferable skill for students to learn. Presentations generally involved demonstrating their results and conclusions to peers and the public audience through using scientific articles, conference presentations, posters and popular science articles. Each group prepared their presentation and selected designated speakers for a given number of slides in running order. At least one practice run was carried out per group. The students of each group presented their findings in the high school amphitheatre in front of about 80 participants consisting of students from other classes, parents, teachers, project partners and administrative employees. At the end of each presentation, five minutes were given for questions from the audience, generally with encouragement from the biology teachers (Figure 5). Finally, two months after the project, YJ and colleagues extended the programme by asking the students to review their knowledge through written scientific exercises on an online scientific blog. To date, 36 articles have been reviewed and published by the science department of the Ethiopian high school (with 19,248 views as of 17.08.2018).

Educational implications

Biology teachers wanting to conduct this field course, should first gain a basic understanding of insect ecology (with the help of entomologists) to aid in the implementation and learning outcomes of the course. When building the proposal for the project, we found it extremely important to integrate the programme "Des insectes et des Hommes" in advance into the school's formal annual plan of science

Figure 5. The French High School Guebre-Mariam, managed by the Mission laïque française and government-regulated with the AEFE (Agency for French education abroad). An example of results produced during the programme and, inside the high school, the amphitheatre that offers the opportunity for students to organise and follow their own symposium, a chance to develop maturity, motivation, leadership and self-confidence (Seq#5#6).

courses. This integration also provided teacher (YJ) an opportunity to be involved in participative science, a goal encouraged by the French Ministry of Education. This programme trains students effectively in scientific writing and communication in at least three different ways. First, students learnt a large array of scientific writing and communication skills, such as labelling, note taking, data entry, analysis, interpretation and oral presentation (e.g. cognitive dimension, Gaskins et al 1994). Second, the students strengthened their scientific reasoning and logic by generating research questions from examining and understanding the component of a problem (e.g. the conservation implications of regional forest fragmentation) and interpreting of the results (e.g. "we observed an increase in the abundance of insects following raining event"). In turn, this may provide an advantage for the students when applying for competitive jobs and university positions. The education project can introduce and illustrate potential vocations in biology such as biodiversity and conservation studies and forest management. Students also learned to use specific entomological equipment and followed rigorous protocols in the field and lab. Finally, we emphasise that being part of a young group of scientists has important social implications (Vérin 1995) and generates beneficial effects and positive group dynamics that enhances the whole experience.

Learning outcomes

Insects are often perceived as pests. Interestingly, this programme helped change students' attitudes towards insects through the experience of sampling and handling live insects. This is one of the main advantages of using light trapping, which yields a large number of live specimens. As we naturally fear what we do not understand, insects trigger strong emotions in us, both positive (diversity, shape and colours) and negative (fear of bites and diseases). Educating about insects through field experience is one way of convincing society at large that insects are more than just "creepy crawlies".

To investigate how the students perceived insects in general and understood their biodiversity and roles in ecosystem functioning, we sent an online questionnaire eighteen months after the programme concluded. We proposed a series of questions to 1) a test-group of students that followed the educational programme and 2) a control-group of students that did not attend the programme (i.e. the 3 absent students). The students who attended the programme gave a very good evaluation (100% of the students gave positive marks). Students were asked to choose a few words from a provided selection to describe the roles of insects in terrestrial ecosystems (Suppl. material 1: Figure S2). The students, who participated the programme, chose mainly "interesting" and "fascinating" (71% and 57%, respectively) and, to a lesser extent, "essential" (29%), "useful" (43%)," vital" (21%) and "curious" (21%). Students who did not participate to the programme described insects mostly as "disgusting", "small" and "ugly". However, with only three students who were absent and forming the control-group, we were not able to statistically confirm this trend. Only the test-group selected "useful" and "vital" and made the link with insect ecosystem services. Most of the students who cited insect groups as agents of ecosystem services included bees and butterflies (included in 60% of their answers). Finally, the students were asked to grade the programme "Des insectes et des Hommes" overall as an education tool for biology education. The answers confirmed that the aims of the programme were fulfilled, as illustrated by the use of specific vocabulary on the importance of biological education ("educational", "informative", "interesting", "rewarding", "patience"), ecological roles of insects ("pollination", "biodiversity", "useful", "fragile") and the emotional feeling associated with emerging curiosity about insects ("surprising", "fascinating", see Suppl. material 1: Figure S2).

Despite the often uncomfortable and unusual working environment, all students selected the fieldwork as their favourite activity during the project (Sequence #3). Our results confirmed that observing and collecting insects in the field can invoke interest, wonder and curiosity towards local natural ecosystems, increase understanding of their importance in terrestrial biodiversity and ecosystem functioning and finally leading the audience to increasing conservation awareness. Due to the limited number of students in the control-group, we were not able to adequately analyse the social benefits and cognitive education merits of our project. However, the overall positive feedback certainly assures the significance of our education programme. We recommended using similar online questionnaires after conducting the programme as this allows for comparisons in the perception of participants and non-participants towards biodiversity and nature conservation.

Conclusion

We conclude that students who participated in this programme gained a better understanding of the extent of terrestrial diversity and its relationship to the crucial ecosystem functions and services provided by insects. Many insect groups, which the students observed during the light trapping, were identified successfully using simple taxonomic identification keys, the illustrated plates and support from demonstrators. Furthermore, the students understood that entomologists are investigating insect functional traits (as observed under microscope) to help find solutions to the challenges our planet faces such as climate change and deforestation (Basset et al. 2017). They were able to relate the insect morphological traits to given functions in the ecosystem (e.g. those that might be disrupted), which increased their beneficial knowledge in ecology and conservation. As acknowledged in the introduction, entomology offers many options by using insects as an educational model in conservation, such as the study of specific functional groups responsible for crucial ecosystems services. Understanding trophic interactions, such as between plants and herbivorous insects and ecosystem functioning, represent an important cognitive knowledge base for increasing awareness of their local environment and conserving their natural habitats. We are encouraging scientists in biodiversity research to share their expertise and participate actively, collaborating with local biological education programmes, to increase essential knowledge in ecology and promote awareness about ecosystem conservation (see Ghimire et al. 2014). Both the French and Ethiopian institutions, local tourist committee and the French international education network AEFE confirmed the importance of environmental education and public outreach in places where natural ecosystems are most perturbed and at risk, such as in remote areas of Eastern Africa. We conclude the programme with a reminder that forest ecosystems in Ethiopia are of exceptional importance and deserve to be protected for future generations.

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Supplementary material 1

Supplementary figures

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