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Climate change and topography as drivers of Latin American biome dynamics

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ACKNOWLEDGEMENTS

ACKNOWLEDGEMENTS

One of the most rewarding responsibilities in writing this thesis has been to look back and remember all those special people and moments that were in my life during the last five years. The rewarding part has to do with having the opportunity to acknowledge them and express my gratitude for helping me in 'getting the job done'. The great responsibility is, then, to remember and to include all those who helped me accomplish what I have attained today.

In doing so, I thank the many of you who are reading these acknowledgements and have stayed along my side, for keeping up with my long hours behind the computer, and for understanding that a passion driven project is not a nine-to-five job. Special thanks are meant as well for all those people who have shared moments with me during conferences, fieldtrips, music and sports; and for those who have inspired me to be in science thus being able to make a contribution in making this world a better place for all of us.

Without a doubt, I dedicate this thesis to my supervisor, Henry Hooghiemstra. You have motivated me since I was a Master's student. Your classes were the reason I left the University of Groningen to come and study at the University of Amsterdam. Our first collaboration during my Master already resulted in a publication thanks to your support. Even when I had long disappeared to Venezuela and Colombia after finishing my Master's Degree, you kept our communication lines open waiting patiently for me to decide when I would be ready for a PhD. You probably knew all along that it was a matter of time for me to be convinced, but I thank you dearly for maintaining the faith that we would again engage in a long-term project. I look back with great pleasure to our year of working together on the proposal, our first 'ping-pong' session, after you had made it very clear that you needed my final decision before you would run out of funding possibilities. We submitted our proposal in February 2012 and hoped for the best as we knew that the chances to get funding from NWO were considered very low. Therefore, in April you proposed that even if we would not get funded, I should and could already start working by other financial means you had figured out yourself. And so I did in September 2012. In November, and by a bit unusual way, we found out that we got fully funded when a colleague asked you for advice as to how you got your NWO proposal ranked number 1 of all proposals!! At that time I was in Colombia accompanied by Elkin Posada (my paranymp) and his family, and we remember vividly the happy moment in receiving that email. Thanks to your faith in the project we had already started working for what was to become a great four years major undertaking.

I want to give you special thanks for believing that I could handle a PhD while being mostly in South America acting on my professional and academic activities; for always giving me time and space to develop myself; for supporting several of the crazy ideas to engage in

unplanned publications and trips; and also for indicating to me during our trip in Brazil in 2013 that my communication should be improved. You showed me how important it has been to maintain a high quality communication in handling any issue that arose, which we did quite smoothly during the last years. It was absolutely great to travel to Ecuador and Peru with you, and I appreciate how you accepted Elizabeth to come along, how you quietly endured sitting in the backseat of the car while curving around all those steep cliffs, and how you gave me the opportunity to plan the trip and be able to celebrate your birthday, as a surprise to you, at Chachapoyas, Leymebamba and Kuelap. Hopefully many more fieldtrips will come in the future as well as ongoing collaborations!

Elkin F. Posada, Paronymph

Our friendship at the beginning of my PhD has been life changing ever since and a gift every single day since we met. You taught me how to be the best of me and more, how to stay at the top of productivity while also recognizing my limits, and how to face challenges while always staying a healthy and happy person. Thank you for your continuous support, your everlasting advices, your patience, your dedication and help to stay in the present moment, while removing distractions from priorities. It's an honor and a great pleasure to have you along my side.

Wendy Veerman, Paronymph

The longest lasting friendship I have also accompanied me during the entire PhD. Our weekends out to different places around the Netherlands were a welcome intermezzo to my work (sorry for cancelling some of them due to....work). Our long talks about life, people, challenges and a lot of laughter characterize our friendship and keep our contact always special and with an amazing interchange of ideas and deepening thoughts. Thank you for being here again at a very special day, for coping with my many saying-goodbye-and-back-again's and for always checking how I am doing during long distance calls. Happy to have you here for the next exciting times to come!

A special word of thanks to my family and friends in the Netherlands who are always there to support me, keeping in touch to find out how I am doing to make sure I don't work "too hard". I want to thank my Mom, my 'über-paronymph', who has given me endless support and understanding for my passion for science, taking every opportunity to let me know how proud she is of my achievements and progress. It was great to have you and Henk in Colombia with me travelling around the country you have known from years ago. I admire your sparkling energy, desire to enjoy every single day in the best possible way, and for climbing impossible mountains by bike, and I thank you for that energy that has always inspired me to be the best I can. Ook wil ik Yvonne en Roy bedanken dat jullie altijd interesse tonen, voor de gezellige lunchafspraken bij jullie thuis en voor de kadootjes die altijd voor me klaarliggen. Ik hoop dat dit proefschrift een inspiratie zal zijn voor mijn broer Marcel om een droom in vervulling te zien gaan waar je lang en hard voor moet werken,

maar met kleine stapjes gedaan krijgt. En mijn lieve oma, ik ben een zeer gelukkig kleinkind dat u bij de speciale dag van mijn promotie aanwezig zult zijn om te kunnen laten zien waar ik zoveel jaren zo hard mee bezig ben geweest. Het was altijd heel fijn om terug te komen uit Colombia en bij u aan te kunnen kloppen, want soms voelde Zuid-Amerika heel ver! And now, I want to express in a very special way my gratitude to my Daddy for always being around to help me out, for joining me frequently at the university for lunches, and for keeping our contact so active. Having you come over to Colombia gave us the excellent opportunity to share much more and to meet the many people you had heard about but never met personally. I enjoy having you nearby.

Ted & Len Compier, Paito & Thomas van Hengstum, and Marion Vink are those kind of friends that I will appreciate forever because I feel them always with me although I am not much around. Ted & Len, altijd vragend wanneer ik weer naar de camping kom, of ik nog wat nodig heb, altijd proberend te begrijpen waar ik nu weer naartoe ben gereisd. De 28ste is een blijvertje, XS. Paito & Thomasito, een voorbeeld van het mooiste stel ter wereld. Ik kom veel te weinig langs, maar ik geniet er altijd heel veel van als we weer bij elkaar zijn. Y Marion, con frecuencia recuerdo nuestras aventuras en Venezuela y la Gran Sabana. Me alegra mucho verte feliz, aterrizada en Holanda (no en Pakistan), y con un niño tan tremendamente guapo. Mujer guerrera eres, siempre pa'delante para una vida mejor. Feliz por haberte conocido y tenerte conmigo!

A large part of my PhD I spent in Colombia where I enjoyed the peacefulness of working at home with a great view over Bogotá. Some amazing friends made sure I left my place regularly, taking me out for coffees, lunches and nice trips. Catalina González, not only a much appreciated co-author, but foremost a dear friend. Working together has always been a great pleasure and you are among the first to visit when I get back to Colombia. Elizabeth Aguilera, 'hermana', thank you for the great weekends at the finca, I can't wait to see it ready for long sleepovers. Inviting you to come with me and Henry to Ecuador and Peru was the best decision ever. You were always the one to jump out of the car first, making sure we had a place to sleep and to eat, and a beer for Henry. I really hope that we will make another fieldtrip somewhere soon!

Other very special friends I had in Bogotá for many years were 'Patty' Franco and Alberto Mendoza. You know much of my history in the country and the many people I have met and shared my life with, and that makes our friendship so special. I always enjoyed our very long conversations and thank you for making me feel part of the family.

My work experience in South America has expanded in an exceptional way thanks to Milton Romero. Working with you in different projects has provided me important insights into many different fields of research in the Neotropics, making my overall profile very versatile while also fulfilling my eagerness to broaden my background knowledge on the tropics.

Thank you for everything you have shared with me and for motivating me in becoming an excellent 'GIS-er', and to share and confirm in me with your experience the important philosophy in producing the highest quality outcomes and in always giving more than one is asked for. Not only was working together very easy and always felt very natural, but you played an important role in my life in Colombia as a very dear friend. Always ready to help me out, to hear how I was doing while inviting me generously to be part of your professional and family life. Many good times we shared and beautiful memories always remain. And thanks to you, I met Olgalú Hernández and Nicolás Giménez who welcomed me to be part of the "animal family" and with whom spending New Year's eve in the mountains of Villa de Leyva was a unique experience. Working with Olgalú was always accompanied with immense hilarity and I recall numerous times we cried with laughter. Thank you for those great times, abrazo para los dos.

The group at IBED has always giving me warm surroundings for work, interested in my whereabouts, asking when I would come back, and making me part of new things to come. Will Gosling, Frank Hammecher, Bas van Geel, Joost Duivenvoorden, Thijs de Boer, Gerard Oostermeijer, Emiel van Loon, Judy Shamoun-Baranes, and Harry Seijmonsbergen just make it immensely fun and inspiring to be at IBED. John van Boxel has been involved in many undertakings since my Master's Degree. Thank you for your critical review of my work, always filtering out the many unnoticed details. You had an important share in IBED's advances for the LAPD and it would be great to keep that effort going. I owe quite a lot to the always very helpful ladies at the secretary, Tanya Noorlander, Maria Dolorita and Mary Parra. You helped me plan many trips and specifically, your help to have me live in a proper house to finish my PhD has been an immense gift from heaven. A special thanks goes to Divyam Steveker for helping me out with the many questions I had concerning the budget, for moving items around to cover all designated purposes, and also for supporting my effort in making sure that the final euros of the project would be spend (although I think that at the end we both were happy the project had finished!).

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From another research group in Europe, I would like to give a special word to Alexandre Antonelli for the very interesting, insightful and inspiring experience while working together, and for giving me the opportunity to get to know his group in Sweden. One of the things I have to thank for is the confidence and certainty I learnt from you at aiming at the highest journals. You also gather an amazing group of people around you, each one of them great scientists and 'one of a kind' people. Meeting Laura Lagomarsino, Christine Bacon, Daniele Silvestro, and Alexander Zizka has been great, and working with Allison Perrigo was an immense pleasure! What a dream team! Hopefully in the future we will all meet and work again.

During the thesis I have been fortunate to be accompanied by many researchers with whom I established common grounds in shared publications. I want to thank each one of them for being my co-authors in the publications that are now bundled in this thesis. It has been a great experience to be leading papers, but it was foremost a pleasure to learn from the unique contribution that each single co-author made. Thank you for what you have shared, for being part of my thesis, and I hope that we will again meet in future papers and exciting collaborations.

During and even from before my PhD, the Neotoma community had welcomed me in a very special way to be part of a global effort to gather paleo-data. Not only have I learned a lot by working together and did I enjoy immensely the meetings, but it was also great to feel supported in my work by so many enthusiastic and leading researchers in their field:

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In closing, I want to share my gratefulness to the Universe for putting in my path the great people who made me who I am today...:

'...quasi nanos, gigantium humeris insidentes, ut possimus plura eis et remotiora videre, non utique proprii visus acumine, aut eminentia corporis, sed quia in altum subvenimur et extollimur magnitudine gigantean.'

John of Salisbury, Metalogicon (1159)

...we are as dwarfs sitting on the shoulders of giants, so that we can see more things than they, and things at a greater distance, not at any rate by virtue of sharpness of sight on our part, or any physical excellence, but because we are assisted and lifted up by their giant size'

So... always make sure you choose your giants wisely!

Suzette G.A. Flantua

April 28th, 2017

CO-AUTHORSHIP STATEMENT

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The following people contributed to the publication of work undertaken as part of this thesis (their current institution and the number of publications they contributed to):

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- Name and institution* = **Henry Hooghiemstra, University of Amsterdam. (8)**
- Name and institution* = **John Van Boxel, University of Amsterdam. (3)**
- Name and institution* = **Catalina González-Arango, Universidad Los Andes. (3)**
- Name and institution* = **Valentí Rull, Institute of Earth Sciences Jaume Almera.(2)**
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Chapter 2: Flantua, S.G.A.¹, Hooghiemstra², H., Grimm³, E.C., Behling⁴, H., Bush⁵, M.B., González-Arango⁶, C., Gosling⁷, W.D., Ledru⁸, M.-P., Lozano-García, S.⁹, Maldonado, A.¹⁰, Prieto, A.R.¹¹, Rull, V.¹², Van Boxel, J.H.¹³, 2015. Updated site compilation of the Latin American Pollen Database. *Review of Palaeobotany and Palynology* 223, 104–115.

The candidate, author 2 and author 13 were the primary authors. The candidate undertook the data collection and assessments, and the writing of the initial drafts of the manuscript to which author 2 and 13 provided comments. Author 4-12 provided feedback on the advanced versions of the manuscript. Author 3 revised and improved the English before publication.

Chapter 3: Flantua, S.G.A.¹, Blaauw, M.², Hooghiemstra, H.³, 2016. Geochronological database and classification system for age uncertainties in Neotropical pollen records. *Climate of the Past* 12, 387–414.

The candidate was the primary author. Author 2 and author 3 contributed to the idea. The candidate created the geochronological database and did all age model processing, and made adjustments to the R scripts for the purpose of this paper. Author 2 contributed with the R scripts developed from a previous paper and adjusted formats. The candidate did the main writing while Author 2 and 3 contributed with comments to the manuscript.

Chapter 4: Flantua, S.G.A.¹, Hooghiemstra, H.², Vuille, M.³, Behling, H.⁴, Carson, J.F.⁵, Gosling, W.D.⁶, Hoyos, I.⁷, Ledru, M.P.⁸, Montoya, E.⁹, Mayle, F.¹⁰, Maldonado, A.¹¹, Rull, V.¹², Tonello, M.S.¹³, Whitney, B.S.¹⁴, González-Arango, C.¹⁵, 2016. Climate variability and human impact in South America during the last 2000 years: synthesis and perspectives from pollen records. *Climate of the Past* 12, 483–523.

The candidate, authors 2 and 14 were the primary authors and conceived the idea of the paper. Author 3 prepared the section on climate, performed the data analysis and produced Figures 1-5. Authors 4-15 each provided a section on their region of specialization. The candidate coordinated all contributions performing quality control and consistency checks. Figures 6-13 were prepared between the candidate and Author 15. Authors 3, 6 and 14 improved the English before submission. Authors 3 and 14 made important contributions to the comments to reviewers.

Chapter 5: Flantua, S.G.A.¹, Van Boxel, J.H.², Hooghiemstra, H.³, Van Smaalen, J.⁴, 2007. Application of GIS and logistic regression to fossil pollen data in modelling present and past spatial distribution of the Colombian savanna. *Climate Dynamics* 29, 697–712.

This paper was part of the Candidate's master project called: "Modeling the spatial distribution of the Colombian savannas: Los llanos Orientales". The initial idea for this project was proposed by Author 3. The candidate undertook the processing and analysis of the data, and author 4 provided GIS assistance. Authors 3 and 2 contributed meaningful comments to the master report and proposed the re-writing of the report to a manuscript. Draft writing was undertaken by the candidate after all authors revised before submission. Author 2 contributed editorial assistance during the process of the manuscript submission to the journal.

Chapter 6: Flantua, S.G.A.¹, Hooghiemstra, H.², Van Boxel, J.H.³, Cabrera, M.⁴, González-Carranza, Z.⁵, González-Arango, C.⁶, 2014. Connectivity dynamics since the Last Glacial Maximum in the Northern Andes; a pollen-driven framework to assess potential migration. Monographs in Systematic Botany from the Missouri Botanical Garden, 128, 98-123. In: W.D. Stevens, O.M. Montiel & P.H. Raven (Eds.), Paleobotany and biogeography: a festschrift for Alan Graham in his 80th year. St. Louis: Missouri Botanical Garden Press.

The candidate, author 2 and author 3 were the primary authors. The candidate performed the data recollection and analysis, and presented the initial drafts of the manuscript. Author 4 dedicated her master thesis to an initial try-out of the idea. Author 5 provided pollen data. Authors 2, 3 and 6 provided feedback to the manuscript.

Chapter 7: Flantua, S.G.A.¹, Hooghiemstra, H.², 2017. Historical connectivity and mountain diversity. C. Hoorn, A. Perrigo and A. Antonelli (Eds.), Wiley.

The candidate and author 2 jointly conceived the idea. The candidate prepared drafts of the manuscript and figures, and author 2 provided feedback for improvements.

Chapter 8: Antonelli, A.¹, Kissling, W.D.², Flantua, S.G.A.³, Bermúdez, M.A.⁴, Mulch, A.⁵, Muellner-Riehl, A.N.⁶, Kreft, H.⁷, Linder, H.P.⁸, Badgley, C.⁹, Fjeldså, J.¹⁰, Fritz, S.A.¹¹, Rahbek, C.¹², Herman, F.¹³, Hooghiemstra, H.¹⁴, Hoorn, C.¹⁵. *In review.* **Geological and climatic determinants of mountain biodiversity.** Nature Geoscience.

Authors 1, 2, 4, 15 and the candidate share first authorship by leading the initiative and preparing the main body of the manuscripts. Additionally, the candidate performed the database compilation and analysis, authors 1 and 15 did the coordinating and networking, and author 2 performed the statistical analysis. Authors 4 and 13 provided the geological database. Author 10 provided the species richness database. Authors 5, 6, 7, 8, 9, 12, 13 provided additional feedback to the manuscript.

Chapter 9: Flantua, S.G.A.¹, Hooghiemstra, H.² Unravelling the mountain fingerprint: topography, paleoclimate and connectivity as drivers of contemporary biodiversity patterns in the Northern Andes

The candidate and author 2 both conceived the idea. The candidate did the manuscript writing and figure design, and author 2 provided feedback for improvements.

BIOGRAPHICAL SKETCH

BIOGRAPHICAL SKETCH



The author was born in San José, Costa Rica. She also lived in Nicaragua and Haiti, returning to the Netherlands at the age of 5. She attended high school in Utrecht after which she left for Colombia at the age of 18 to engage in voluntary work and learn Spanish. She graduated with a Bachelor in Biology at the University of Groningen in 2004, with a specialization in Marine Biology. She decided to expand her Bachelor with some extra courses at the University of

Amsterdam. After following Paleo-ecology and Tropical ecology, she switched to Amsterdam to initiate her degree in Masters there. She started to work with Henry Hooghiemstra and John Van Boxel in a Master project on analyzing fossil pollen records in GIS which resulted in her first scientific publication. During the second half of her Master she went to Venezuela to engage in a fieldwork project in the National Park of Canaima working with indigenous people. She finished her Master degree in Biological Sciences in 2008 and decided to stay in Venezuela to get more work experience and engaging in numerous fieldwork trips more. After several years in Venezuela she moved to Colombia. Much of her workexperience in GIS and remote sensing she obtained during the years that followed working for different companies and governmental institutes, publishing in a range of different topics. She expanded her interests to sustainable development, focusing on current climate change, spatial planning, risk assessments, and land use cover changes. While being in Colombia she started to work with the Latin American Pollen Database supported several times by funding from the Hugo de Vries Fonds. This formed the base to start the doctoral studies in 2012 at the University of Amsterdam.

Photo taken in the Sierra Nevada de Cocuy, Colombia - August 2014

LIST OF PUBLICATIONS

Published/accepted publications

- 1) **Flantua, S.G.A.**, Hooghiemstra, H. Historical connectivity and mountain biodiversity. In: Hoorn C., Perrigo, A., Antonelli A. (eds.), *Mountains, Climate and Biodiversity*. Wiley, In press.
- 2) Hoorn, C., Bogotá-Angel, G.R., Romero-Baez, M., Lammertsma, E.I., **Flantua, S.G.A.**, Dantas, E.I., Dino, R., do Carmo, D.A., Chemale Jr, F. The Amazon at sea: Onset and stages of the Amazon River from a marine record, with special reference to Neogene plant turnover in the drainage basin. *Global and Planetary Change*. In press.
- 3) **Flantua, S.G.A.**, Hooghiemstra, H., Vuille, M., Behling, H., Carson, J.F., Gosling, W.D., Hoyos, I., Ledru, M.P., Montoya, E., Mayle, F., Maldonado, A., Rull, V., Tonello, M.S., Whitney, B.S., González-Arango, C., 2016a. Climate variability and human impact in South America during the last 2000 years: synthesis and perspectives from pollen records. *Climate of the Past* 12, 483–523.
- 4) **Flantua, S.G.A.**, Blaauw, M., Hooghiemstra, H., 2016b. Geochronological database and classification system for age uncertainties in Neotropical pollen records. *Climate of the Past* 12, 387–414.
- 5) Salamanca, S.S., Van Soelen, E.E., Van Manen, M.L.T., **Flantua, S.G.A.**, Santos, R.V., Roddaz, M., Dantas, E.L., Van Loon, E., Sinninghe Damsté, J.S., Kim, J.H., Hoorn, C., 2016. Amazon forest dynamics under changing abiotic conditions in the early Miocene (Colombian Amazonia). *Journal of Biogeography* 14, 2424-2437.
- 6) **Flantua, S.G.A.**, Hooghiemstra, H., Grimm, E.C., Behling, H., Bush, M.B., González-Arango, C., Gosling, W.D., Ledru, M.-P., Lozano-García, S., Maldonado, A., Prieto, A.R., Rull, V., Van Boxel, J.H., 2015. Updated site compilation of the Latin American Pollen Database. *Review of Palaeobotany and Palynology* 223, 104–115.
- 7) Hoorn, H., **Flantua, S.G.A.** 2015. An early start for the Panama land bridge. *Science* 348 (6231): 186-187. Review of 'Middle Miocene closure of the Central American Seaway' [*Science* 348: 226-229; 2015].
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TRAINING AND EDUCATION

International symposia and conferences

- ABEQUA congress - 2nd LaACER: Latin-American Abrupt Climate Changes and Environmental Responses. Natal, Brazil. Presentation. (2013)
- Royal Geographical Society - IBG Annual International Conference. London, UK. Presentation. (2013)
- Netherlands Earth Sciences Congress XII (NAC12). Veldhoven, The Netherlands. Presentation. (2014)
- 4th meeting of the Network for Neotropical Biogeography. Panama City, Panama. Poster. (2015)
- International Biogeography Society 7th Biennial Meeting, Bayreuth, Germany. Presentation. (2015)
- XIX INQUA Congress - Quaternary perspectives on climate change, natural hazards and civilization. Nagoya, Japan. Presentation. (2015)
- GTÖ Congress Tropical diversity, ecology and land use. Göttingen, Germany. Presentation and Poster. (2016)
- Annual meeting of the Association for the Tropical Biology and Conservation. Montpellier, France. Presentation. (2016)
- II International Conference on Island Evolution, Ecology, and Conservation. Azores, Portugal. Presentation. (2016)
- ESRI GIS Conference. Rotterdam, The Netherlands. (2016)
- 8th Biennial Conference of the International Biogeography Society. Tucson, USA. (2017)

Competence strengthening / skills courses

- Complex dynamics in human-environment systems; SENSE (2013)
- English academic writing; University of Amsterdam (2013)
- Time and Project management; Wageningen University (2013)
- Tools for analyzing landscape connectivity: methods and applications; Universidad Politécnica de Madrid (2013)
- Modelling and mapping species distribution; University of Amsterdam (2013)
- The Data Scientist's Toolbox. Coursera (2014)
- Analyses and visualization of spatial data in R. Network for Neotropical Biogeography congress (2015)
- Advanced Grant Writing and Proposal Development, University of Amsterdam (2016)

Workgroup meetings and workshops

- International PAGES workgroup. LaAcer I Millennial scale climate variability over the last glacial period in tropical and subtropical America (2012)
- Harmonization of Database Chronologies; ACER-INTIMATE joint workshop (2012)
- Age Models, Chronologies, and Databases Workshop (2014)

- The Antonelli Lab meeting – Evolution and biogeography with focus on the Neotropics (2014)
- Cross-disciplinary Palaeo-Environmental Research Training (XPRT) network - Summer school and fieldwork (2015)
- Palaeoecological and remote sensing discipline-bridging workshop (2015)
- PAGES Landcover mapping 6k workshop on pollen-vegetation mapping techniques, REVEALS, LOVE and modelling anthropogenic land-cover changes (2015)
- Neotoma Paleocommunity Database workshop (2010, 2011,2016)
- European Pollen Database meeting and workshops (2016)
- LandCover6k Workshop (2016)

Lecturing / supervision of practical / fieldwork in courses

- Bachelor course Biodiversity & Global Change (2014, 2015, 2016)
- Paleoecology (2014, 2015, 2016)
- Pre-congress training course for young scientists LOTRED – South American (2014)

Supervision of students

- Connectivity and isolation in the Puna of Peru and Bolivia and its effect on species distribution; Anna Schwarz (2014)
- Population dynamics and choice of settlement in Peru from carbon-14 dated archaeological sites; Jesse Zondervan (2016)
- Summer internship on literature compilation and review of the Latin American Pollen Database; Seringe Huisman, Mayke Nieuwkerk, Nina Witteveen, Johnny Vogel (2016)

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