School of Doctoral Studies in Biological Sciences

University of South Bohemia in České Budějovice

Faculty of Science

Environmental and socio-cultural determinants of language skills and ethnobiological knowledge in Papua New Guinea and Cameroon

Ph.D. Thesis

Alfred Kik MSc.

Supervisor: RNDr. Pavel Duda, Ph.D.

Department of Zoology, Faculty of Science, University of South Bohemia in České Budějovice

Consultant: Prof. RNDr. Vojtěch Novotný, CSc.

Department of Zoology, Faculty of Science, University of South Bohemia in České Budějovice

Institute of Entomology, Biology Centre of the Czech Academy of Sciences

České Budějovice 2023

This thesis should be cited as:

Kik, A. (2023). Environmental and socio-cultural determinants of language skills and ethnobiological knowledge in Papua New Guinea and Cameroon. University of South Bohemia, Faculty of Science, School of Doctoral Studies in Biological Sciences, České Budějovice, Czech Republic, 205 pp.

Annotation

This thesis investigates the current state of language skills and ethnobiological knowledge of young, educated population cohort in Papua New Guinea (PNG) and Cameroon, parts of the two largest linguistic diversity hotspots: Papuan and Central African one. First, language skills and bird and plant knowledge of secondary school students in PNG were measured. Language skills of students and parents were compared in order to determine the extent of intergenerational language loss. Additionally, the socioeconomic drivers of the loss of language skills and ethnobiological knowledge were determined, and their future trends were modeled. Next, the state of students' hunting skills was investigated and implications for conservation were discussed, given the importance of hunting for conservation in PNG. Another topic this thesis focuses on is how big languages in PNG cope with the rapid lifestyle changes. To this end, the language skills and ethnobiological knowledge of Melpa-speaking students were analyzed in detail. Finally, the language skills and ethnobiological knowledge of young Cameroonians were measured using the same methods and the results were compared to those from PNG.

Declaration

I hereby declare that I am the author of this dissertation and that I have used only those sources and literature detailed in the list of references.

České Budějovice, 10th of November 2023

....

Alfred Kik

This thesis originated from a partnership of Faculty of Science, University of South Bohemia, and Institute of Entomology, Biology Centre CAS, supporting doctoral studies in the Entomology study program.

Přírodovědecká fakulta
Faculty of Science

BIOLOGICKÉ CENTRUM
AV ČR, v. v. i.

Financial support

AK and the works presented in this thesis were financially supported by the Czech Science Foundation, Grant/Award Number: 18-23889S; the European Research Council, Grant/Award Number: 669609; The Christensen Fund, Grant/Award Number: 2017-10237; The Darwin Initiative for the Survival of the Species Grant/Award Number: DIR25S1\100123; and the New Guinea Binatang Research Centre.

Acknowledgments

This work would not have been possible without the invaluably efficient and topnotch supervising of Dr. Pavel Duda and prof. Vojtěch Novotný. Their excellent ideas, guidance, and support by way of questions, comments and insights have not only made me to think more clearly, organize better and aim higher, but also improved greatly the scope of the manuscripts and the thesis. Thank you very much! Thanks to prof. Jan Zrzavý for securing part of the funds for this study.

Thanks to prof. Paige West for allowing me to use her lab during my stay at Columbia University. I am indebted to the provincial education advisors, principals, teachers and students of numerous secondary schools in PNG and Cameroon who participated in the survey. Equal gratitude goes to the management and staff of New Guinea Binatang Research Center for logistic and administrative support during the course of my data collection and data entry. I also recognize the invaluable support and guidance from my co-authors and external collaborators. I thank prof. Rodrigo Cámara Leret and Juan C. Copete for the inclusion of our co-authored paper in my thesis as an appendix.

Prof. Radim Šumbera, chairman of the specialist board of the Ph.D. study programme Zoology, and Petra Korcová from Students Affairs department, were always helpful and kind. I owe a debt of gratitude to Jarmila Bajzeková for her outstanding data curation abilities, which greatly helped my data analysis and manuscript writing. Not to mention her wonderful sense of humor and engaging conversations, which enhanced a positive work environment in the office we shared.

Thanks to my current and former colleagues from the Zoology department and Biology Center: Pagi Toko, Sentiko Ibalim, Heveakore Maraia, Pita. K. Amick, Jimmy Moses, Amelia. J. Philip, Gabriel Petuel, Gibson Aubona, Daniel Okena, Kari Lamba, Legi Sam, Petr Klimeš, Martin Libra, Phil Butterill, Gabriel Saffa, and others, too many to mention. Thanks to the miracle ladies: Eva Chocholová, Klára Aurová, Hanka Butterill, Hana

Konvičková, and Michaela Borovanská for the logistics and administrative support throughout my study program. Not forgetting my BC Canteen lunch team members, namely: Jarmila Bajzeková, Iveta Bláhová, Andrea Weberová, Jitka Jančúchová Lásková and others, for their kind and stimulating atmosphere during my studies.

I would not have come this far without the unshakeable love, support and patience of my wife Kerin Koi, our sons Ezekiel Erewei, Fredrickiel Kiapulga and Katep Dupai, my parents Paula Kuk, Anna Dupai, Maggie Rauna, Ranu Brian Ta, Wan Koi, Kik Etapana and Koi Ranpi and my siblings Jenny Issac, Mariah Dupai, Susan Dupai, Alice Kik, Mathew Kik, Esther Polye, Stephanie Mathew, Seth Dum, Vincent Kik, Andy Kik, Daniel Dom Raim, Elijah Kewa, Philip Pil, Masta Issac Gandil and others. I thank them dearly. Finally, I thank the good Lord in Heaven for His goodness in my life.

List of papers, manuscripts and author's contribution

The thesis is based on the following papers and manuscripts:

Chapter I

Kik, A., Adamec, M., Aikhenvald, Y. A., Bajzekova, J., Baro, N., Bowern, C., Colwell, K. R., Drozd, P., Duda, P., Ibalim, S., Jorge, R. L., Mogina, J., Ruli, B., Sam, K., Sarvasy, H., Saulei, S., Weiblen, D.W., Zrzavy, J., & Novotny, V. (2021). Language and ethnobiological skills decline precipitously in Papua New Guinea, the world's most linguistically diverse nation. *Proceedings of the National Academy of Sciences* **(IF: 12.779)**. https://doi.org/10.1073/pnas.2100096118

AK conceptualized the study (50 %), participated in the data collection (80 %), contributed to data curation and analysis (40 %), contributed to preparing figures and tables (20 %), and contributed to the writing of the manuscript (60 %).

Chapter II

Kik, A., Duda, P., Bajzekova, J., Baro, N., Opasa, R., Sosanika, G., Jorge, R. L., West, P., Sam, K., Zrzavy, J., & Novotny, V. (2023). Hunting skills and ethnobiological knowledge among the young, educated Papua New Guineans: Implications for conservation. *Global Ecology and Conservation* **(IF: 3.97)**. https://doi.org/10.1016/j.gecco.2023.e02435

AK conceptualized (50 %) and participated in the data collection (80 %), performed data analysis (95 %), prepared the figures and tables (100 %) and led the writing of the manuscript (90 %).

Chapter III

Kik, A., Duda, P., Bajzekova, J., Kama, K., Jorge, R. L., & Novotny, V. Language skills and ethnobiological knowledge in the young and educated Indigenous Melpa speakers in Papua New Guinea. *Journal of Ethnobiology* (Manuscript pending minor review) **(IF = 2.9)**.

AK conceptualized the study (50 %), participated in the data collection (80 %), performed data analysis (90%), prepared the figures and tables (90 %), and led the writing of the manuscript (90 %).

Chapter IV

Kik, A., Neku, N.A., D, Ewome, L. F., Jorge, R. L., Hodieb, L., Good, J., Bajzekova J., Albrecht, T., Sam, K., Aikhenvald, Y. A., Drozd, P., Duda, P., Sarvasy, H., & Novotny, V. Parallel drivers of decline in language skills and ethnobiological knowledge in two prominent linguistic hotspots: West Africa and New Guinea. *Manuscript.*

AK conceptualized the study (50 %), participated in the data collection (50 %), contributed to data curation and analysis (30 %), contributed to preparing figures and tables (10 %), and contributed to the writing of the manuscript (50 %).

Co-author agreement

Pavel Duda, the supervisor of this Ph. D. thesis and co-author in chapters I, II, III & IV, fully acknowledges the major contribution of Alfred Kik to these manuscripts.

....

RNDr. Pavel Duda, PhD

Vojtěch Novotný, the co-supervisor of this Ph.D. thesis and senior author of chapters I, II, III & IV, fully acknowledges the major contribution of Alfred Kik to these manuscripts.

....

prof. RNDr. Vojtěch Novotný, CSc.

Table of Contents

GENERAL INTRODUCTION

Language diversity distribution and endangerment

Approximately 7000 different languages spoken across the world today are geographically highly unevenly distributed as language diversity peaks in the tropics and declines with increasing latitude. Further, most languages are spoken by a small number of speakers so that about 10 % of the world's population speaks about 90% of the world's languages (Simons & Lewis, 2013). Analogous to 'Rapoport's rule' of the distribution of plant and animal species, where geographic range size of species increases with increasing latitude, language geographic range sizes in the tropics are smallest in the tropics and this is exacerbated by the fact that language geographic ranges generally do not overlap. This situation puts languages in linguistically diverse areas at a higher risk of extinction as threats to indigenous languages worldwide increase at an unprecedented rate (Amano et al., 2014). A language is considered endangered when its speakers cease to use it or they use it across an increasingly smaller number of communicative domains, or when the children in a community are spoken to in a language other than the parents' language (Rogers & Campbell, 2015). Several authors have categorized levels of language endangerment (e.g., Krauss, 1992; Moseley, 2010; Simons & Lewis, 2013).

While languages can differentiate and evolve into new languages rapidly, over the time scale of thousands of years (Bakker, 2000; Greenhill et al., 2010), the current language extinction rate is much higher, exceeding the well documented loss of biodiversity (Sutherland, 2003). A general consensus is that about half of the world's languages are under threat (Austin & Sallabank, 2011; Campbell & Belew, 2018; Eberhard et al., 2019; Moseley, 2010; Rehg & Campbell, 2018; Sutherland, 2003), and these include a majority of languages in the tropics (Figure 1). The most pessimistic prediction states that 90% of the total global languages will become extinct of moribund by the end of the 21st century (Krauss, 1992). A more recent study (Bromham et al., 2022) proposes somewhat less alarming, but still concerning scenario, that language extinction rate will triple within the next 40 years, with at least one language lost per month, and about 20% of all languages will become extinct by the end of the century, unless effective measures are taken. This estimate is somewhat lower than that of Rogers and Campbell's (2015), who claim that one language disappears every 3.5 months. Regardless of quantitative differences in these assessments, there is no doubt that language diversity is in serious danger and that small languages in the tropics are particularly vulnerable.

This impending loss of indigenous languages has drawn the attention of not only linguists and anthropologists but also various international organizations and projects such as the National Geographic (the Enduring Voices Project); Endangered Languages Project; the International Union for Conservation of Nature (IUCN); and the United Nations Educational, Scientific and Cultural Organization (UNESCO). UNESCO, for instance, declared the UN International Decade of Indigenous Languages in 2022 as an initiative to protect, revitalize and promote the indigenous languages that are falling out of use. While these organizations develop strategies and undertake efforts to address the demise of languages, it is critical to understand the cause and consequences of language loss, examining individual languages and their speakers.

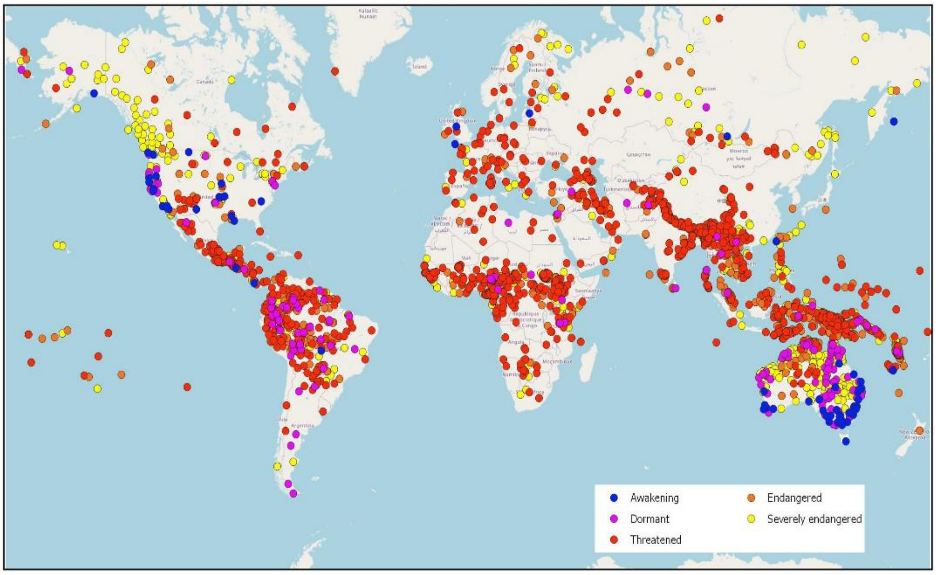


Figure 1. Languages under threat: Locations of 3006 languages rated as awakening, dormant, threatened, endangered, and severely endangered. The map was generated using data downloaded from Endangered Languages Project (endangeredlanguages.com).

The importance of language and traditional ethnobiological knowledge

As language preservation advocates, both individuals and organizations, increasingly focus their attention to the endangerment and looming extinction of most of the world's small languages, one may ask why considering the loss of native languages should be considered a tragedy if their indigenous speakers want to abandon these languages and join the modern world by shifting to more widespread languages? According to some views, it may be seen as a pointless waste of time and resources trying to save a language that is not supported by its own speakers (Agwuele, 2010). However, language loss has serious consequences for the traditional ethnobiological and cultural knowledge, and since each language is unique it can also be considered a loss for science and humanity in general.

Languages are links to the cultural past, and form part of their speakers' identity as they are a primary tool for expression and communication that shape much of their social and cognitive lives (Rogers & Campbell, 2015). Individuals having high regard of their cultural identities should insure the protection and survival of the language and therefore language diversity (Levy, 2005). Equally important are the roles languages play as carriers of environmental and biocultural knowledge. Thus, a loss of a language is a loss of unique knowledge that is specific to a given place and time, that has been developing over generations through experimentation, adaptation, and coevolution (Chaudhary et al., 2017; Vliet et al., 2022). It would have significant repercussions on people's quality of life as well as the environment in which they live, including a decline in environmental management skills and knowledge.

Additionally, the loss of language may compromise the benefits of integrating traditional and scientific knowledge in bioprospecting, in solving the current biodiversity crisis, and in community-level environmental disaster risk reduction measures, including climate change (Copete et al., 2023; Ogar et al., 2020; Ray, 2023; Turner et al., 2022; Wang et al., 2019). To involve indigenous people in research may be a way forward to curb the loss of language skills and ethnobiological knowledge while also studying local biological and cultural diversity more efficiently (Copete et al., 2023). Interestingly, maintaining traditional biocultural knowledge could also help maintain language diversity and biodiversity. Sustaining native languages and customs may be achieved by strengthening and supporting indigenous or local groups who take the initiative to create their own programs for maintaining and protecting rare species in their lands and waters (Wilder et al., 2016).

The survival of languages and ethnobiological knowledge very much depends on the changing socioeconomic pressures (Bromham et al. 2020; 2022) as well as the attitudes of the speaker populations. This entails peoples of various socioeconomic status, living in different environments from urban areas to agricultural landscapes, not only in remote rainforest areas, as is the common perception (Reyes-García et al., 2013). Additionally, connecting children to the natural world through traditional knowledge conveyed in indigenous language is critical to conserving the biosphere because childhood experiences with nature motivate later conservation efforts (Ives et al., 2018). Thus, it is critical to understand the drivers of language loss and the attitudes of speakers towards their native languages to determine the alarming rate of language loss and ethnobiological knowledge.

Drivers of language loss

Numerous studies have been conducted to examine the causes of language loss on a global, regional, and local level. These studies either examine the properties of the entire languages, such as their population size, geographic location, economic or education systems, or investigate individual members within language populations, including their cultural, social and economic circumstances. There are studies that examine how environmental and socioeconomic factors drive language range size or speaker population size at the global level (Amano et al., 2014; Axelsen & Manrubia, 2014; Currie & Mace, 2009; Hua et al., 2019). These studies provide analyses of factors leading to language vulnerability and model patterns of current and future language endangerment (Bromham et al., 2022), but they also examine how socioeconomic factors affect language skills among young people in different regions of the world (Kik et al., 2021; Kik et al., in rev. a).The global predictors of language loss may be modified by important factors of language vitality at the regional and local levels which are subject to specific social, demographic, and political pressures (Bromham et al., 2020). The major universal key drivers of language loss include economic growth, higher road density, years of schooling, urbanization, language use at home, and mixed marriages.

All these socioeconomic factors influence each other. Economic development leads to changes of lifestyle by increasing employment, supporting the development of infrastructure including road and rail networks, which, coupled with increasing urbanization, causes people from different cultures to leave their natal communities and migrate to towns and cities in search of a better life. They then have to adapt to ways of life that are different from their rural settings and learn to speak a language that allows them to communicate with one another. The multi-cultural urbanized society includes schools and workplaces where languages of wider communication are used. Moreover, these environments provide an avenue for intermarriage resulting in increased share of linguistically mixed families – an important component of impending language shift (Cheng, 2003; Kik et al., 2021). These interconnected changes generate parallel correlations between the loss of language and urbanization, formal education, employment, intermarriage as well as economic status (Bromham et al., 2020).

Language attitude

When predicting language shift and endangerment, the community's relationship with the language used by its members is crucial (Grenoble & Whaley, 1998). One of the factors that contributes to language endangerment in indigenous communities is what language parents decide to teach their children – either their indigenous language, or some language of wider communication. Learning some of the world's most widely spoken language can help the child in education and aid in finding a job and launching a successful career (Rao, 2019). For this reason, many parents are against formal education in small indigenous languages (Troolin, 2013). Languages of wider communication are usually disproportionately used in areas such as administration, politics and legislation. Finally, in the age of internet, these languages, English in particular, provide access to information and thus are considered desirable by the young generation (McKay, 2012). As a result, the underprivileged minority languages, while they may be continuously used locally in rural settings, are becoming a burden for career and social aspirations. This may even lead to people distancing from their languages in order to distance themselves from negative stereotypes of being culturally backward or unsophisticated (Tsunoda, 2006). In some situations, particularly in urban settings, indigenous language may be even a safety concern in case there are tribal rivalries between speakers of different languages back in the place of their origin, as is sometimes the case in Papua New Guinea (PNG).

Some countries have language laws that promote language unity, particularly in education or administration. In the past, students found speaking indigenous languages were humiliated and subjected to corporal punishment, as in the case of students attending North America residential schools (Thomason, 2015). Even today, for instance in PNG, schools have a strict policy that requires all students to speak English when in the school campus (Geeves, 2019). Children's cultural and linguistic continuity is often disrupted after they move away from their families to attend school. Such practice can lead to endangerment of dozens of indigenous languages.

Drivers of ethnobiological knowledge and traditional skills

More than 40 years ago, Robert Pyle coined the term "extinction of experience" after observing a progressive loss of the interactions people have with nature (Pyle, 1978). Today human-nature disconnection is rapidly increasing. The effective development and mastery of ethnobiological knowledge and traditional skills depends on a long-term, regular engagement of people with the natural world (Murrup-Stewart et al., 2021). Multiple socioeconomic and cultural factors play a role, either alone or in combination, in limiting people's contact with the natural world, and diverting their attention from their cultural and traditional activities. Modernization, including increasing social status of and interest in formal education (e.g., Bruyere et al., 2016; Kik et al., 2023; Poole, 2023), increased road connectivity and transportation (Atreya et al., 2018; Bhat et al., 2021; Kik et al., 2021), migration and urbanization (Luz et al., 2015; Reyes-García et al., 2013) and employment opportunities (Atreya et al., 2018), among others, have been some of the main drivers of lifestyle changes that lead away from subsistence agriculture and the loss of traditional knowledge and skills. For example, studies conducted in different parts of the world found that people with higher levels of formal education or who spent more time at school spends less time hunting, which leads to worse knowledge of animals and natural habitats they live in (Kik et al., 2023; Luz et al., 2015). Increased road connectivity with easy transport accessibility may encourage people to shift from subsistence to cash-oriented agriculture, and therefore to shift from forests to plantations, with decreasing knowledge of the forests and plants, including medicinal ones. Having money allows people to rely on market goods, including food and medication. They also have access to healthcare, shifting away from traditional medicinal plants (Reyes-García et al., 2014). According to a study conducted in the Kashmir region in the Himalayas, the disappearance of ancient traditional knowledge has been caused by increased road connectivity and improvements of rural infrastructure (Bhat et al., 2021).

Current trends in language and ethnobiological knowledge in Papua New Guinea.

One of the language hotspots in the world is New Guinea with 1,065 languages divided into two main groups: the Austronesian and Papuan languages. While Austronesian is a single, well-attested language family, Papuan languages is a geographic grouping of unrelated languages that has been formally classified into approximately 43 language families (Figure 2), most of them endemic to New Guinea (Palmer, 2018). Most of these languages have small speaker populations, the majority of them are found in the eastern part of the island, in Papua New Guinea. The relationships between and within these language families need to be further studied, just like genetic relatedness of their speakers. However, it is already clear that there are large genetic differences between PNG ethnolinguistic groups due to their long-term geographic and cultural isolation (Bergström et al., 2017). Out of 841 living indigenous languages spoken in PNG apart from the four official languages of wider communication (Tok Pisin, English, Hiri Motu, and Papua New Guinean Sign Language), only about 97 languages have more than 10,000 speakers, while 389 languages have between 1,000 and 10,0000 speakers, and nearly half of the languages have less than 1,000 speakers (Eberhard et al., 2021). About 35 % (294) of these languages are estimated to be spoken by groups of 50 to 500 people (Kulick, 2019; Sumbuk, 2006).

Having so many languages with small speaker populations in the face of increasing global language endangerment is concerning. PNG is currently experiencing rapid cultural, social, and economic changes on an unprecedented scale. As a developing country and a part of the global community, these changes are unavoidable. As they are underway, traditional communities become less reliant on local resources and begin to adapt to modern lifestyles. This puts small languages at risk of decline, together with the traditional knowledge they contain. Some factors behind attrition of language skills and ethnobiological knowledge in PNG may be universal, while some may be specific to particular areas and PNG. Some can be mitigated by appropriate intervention, others cannot.

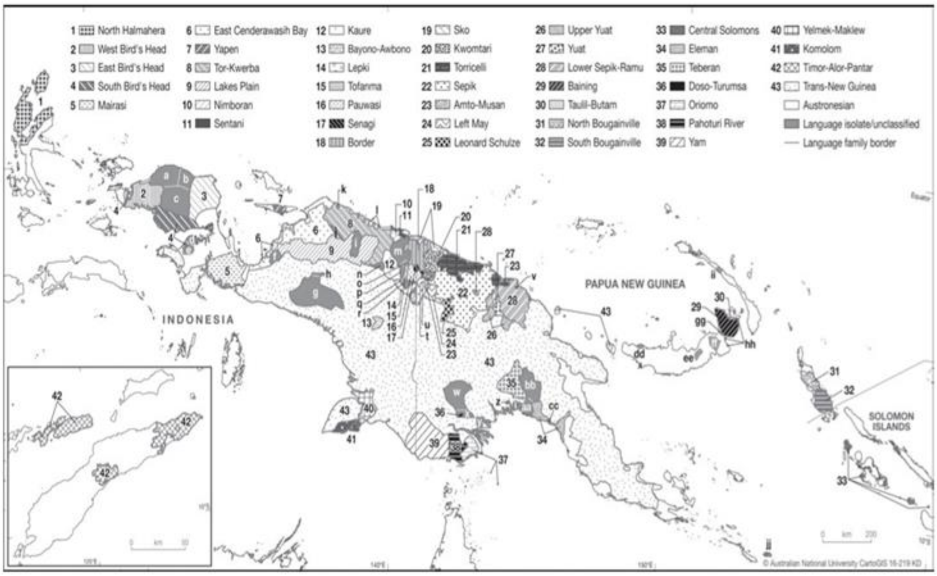


Figure 2. Language families of New Guinea. Isolates and unclassified languages are included (adapted from Palmer, 2018).

Lingua franca threatens indigenous languages

In a country with such unprecedented language richness, the development of one or several languages of wider communication (lingua franca) is inevitable. In PNG, early missionaries adopted an indigenous language and used it in larger areas, such as Yabem language by the Lutheran Church in the northern part of the country (Kulick, 1997). Likewise, early colonial British administration used modified Motu as lingua franca in Papua. However, Tok Pisin (an English-lexified pidgin) and English (as the language of formal education) have eventually become widespread.

The spontaneous expansion of Tok Pisin has been driven by increasingly common contacts between local ethnolinguistic groups, that were very rare in the pre-colonial times. Presently, almost the entire adult population of PNG speaks Tok Pisin and/or English as their second, and sometimes, first language. For instance, Tok Pisin became essential for communication in multi-ethnic settings such as schools where students usually come from more than one language area. The importance of Tok Pisin and English has further increased with the arrival of mobile phones and increased mobile signal coverage even in remote areas which have not been previously exposed to outside influences (Foster & Horst, 2018). Tok Pisin also provides a culturally neutral way of communication free of tribal limitations and cultural rivalries (Boer & Williams, 2017).

Children from mixed marriages in urban settings in PNG have been using Tok Pisin as their first language for decades. Today, Tok Pisin is a vigorous lingua franca, used as a first language in most households and communities in urban as well as in rural areas of PNG (Kik et al., 2021; Wakizaka, 2009). Almost all children favor Tok Pisin to their indigenous languages regardless of their social background (Aikhenvald & Stebbins, 2007). In 1971, the percentage of Papua New Guineans over the age of 10 who were able to speak only indigenous language ranged from 5.7 % in New Ireland to 82.9 % in Southern Highlands (Sankoff, 1980) while in the contemporary PNG this percentage is negligible.

Some languages have become endangered as their speakers shifted rapidly to Tok Pisin, for instance Tenis (Wurm, 2007), Kuot (Lindström, 2005), or Kaki Ae (Clifton, 1994). Some languages that were already extinct such as Guramalum have also fallen victim to Tok Pisin (Eberhard et al., 2021). Further, while most of the nearly extinct languages have been reported to be under pressure from Tok Pisin, it is concerning that Tok Pisin and English could crowd out many more local languages in PNG (Harrison, 2007) as it happens with languages of broader communication elsewhere (e.g., Batibo, 2005; Coupland, 2011; Crystal, 2000).

Threat to large indigenous languages

The common perception is that languages with large speaker populations are usually safe. Based on Krauss's (1992) criteria, which consider a language safe when it has a population of 100,000 speakers, there are only four safe indigenous languages in PNG: Enga (300,000 speakers), Huli (150, 000 speakers), Kuman (115,000 speakers), and Melpa (100,000 speakers) (Eberhard et al., 2021). The rest can be considered threatened or vulnerable. However, there are cases when even languages that have millions of speakers decline steadily due to the declining interest of their speakers and increasing use of more prestigious languages (Crystal, 2000). For example, Breton in France declined from 1.4 million speakers to 250,000; Yoruba with 20 million speakers has been also declined significantly. Importantly, even when large languages remain healthy, the knowledge they carry can be lost or restructured (Hunn, 2008; Si, 2020). For example, in a recent survey, Melpa high school students lack knowledge about culturally important birds and plants even though they remain fluent in their native language (Kik et al. in rev. b). The process of "extinction of experience" is already underway in PNG. This means that PNG's vast biocultural knowledge, contained within its immense linguistic diversity, which has been developing for centuries is at stake.

Technological advancement

Modernization in all domains of life, particularly technological advancement, is so widespread that every society has to somehow adapt to them (Ibrahim et al., 2011). PNG has been experiencing an unprecedented technological advancement in the past 15 years. Affordable and accessible personal computers, laptops, tablets and especially mobile phones are bridging cultural and economic divides and help people communicate more effectively than ever before (Curry et al., 2016). This creates an ideal environment for the widespread use of lingua francas, particularly Tok Pisin. Furthermore, increasing communication and travel facilitated by increased road network connectivity is leading to high rate of rural-urban migration and in turn a high rate of mixed marriages, which is further encouraging the use of Tok Pisin in families, including when talking to children. The predicted increase in road density in PNG (Meijer et al., 2018) is expected to result in extinction of many languages (Bromham et al., 2022). The increased focus on education combined with the use of mobile phones, operating in English language environment and increasing access to social media such as Facebook are further encouraging the use of English and Tok Pisin.

All these factors may cause a decline in language skills and ethnobiological knowledge in PNG, but no adequate surveys that would document the scale and the pace of these processes are available.

Current trends in language and ethnobiological knowledge in Cameroon.

The second largest language diversity hotspot is found in West Africa, and spans across countries of Nigeria, Cameroon and Chad. It includes a total of 872 languages. When combined, New Guinean and West African hotspot comprise over 20% of all extant languages. It is therefore reasonable to focus attention to this region when studying loss of language skills, and its causes.

Cameroon is home to 273 indigenous languages (Figure 3), most of them is found in the English-speaking western part. The language situation is similar to PNG, where numerous small languages, French, English and Pidgin English used as lingua francas (Kouega, 2007). Cameroon's indigenous languages belong to three established language macro-families: Niger-Congo, Afro-Asiatic, and Nilo-Saharan.

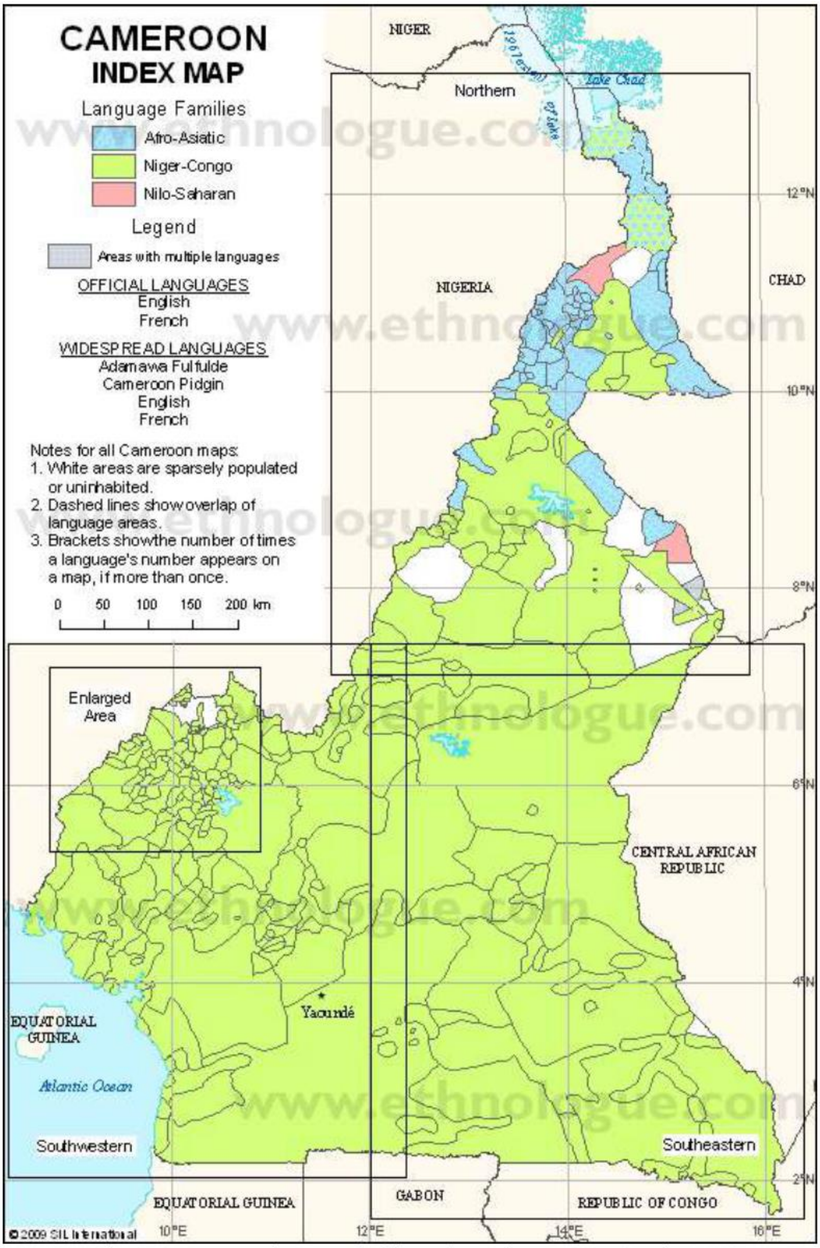


Figure 3. Language families and groups of Cameroon. The map is the property of SIL International and was taken from Nana (2016).

During the colonial period, between 1920 and 1957, and the postcolonial period, between 1970 to 1977, indigenous languages were used and taught in Cameroon's educational system. This has, however, been perceived as a policy that strengthens tribal identities and it was therefore abolished by the post-colonial government (Anchimbe, 2006; Bird, 2001). Also, parents in Cameroon wanted their children to be taught in the official languages so that they could enter higher education and had better career prospects. This is similar to situation in PNG where the bill passed in 1989 that allowed children to use vernacular language in reading and writing was abolished in 2012 after parents' dissatisfaction with vernacular-based education system. Thirteen years ago, Felix Awung reported that indigenous Cameroonian languages were spoken by fewer people, particularly the young ones, and also described the causes of language and ethnobiological knowledge attrition, such as urbanization, and high regard for official languages (Awung, 2009). Even today, the attitude towards indigenous languages and their use at schools is mixed (Ngouo, 2022). This is similar to situation in PNG, where indigenous languages are relegated to the background and official languages are widely spoken. Cameroon is one of those countries where language endangerment and extinction is most imminent (Ugwu, 2019). Cameroon's current state of biocultural knowledge could be declining as well, but the data are lacking.

Aims and outline of the thesis

PNG and Cameroon are located in the two largest linguistic hotspots: New Guinean and West African respectively. As the most culturally and linguistically diverse countries in the world, they are of the highest importance for the study of language diversity and factors that endanger it. Languages in these countries are repositories of rich and diverse biocultural knowledge accumulated through interaction with local environment over generations (Lavachery & Cornelissen, 2000; Stepp et al., 2005; Westaway et al., 2017). However, the accelerating loss of language and biocultural knowledge worldwide, particularly in tropical developing countries, makes it important to assess the current status and future trends of language and biocultural knowledge. The aim of this thesis is to examine the current status of young people's language skills and ethnobiological knowledge in Papua New Guinea and Cameroon, and to identify the sociocultural and economic factors contributing to their deterioration. The thesis presents the findings of two nationwide surveys, each one being the first of each kind, and brings a unique comparison of the two largest linguistic hotspots in the world.

Chapter One presents the results of a particularly large survey of language skills and ethnobiological knowledge of senior high school students representing the young generation in PNG. It compares the students' self-assessed language fluency results with those of their parents to evaluate inter-generational transfer of language skills. It also assesses the language skills of students directly, together with their ethnobiological knowledge of local birds and plants. It uses individual-level variables derived from family background, skills, and lifestyle to identify the drivers of the language skills and ethnobiological knowledge decline and model their future trends. **Chapter Two** assesses the hunting skills of these students as a measure of students' perceptions of traditional subsistence activities in the face of rapid lifestyle changes in contemporary PNG. Hunting is an important activity as it is potentially harmful for the populations of endangered animal species (Worldometers, 2020; Nugi & Whitmore, 2020), but hunting skills also reflect the attitude to traditional lifestyle in the young, educated people in PNG. **Chapter Three** examines in detail one of the largest indigenous languages in PNG – the Melpa. I assess the language skills and traditional knowledge of birds and plants of young and educated cohort of indigenous Melpa-speakers to understand the main causes of the decline of this domain of knowledge. Finally, **Chapter Four** examines the decline in language skills and ethnobiological knowledge among Cameroonian senior high school students and compares the results with those based on the PNG survey. This comparison between the two countries that are to a degree socially and economically similar provides insight into general as well as locally specific causes of the loss of language skills and biocultural knowledge faced by indigenous communities in the tropics.

References

Agwuele, O. (2010). Globalization, dying languages and the futility of saving them. Internet-Zeitschrift Für Kulturwissenschaften.

Aikhenvald, A., & Stebbins, T. N. (2007). Languages of New Guinea. In 'Vanishing Languages of the Pacific Rim'.(Eds O. Miyaoka, O. Sakiyama, and ME Krauss.) pp. 239–266.

Amano, T., Sandel, B., Eager, H., Bulteau, E., Svenning, J. C., Dalsgaard, B., ... & Sutherland, W. J. (2014). Global distribution and drivers of language extinction risk. *Proceedings of the Royal Society B: Biological Sciences*, *281*(1793), 20141574.

Anchimbe, E. A. (2006). Socio-pragmatic constraints to native or indigenous language education in Cameroon. In Selected Proceedings of the 36th Annual Conference on African Linguistics (pp. 133-141). Somerville, MA: Cascadilla Proceedings Project.

Atreya, K., Pyakurel, D., Thagunna, K. S., Bhatta, L. D., Uprety, Y., Chaudhary, R. P., ... & Rimal, S. K. (2018). Factors contributing to the decline of traditional practices in communities from the gwallek–kedar area, kailash sacred landscape, Nepal. *Environmental management*, *61*, 741-755.

Austin, P. K., & Sallabank, J. (Eds.). (2011). *The Cambridge handbook of endangered languages*. Cambridge University Press.

Awung, F. (2009). *The native language impasse in Cameroon: a problem of identity versus empowerment* [Paper presentation] 10th LASU International Conference. National University of Lesotho, Lesotho.

Axelsen, J. B., & Manrubia, S. (2014). River density and landscape roughness are universal determinants of linguistic diversity. *Proceedings of the Royal Society B: Biological Sciences*, *281*(1784), 20133029–20133029.

Bakker, P. (2000). Rapid language change: Creolization, intertwining, convergence. *Time depth in historical linguistics*, *2*, 585-620.

Batibo, H. (2005). *Language decline and death in Africa: Causes, consequences,* *and challenges* (Vol. 132). Multilingual Matters.

Bergström, A., Oppenheimer, S. J., Mentzer, A. J., Auckland, K., Robson, K., Attenborough, R., ... & Tyler-Smith, C. (2017). A Neolithic expansion, but strong genetic structure, in the independent history of New Guinea. *Science*, *357*(6356), 1160-1163.

Bhat, M. N., Singh, B., Surmal, O., Singh, B., Shivgotra, V., & Musarella, C. M. (2021). Ethnobotany of the Himalayas: Safeguarding medical practices and traditional uses of Kashmir regions. *Biology*, *10*(9), 851.

Bird, S. (2001). Orthography and identity in Cameroon. *Written Language & Literacy*, *4*(2), 131-162.

Boer, J., & Williams, C. (2017). Tok Pisin phonology: A preliminary study. *Language and Linguistics in Melanesia*, *35*(1), 55-81.

Bromham, L., Dinnage, R., Skirgård, H., Ritchie, A., Cardillo, M., Meakins, F., ... & Hua, X. (2022). Global predictors of language endangerment and the future of linguistic diversity. *Nature ecology & evolution*, *6*(2), 163-173.

Bromham, L., Hua, X., Algy, C., & Meakins, F. (2020). Language endangerment: A multidimensional analysis of risk factors. *Journal of Language Evolution*, *5*(1), 75-91.

Bruyere, B. L., Trimarco, J., & Lemungesi, S. (2016). A comparison of traditional plant knowledge between students and herders in northern Kenya. *Journal of ethnobiology and ethnomedicine*, *12*(1), 1-10.

Campbell, L., & Belew, A. (Eds.). (2018). *Cataloguing the world's endangered languages*. Routledge.

Chaudhary, R. P., Bhattarai, S. H., Basnet, G., Bhatta, K. P., Uprety, Y., Bhatta, L. D., ... & Sharma, U. R. (2017). Traditional practice and knowledge of indigenous and local communities in Kailash Sacred Landscape, Nepal. *ICIMOD Working Paper*, (2017/1).

Cheng, K, K. Y. (2003). Language shift and language maintenance in mixed marriages: A case study of a Malaysian-Chinese family. *International*

Journal of Sociology of Language 161. 81–90.

Clifton, J. (1994). Stable multilingualism in a small language group: The case of Kaki Ae.’. *Language and Linguistics in Melanesia, 25*(10), 124.

Copete, J. C., Kik, A., Novotny, V., & Cámara-Leret, R. (2023). The importance of Indigenous and local people for cataloging biodiversity. *Trends in Ecology & Evolution*.

Coupland, N. (2011). The handbook of language and globalization (Vol. 64). *Hoboken: John Wiley & Sons*.

Crystal, D. (2000). *Language death*. Cambridge: Cambridge University Press.

Currie, T. E., & Mace, R. (2009). Political complexity predicts the spread of ethnolinguistic groups. *Proceedings of the National Academy of Sciences of the United States of America*, *106*, 7339–7344.

Curry, G. N., Dumu, E., & Koczberski, G. (2016). Bridging the digital divide: Everyday use of mobile phones among market sellers in Papua New Guinea. *Communicating, Networking: Interacting: The International Year of Global Understanding-IYGU*, 39-52.

Eberhard, D. M., Simons, G. F., & Fennig, C. D. (2019). Ethnologue: Languages of Asia. SIL International.

Eberhard, D. M., Simons, G. F., & Fennig. C. D. (eds.). 2021. Ethnologue: Languages of the World. Twenty-fourth edition. Dallas, Texas: SIL International. Online: http://www.ethnologue.com.

Foster, R. & Horst, H. (Eds). (2018). *The moral economy of mobile phones: Pacific Islands perspectives*. Canberra, ACT: ANU Press.

Geeves, R. (2019). Corporal punishment in schools: Understanding the impacts. Retrieved October 16, 2023 from https://devpolicy.org/corporal-punishment-op-ed-20190620/

Greenhill, S. J., Atkinson, Q. D., Meade, A., & Gray, R. D. (2010). The shape and tempo of language evolution. *Proceedings of the Royal Society B: Biological Sciences*, *277*(1693), 2443-2450.

Grenoble, L. A., & Whaley, L. J. (Eds.). (1998). *Endangered languages: Language loss and community response*. Cambridge University Press.

Harrison, K. D. (2007). *When languages die: The extinction of the world's languages and the erosion of human knowledge*. Oxford University Press.

Hua, X., Greenhill, S. J., Cardillo, M., Schneemann, H., & Bromham, L. (2019). The ecological drivers of variation in global language diversity. *Nature Communications*, *10*(1), 2047.

Hunn, E. S. (2008). *A Zapotec Natural History: Trees, Herbs, and Flowers, Birds, Beasts, and Bugs in the Life of San Juan Gb ‘‘*. University of Arizona Press.

Ibrahim, S., Abbasi, M. H., Adnan, A., & Bhatti, W. (2011). Cognition and impact of modernization in changing normative structure of family system (a case study). *International Journal of Business and Social Science*, *2*(14).

Ives, C. D., Abson, D. J., Von Wehrden, H., Dorninger, C., Klaniecki, K., & Fischer, J. (2018). Reconnecting with nature for sustainability. *Sustainability science*, *13*, 1389-1397.

Kik, A., Adamec, M., Aikhenvald, A. Y., Bajzekova, J., Baro, N., Bowern, C., ... & Novotny, V. (2021). Language and ethnobiological skills decline precipitously in Papua New Guinea, the world’s most linguistically diverse nation. *Proceedings of the National Academy of Sciences*, *118*(22), e2100096118.

Kik, A., Duda, P., Bajzekova, J., Baro, N., Opasa, R., Sosanika, G., ... & Novotny, V. (2023). Hunting skills and ethnobiological knowledge among the young, educated Papua New Guineans: Implications for conservation. *Global Ecology and Conservation*, *43*, e02435.

Kik, A., Duda, P., Bajzeková, J., Kama, K., Jorge, R. L & Novotný, V. (2023b). Language skills and ethnobiological knowledge in the young and educated Indigenous Melpa speakers in Papua New Guinea. Manuscript in review.

Kik, A., Neku. N.A, Ewome. L. F., Jorge, R. L., Hodieb, L., Good, J., Bajzekova.

J., Albrecht, T., Sam, K., Aikhenvald, Y. A., Drozd, P., Duda, P., Sarvasy, H., & Novotny, V. (2023 a). Decline in language proficiency and ethnobiological knowledge in major linguistic hotspots: West Africa and New Guinea. Manuscript in review.

Kouega, J. P. (2007). The language situation in Cameroon. *Current issues in language planning*, *8*(1), 3-93.

Krauss, M. (1992). The world's languages in crisis. *Language, 68*(1), 4-10.

Kulick, D. (2019). *A death in the rainforest: How a language and a way of life came to an end in Papua New Guinea*. Algonquin Books.

Kulick, D. (1997). *Language shift and cultural reproduction: Socialization, self and syncretism in a Papua New Guinean village* (No. 14). Cambridge University Press.

Lavachery, P., & Cornelissen, E. (2000). Natural and cultural spatial patterning in the Late Holocene deposits of Shum Laka Rock Shelter, Cameroon. *Journal of Field Archaeology*, *27*(2), 153-168.

Levy, C. (2005). Language research in Papua New Guinea: A case study of Awar. *Contemporary PNG Studies*, *2*, 79-92.

Lindström, E. (2005). Literacy in a dying language: The case of Kuot, New Ireland, Papua New Guinea. *Current Issues in Language Planning*, *6*(2), 200-223.

Luz, A. C., Guèze, M., Paneque-Gálvez, J., Pino, J., Macia, M. J., Orta-Martinez, M., & Reyes-Garcia, V. (2015). How does cultural change affect indigenous peoples' hunting activity? An empirical study among the Tsimane'in the Bolivian Amazon. *Conservation and Society*, *13*(4), 382-394.

McKay, S. L. (2012). Principles of teaching English as an international language. In *Principles and practices for teaching English as an international language* (pp. 28-46). Routledge.

Meijer, J. R., Huijbregts, M. A., Schotten, K. C., & Schipper, A. M. (2018). Global patterns of current and future road infrastructure. *Environmental*

Research Letters, 13(6), 064006.

Moseley, C. (Ed.). (2010). *Atlas of the World's Languages in Danger*. Unesco.

Murrup-Stewart, C., Whyman, T., Jobson, L., & Adams, K. (2021). “Connection to culture is like a massive lifeline”: Yarning with Aboriginal young people about culture and social and emotional wellbeing. *Qualitative Health Research, 31*(10), 1833-1846.

Nana, G. (2016). Language Ideology and the Colonial Legacy in Cameroon Schools: A Historical Perspective. *Journal of Education and Training Studies*, *4*(4), 168-196.

Ngouo, H. R. (2022). A Prospective Survey of Native Population’s Attitude towards Mother Tongue Based Multilingual Education (MTBMLE) and Fulfulde as Medium of Instruction in the Far North Region of Cameroon. *European Journal of Language and Culture Studies, 1*(5), 49 -61

Nugi, G., & Whitmore, N. (2020). More dead than alive: harvest for ceremonial headdresses threatens Pesquet’s Parrot in Papua New Guinea. *Emu-Austral Ornithology, 120*(2), 156-161.

Ogar, E., Pecl, G., & Mustonen, T. (2020). Science must embrace traditional and indigenous knowledge to solve our biodiversity crisis. *One Earth, 3*(2), 162-165.

Palmer, B. (2018). Language families of the New Guinea Area, in *The Languages and Linguistics of the New Guinea Area: A Comprehensive Guide*, B. Palmer, Ed. (De Gruyter Mouton), 1–19.

Poole, A. K. (2023). Education as a driver of extinction of experience or conservation of biocultural heritage. In *Field Environmental Philosophy: Education for Biocultural Conservation* (pp. 247-262). Cham: Springer International Publishing.

Pyle, R. M. (1978). The extinction of experience. *Horticulture, 56*(1), 64–67.

Rao, P. S. (2019). The role of English as a global language. *Research Journal of English, 4*(1), 65-79.

Ray, S. (2023). Weaving the links: Traditional knowledge into modern science. *Futures*, *145*, 103081.

Rehg, K. L., & Campbell, L. (Eds.). (2018). *The Oxford handbook of endangered languages*. Oxford University Press.

Reyes-García, V., Guèze, M., Luz, A. C., Paneque-Gálvez, J., Macía, M. J., Orta-Martínez, M., ... & Rubio-Campillo, X. (2013). Evidence of traditional knowledge loss among a contemporary indigenous society. *Evolution and Human Behavior*, *34*(4), 249-257.

Reyes-García, V., Paneque-Gálvez, J., Luz, A., Gueze, M., Macía, M., Orta-Martínez, M., & Pino, J. (2014). Cultural change and traditional ecological knowledge: an empirical analysis from the Tsimane'in the Bolivian Amazon. *Human Organization*, *73*(2), 162-173.

Rogers, C., & Campbell, L. (2015). Endangered Languages. *In Oxford Research Encyclopedia of Linguistics.* Oxford University Press

Sankoff, G. (Ed). (1980). (Ed.), The Social Life of Language, University of Pennsylvania Press, Philadelphia, pp. 311-345

Si, A. (2020). Patterns in the transmission of traditional ecological knowledge: a case study from Arnhem Land, Australia. *Journal of ethnobiology and ethnomedicine*, *16*, 1-18.

Simons, G. F., & Lewis, M. (2013). The world's languages in crisis. A 20-year update. *Responses to language endangerment: In honor of Mickey Noonan. New directions in language documentation and language revitalization*, 3-20.

Stepp, J. R., Castaneda, H., & Cervone, S. (2005). Mountains and biocultural diversity. *Mountain research and development*, *25*(3), 223-227.

Sumbuk, K. M. (2006). Papua New Guinea's Languages: Will They Survive?. *Multilingual Matters*, *134*, 85.

Sutherland, W. J. (2003). Parallel extinction risk and global distribution of languages and species. *Nature*, *423*(6937), 276-279.

Thomason, S. G. (2015). *Endangered languages*. Cambridge University Press.

Troolin, D. (2013). Navigating contested terrain: Vernacular education in a Papua New Guinean village. *Current Issues in Language Planning*, *14*(2), 283-299.

Tsunoda, T. (2006). *Language Endangerment and Language Revitalization*. Berlin: Mouton de Gruyter.

Turner, N. J., Cuerrier, A., & Joseph, L. (2022). Well grounded: Indigenous Peoples' knowledge, ethnobiology and sustainability. *People and Nature*, *4*(3), 627-651.

Ugwu, E. O. (2019). Africa on the verge of a linguistic genocide: The need for action. *European Scientific Journal*, *15*(23), 57-75.

van Vliet, N., Millar, N., Melville, A., David, O., & Ignacio, L. (2022). Participation in subsistence activities and maintenance of traditional skills among indigenous youth in the South Rupununi, Guyana. *Ethnobiology and Conservation*, *11*.

Wakizaka, M. (2009). *On the issues of language contact and language shift in Tok Pisin - focusing on two "non-standard" varieties: Highlands pidgin and anglicised pidgin.* (Doctoral dissertation). https://digital.library.adelaide.edu.au/dspace/handle/2440/60069

Wang, Z., Liu, J., Xu, N., Fan, C., Fan, Y., He, S., ... & Ma, N. (2019). The role of indigenous knowledge in integrating scientific and indigenous knowledge for community-based disaster risk reduction: A case of Haikou Village in Ningxia, China. *International Journal of Disaster Risk Reduction*, *41*, 101309.

Westaway, K. E., Louys, J., Awe, R. D., Morwood, M. J., Price, G. J., Zhao, J. X., ... & Sulistyanto, B. (2017). An early modern human presence in Sumatra 73,000–63,000 years ago. *Nature*, *548*(7667), 322-325.

Wilder, B. T., O'meara, C., Monti, L., & Nabhan, G. P. (2016). The importance of indigenous knowledge in curbing the loss of language and biodiversity. *BioScience*, *66*(6), 499-509.

Worldometers (2020). Papua New Guinea Population. Retrieved September 24, 2023, from https://www.worldometers.info/world-population/papua-new-guineapopulation/

Wurm, S. A. (2007). Threatened languages in the Western Pacific area from Taiwan to, and including, Papua New Guinea. *Language diversity endangered*, 374-390.

CHAPTER I

Language and ethnobiological skills decline precipitously in Papua New Guinea, the world's most linguistically diverse nation

[*PNAS*: https://doi.org/10.1073/pnas.2100096118]

(IF = 12.779)

Language and ethnobiological skills decline precipitously in Papua New Guinea, the world's most linguistically diverse nation

Alfred Kik[a,b,c,1], Martin Adamec[d], Alexandra Y. Aikhenvald[e], Jarmila Bajzekova[a,c], Nigel Baro[f,g], Claire Bowern[h], Robert K. Colwell[i,j], Pavel Drozd[d], Pavel Duda[a], Sentiko Ibalim[a,c,f], Leonardo R. Jorge[c], Jane Mogina[k], Ben Ruli[f], Katerina Sam[a,c], Hannah Sarvasy[l], Simon Saulei[g], George D. Weiblen[m], Jan Zrzavy[a], and Vojtech Novotny[a,c,1]

[a]Faculty of Sciences, University of South Bohemia, 37011 Ceske Budejovice, Czech Republic; [b]School of Science and Technology, University of Goroka, 441 Goroka, Papua New Guinea; [c]Biology Centre, Czech Academy of Sciences, 37011 Ceske Budejovice, Czech Republic; [d]Faculty of Sciences, University of Ostrava, 70200 Ostrava, Czech Republic; [e]Language and Culture Research Centre, James Cook University, QLD 4870 Cairns, Australia; [f]New Guinea Binatang Research Center, 511 Madang, Papua New Guinea; [g]School of Natural and Physical Sciences, University of Papua New Guinea, 121 Port Moresby, Papua New Guinea; [h]Department of Linguistics, Yale University, New Haven, CT 06511; [i]Ecology and Evolutionary Biology, University of Connecticut, Storrs, CT 06269; [j]Department of Entomology, University of Colorado Museum of Natural History, Boulder, CO 80302; [k]Jane Mogina Environment Consultants, 121 Port Moresby, Papua New Guinea; [l]MARCS Institute for Brain, Behaviour and Development, Western Sydney University, NSW 2751 Penrith, Australia; and [m]Department of Plant and Microbial Biology, University of Minnesota, St. Paul, MN 55108

Edited by Nicholas Evans, Australian National University, Canberra, Australia, and accepted by Editorial Board Member Elsa M. Redmond April 13, 2021 (received for review January 4, 2021)

Papua New Guinea is home to >10% of the world's languages and rich and varied biocultural knowledge, but the future of this diversity remains unclear. We measured language skills of 6,190 students speaking 392 languages (5.5% of the global total) and modeled their future trends using individual-level variables characterizing family language use, socioeconomic conditions, students' skills, and language traits. This approach showed that only 58% of the students, compared to 91% of their parents, were fluent in indigenous languages, while the trends in key drivers of language skills (language use at home, proportion of mixed-language families, urbanization, students' traditional skills) predicted accelerating decline of fluency to an estimated 26% in the next generation of students. Ethnobiological knowledge declined in close parallel with language skills. Varied medicinal plant uses known to the students speaking indigenous languages are replaced by a few, mostly nonnative species for the students speaking English or Tok Pisin, the national lingua franca. Most (88%) students want to teach indigenous language to their children. While crucial for keeping languages alive, this intention faces powerful external pressures as key factors (education, cash economy, road networks, and urbanization) associated with language attrition are valued in contemporary society.

ethnobiology | language attrition | language endangerment | biocultural diversity | Papua New Guinea

When evaluated against a common set of extinction-risk criteria, the world's ~7,000 extant languages (1) are even more threatened than its biological diversity (2). Orally transmitted cultural knowledge may be threatened by similar forces (3, 4). Language population sizes approximate a log-normal distribution (5), such that the majority of languages have relatively few speakers (1). Nearly half of the world's languages are considered endangered (1, 6). Language extinction is accelerating, with 30% of recorded extinctions having occurred since 1960 (6). Language vulnerability to extinction depends on speakers' attitudes toward their languages as well as on socioeconomic factors (7). However, quantitative evidence on the relative impact of individual drivers of language endangerment is almost nonexistent (8, 9), making it impossible to understand and predict language attrition. Furthermore, language skills and ethnobiological knowledge are rarely examined in relation to socioeconomic variables for individual speakers, as required for mechanistic understanding of language attrition and loss of ethnobiological knowledge (10–12). The present study uses a modeling approach to assess multiple drivers of language attrition and ethnobiological knowledge loss, based on extensive data for individual speakers, to predict future trends in a global hotspot of linguistic and cultural diversity.

Papua New Guinea (PNG) is the world's most linguistically diverse nation, where ~9 million people speak ~840 languages (5, 13). PNG's languages are highly diverse, classified into at least 33 families (14). Until recently, these languages enjoyed widespread vitality due to the absence of a dominant language in the region, stable small-scale multilingualism (15), and focus on language as a marker of group identity (7, 16). New Guinea is also the world's most floristically diverse island (17), comprising ~5% of the world's biodiversity (18). Throughout PNG, numerous indigenous communities have explored, systematized, used, and managed the extraordinary biodiversity in their natural environment, thus generating extensive biocultural knowledge of local ecosystems (19–21). The traditional

Significance

Around the world, more than 7,000 languages are spoken, most of them by small populations of speakers in the tropics. Globalization puts small languages at a disadvantage, but our understanding of the drivers and rate of language loss remains incomplete. When we tested key factors causing language attrition among Papua New Guinean students speaking 392 different indigenous languages, we found an unexpectedly rapid decline in their language skills compared to their parents and predicted further acceleration of language loss in the next generation. Language attrition was accompanied by decline in the traditional knowledge of nature among the students, pointing to an uncertain future for languages and biocultural knowledge in the most linguistically diverse place on Earth.

Author contributions: A.K. and V.N. designed research; A.K., N.B., S.I., and B.R. performed research; L.R.J. contributed new analytic tools; A.K., M.A., A.Y.A., J.B., N.B., C.B., R.K.C., P. Drozd, P. Duda, S.I., L.R.J., J.M., B.R., K.S., H.S., S.S., G.D.W., J.Z., and V.N. analyzed data; and A.K., M.A., A.Y.A., J.B., N.B., C.B., R.K.C., P. Drozd, P. Duda, S.I., L.R.J., J.M., B.R., K.S., H.S., S.S., G.D.W., J.Z., and V.N. wrote the paper.

The authors declare no competing interest.

This article is a PNAS Direct Submission. N.E. is a guest editor invited by the Editorial Board.

[1]To whom correspondence may be addressed. Email: akik@prf.jcu.cz or novotny@entu.cas.cz.

This article contains supporting information online at https://www.pnas.org/lookup/suppl/doi:10.1073/pnas.2100096118/-/DCSupplemental.

Published May 26, 2021.

environmental knowledge of indigenous communities is in decline world-wide in response to the forces of cultural and economic globalization (22). Only 20% of PNG ethnolinguistic groups have any of their traditional plant uses recorded in the literature, and detailed information (>100 plant-use records) exists for only 2.5% of groups (3). Likewise, the contemporary status on this knowledge remains poorly documented.

At present, 32% of indigenous languages in PNG are considered endangered (1) largely due to their replacement by Tok Pisin (an English-based creole and PNG's major lingua franca) or English (the language of formal education) (23). However, the true status of the country's languages cannot be assessed in the absence of a national linguistic survey (24). This study presents such a survey and examines the present status and future dynamics of language and biocultural knowledge loss.

Results and Discussion

Language-Skills Drivers. We used questionnaires that compiled information on socioeconomic background and self-reported language fluency for 6,190 secondary-school students followed by tests of their language skills and ethnobiological knowledge. This survey captured 392 languages (46% of languages spoken in PNG and 5.5% worldwide), including 110 languages with ≥10 respondents (Fig. 1 and Dataset S1). We have uncovered a dramatic decline in the language skills in a single generation. While 90.8% of students' parents reportedly speak an indigenous language fluently and only 0.3% of them have no indigenous language skills, just 57.7% of students consider themselves fluent in an indigenous language, whereas 2.0% of students reported a complete lack of indigenous language (Fig. 2*A*). The 110 languages with ≥10 respondents lost, on average, 40 ± 2.1% (±SE) of fluent speakers in the contemporary generation, from parents to the secondary school students we studied (Fig. 2*B*). The parent–student comparison suggests that language attrition is a recent phenomenon and thus not a direct consequence of the colonial past of PNG (until 1975) but rather a result of economic and social development of a country undergoing globalization.

We tested a set of factors characterizing students' life skills, family language use, socioeconomic conditions, and language traits that potentially affect language skills (7) (Fig. 3 and *SI Appendix*, Fig. S1 and Table S1). The language used at home was the most important predictor of language skills. Indigenous languages, used in 30% of all families, competed with Tok Pisin and English, used in 66% and 4% of families, respectively. More interestingly, home language use was also strongly impacted by mixed-language family background, the second most important predictor of language skills. The effect of mixed-language family remained large even after taking into account its effect on home language use, since only 16% of mixed-language families used an indigenous language at home compared to 38% of same-language families.

The small-scale multilingualism that was historically widespread in PNG and continues in rural parts of the country (25, 26) does not lead to language attrition (27). However, modern urban mixing with communication in Tok Pisin or English is different (28). Presently, 37% of the surveyed students grew up in mixed-language families. The secondary schools we surveyed are a favorable environment for language mixing, attended by students speaking 17 to 124 languages per school (*SI Appendix*, Table S2). Only 35% of the students speak the same indigenous language as their best friend, which is not very different from the 23% of students expected to do so if friendships were formed randomly with respect to the languages spoken by students. This pattern indicates a potential for further increase in nontraditional mixed-language marriages of these students.

Urbanization, another important factor correlated with language skills, often interrupts contacts between generations crucial for language transfer (7, 10). Urbanization in PNG has been kept low (87% of the population is rural) (29) by customary land ownership (92% of families in our study owned land), since urban dwellers could lose their land rights to relatives who continue to live on their land in villages (30). Urban environment had a strong negative impact on language skills among the 35% of students growing up in towns and cities compared to those growing up in a rural setting, particularly in a remote village.

Parents' education and employment had only small effects on language skills once the related factors of urbanization and home language use were accounted for (Fig. 3). Students whose parents had salaried employment had lower language skills compared to those with parents growing cash crops or food for subsistence. The statistical importance of parents' language skills was low, since almost all were fluent in an indigenous language. Indigenous language skills were positively correlated with a student's reported traditional skills (hunting, fishing, farming, house building, and medicinal plant use) and negatively with contemporary technical skills (mobile phone and computer use). The individual differences in students' skills thus remain important within both rural and urban environments, apart from a large decline in traditional skills and improvement in contemporary technical skills associated with transition from rural to urban lifestyle. We did not survey changes in traditional skills between students and their parents,

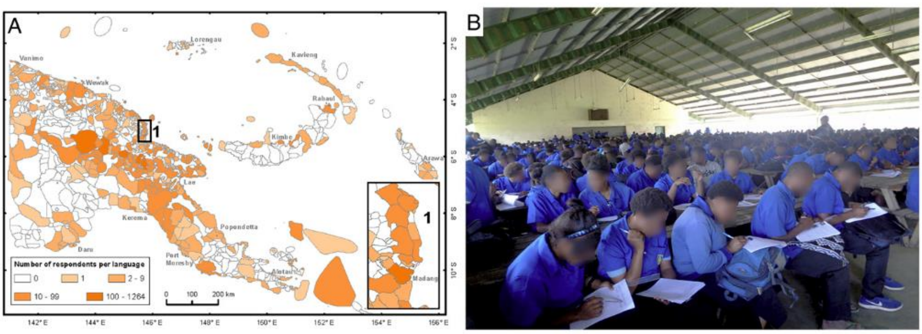


Fig. 1. Languages studied in Papua New Guinea. (*A*) Language map (*1*) with the number of students surveyed. (*B*) Survey of 486 students speaking 37 indigenous languages at the Mt. Hagen Secondary School.

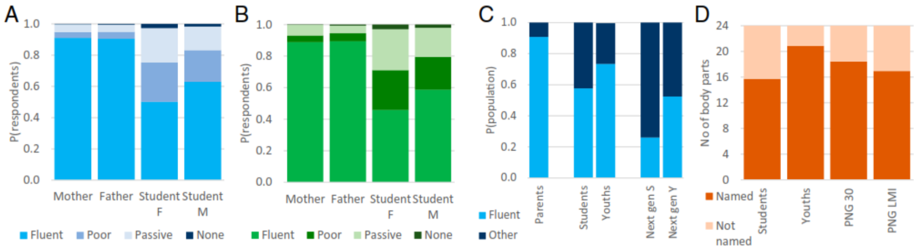


Fig. 2. Indigenous language skills in present and future PNG populations. (*A*) Language skills (L2) of 6,190 students (female and male) and their parents. (*B*) Mean language skills (L2) for 110 well-sampled languages ($n \geq 10$ students per language). (*C*) The proportion of fluent speakers among parents and students extrapolated to the entire 18- to 20-y-old cohort in PNG (Youths) and to the next generation of students (Next gen S) and all 18- to 20-y-olds (Next gen Y). (*D*) Language skills (L1) of the students, predictions from models characterizing the 18- to 20-y-olds in PNG at present (Youths) and in 30 y (PNG 30), and language skills assuming that PNG will come to match the mean socioeconomic parameters of lower-middle income countries (PNG LMI). Language skills were quantified as the number of body parts (from the total of 24) correctly named from photographs (L1) or by assessment by respondents for themselves and their parents on a four-point scale: no language skills (0), passive understanding (1), speaking but poorly (2), or fluent use (3) (L2).

but it is likely that good farming skills, in particular, are almost universal among the parents compared to 68% for the students. Interestingly, the students' English skills and mathematical skills had no effect on language skills, showing the limited direct effect of formal school education compared to lifestyle changes. Finally, language skills did not differ between female and male students.

The EGIDS (Expanded Graded Intergenerational Disruption Scale) (31) language endangerment classification, based on intergeneration transfer of languages and social domains of their use, is a significant predictor of language skills. Our study thus validates this endangerment parameter. Unlike some other measures of endangerment (2, 8), EGIDS does not consider the number of speakers of a language. We tested language size separately and found it had no significant effect on language skills; this finding bodes well for the survival prospects of numerous small languages in PNG (in 2000, the median language had only 1,201 speakers; Dataset S1).

In PNG, 87% of languages have a writing system, but only 15% of those languages have even a limited dictionary (1). Literature is thought to promote language vitality (31), but the existence of a Bible translation, typically the only written text in indigenous languages of PNG, did not improve language skills for the 84% of students who speak indigenous languages with Bible translations. This result could reflect the fact that only one-third of Bible translations are extensively used (32). The students' language skills also differ across geographic regions of PNG, probably reflecting regional differences in environmental or socioeconomic factors not directly captured by the analysis.

While many of the language-attrition drivers we detected have been documented previously (8, 10, 33), our analysis quantified their relative importance and revealed that multiple factors, even when correlated, have significant, statistically independent effects. For instance, urban lifestyle was correlated with better education and salaried employment of parents and with low traditional and high contemporary technical skills of students, but all these variables remained significant, independent predictors of language skills (*SI Appendix*, Fig. S2).

Future Trends in Language Skills. Only 15% of young people in PNG attend secondary school (34). They tend to come from towns and cities (35% in our sample versus 13% in the general population), have educated parents (17% with tertiary education versus 5% country wide in the age cohort 45 to 54 y), and rely less on subsistence agriculture (31% versus 57% in the general population) (34) (*SI Appendix*, Table S1). Rural families can often afford education beyond primary level for only one or a minority of their children.

Considering these selection biases, we estimated indigenous language fluency for the entire 18- to 20-y-old cohort of PNG using country-wide values for urbanization, parents' education, and parents' employment as independent variables. We also used these variables to estimate the country-wide proportion of linguistically mixed families and the proportion of households using any indigenous language. Our model estimated that 73.5% of the 18- to 20-y-olds in PNG are fluent in an indigenous language—a higher proportion than among secondary students but representing a significant decline from their parents, of whom >90% are likely fluent in at least one indigenous language (Fig. 2*C*). While the share of fluent speakers decreased dramatically from parents to their children, the PNG population almost doubled during the same period from 4.62 million in 1990 to 8.95 million at present (29). It is predicted to grow further to 27 million in 2100 (35). The absolute number of fluent speakers thus probably increased in the past 30 y for most indigenous languages in PNG and may continue to grow in the future while representing a rapidly diminishing share of the total population. Such an increasingly minor position may be detrimental for the survival of indigenous languages irrespective of the number of speakers.

We used extrapolated values of language-skills drivers to model the situation for students and all 18- to 20-y-olds in the next generation. Unlike most other countries, PNG is predicted to remain predominantly (76%) rural in 2050 (36). Higher mobility, including travel for education and employment, will likely lead to an increase in the already high proportion (37%) of linguistically mixed families; a hypothetical random selection of partners would result in 99% of mixed families based on our population size estimates for PNG languages (Dataset S1). We used the proportion of students whose best friend speaks a different first language (65%) as a proxy for the future share of mixed-language families. The share of the population with secondary or tertiary education is expected to increase from 19 to 31% by 2050 (34), but the proportion of the population with salaried employment was modeled as constant (31%), since there has not been a definitive trend over the past 30 y (37).

Our model predicted that the current students' 58% fluency in indigenous languages will shrink to 26% for the next generation. Furthermore, we estimated 52% fluent indigenous-language speakers in the entire 18- to 20-y-old cohort of the next generation in PNG (Fig. 2*C*). We also modeled the scenario of PNG converging to the mean socioeconomic parameters for lower-middle income countries,

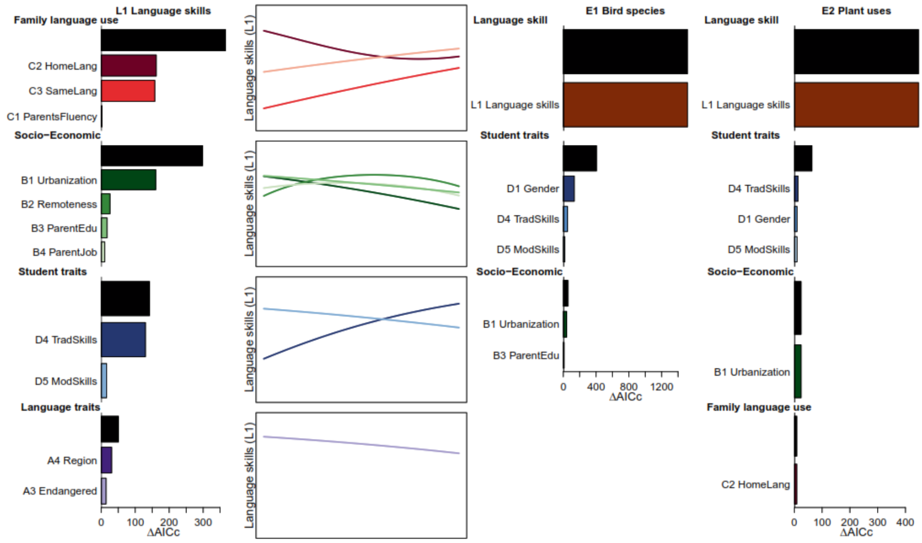


Fig. 3. Effects of language and socioeconomic factors on indigenous language skills and ethnobiological knowledge. GLMMs describe variability in student language skills (L1) and in knowledge of bird species (E1) and traditional plant uses (E2). The language-skills model incorporated 11 fixed variables divided into four classes: (A) language traits, endangerment (A3) and geographic regions (A4); (B) socioeconomic traits, birthplace urbanization (B1) and remoteness (B2) and parents' education (B3) and employment (B4); (C) family language use, parents' language skills (C1), home language use (C2), and whether parents speak the same first language (C3); and (D) student traits: traditional skills (hunting, fishing, growing food, house building, and medicinal plants) (D4) and contemporary technical skills (mobile phone and computer use) (D5). The variables were selected within each class (*SI Appendix*, Table S2) before being included in a global model (*SI Appendix*, Table S3). The bars show the AIC improvement due to the addition of each group (black) and each variable within each group into a model that includes all other variables, quantifying the marginal effect of each class/variable. The line plots show the shape of the effect of each variable across its range (except categorical A4) while keeping the other variables constant. Only significant ($P < 0.05$) variables are shown. The models describing variability in student knowledge of bird species (E1) and traditional plant uses (E2) used language skills (L1) and three classes of explanatory variables (family language use, socioeconomic traits, and student traits, including D1—gender) (*SI Appendix*, Tables S5 and S6). L1 is defined in Fig. 2 and other variables in *Materials and Methods*.

and this model predicted even greater attrition in language skills in the general population (Fig. 2*D*).

Ethnobiological Knowledge in Decline. We tested the knowledge of indigenous bird species and traditional uses of plants as two important components of biocultural knowledge (20). The knowledge of both bird species and plant uses was closely predicted by indigenous language skills and, therefore, is in decline (Fig. 3 and *SI Appendix*, Fig. S3). This result was expected, as most indigenous plant and animal names lack established translations into Tok Pisin or English and scientific species identifications (19). The continued maintenance of traditional knowledge in the face of severe language loss is rare, and this knowledge may be lost or restructured even when the indigenous language remains healthy (38, 39). Language shift, together with formal education, transition to a market economy, new technologies, urbanization, interethnic contact, habitat degradation, modern health care, religious belief, change in values, and modern media have been identified as global drivers of decline in ethnobiological knowledge and its replacement or fusion with new information from external sources (22, 38, 39).

Male students knew birds better than female students, probably because the knowledge of birds was correlated with hunting skills, which were better developed in male students. Several other student and socioeconomic traits were correlated with ethnobiological knowledge, but their importance was low (Fig. 3). The close correlation between language skills and ethnobiological knowledge may result partly from the focus of our ethnobiology tests on naming species. However, the ability to recognize and name species is a prerequisite for acquiring deeper ecological and cultural knowledge of plants and animals, as we have observed when training paraecologists, who use their traditional knowledge of the natural world to build modern research skills (40).

Student traits, including traditional skills and socioeconomic traits, particularly urbanization, were the best predictors of ethnobiological knowledge when language skill itself was not used as an explanatory variable (*SI Appendix*, Fig. S4). The intricate details of biology are often learned during teenage years spent in rainforests (41), an option no longer available to many students growing up in towns or leaving villages for boarding schools. Even the iconic and culturally important cassowary (*Casuarius* spp.) (42) could be named in an indigenous language by only 64% of respondents.

The students were asked to list up to 10 plant species with their traditional uses in indigenous languages; when they did not know any, they used Tok Pisin or English names. The majority of the plant uses reported in indigenous languages and in Tok Pisin/English were medicinal, but the proportion was greater in Tok Pisin/English responses, in which 80% were medicinal versus just

53% for plants reported in indigenous languages. Although medicinal use is often one of the most salient across cultures (20), plants reported in indigenous languages had a wide range of reported uses including sorcery, house building, and ceremonies (Fig. 4*A*) (43). Furthermore, the Tok Pisin/English medicinal uses were dominated by merely 10 plant species, only two of them (*Laportea* sp. and *Morinda citrifolia*) native to PNG (Fig. 4*B*). *Laportea* is widely distributed and used across PNG, while *M. citrifolia* is a lowland species that has become commercialized throughout the Pacific (44). Students with poor indigenous language skills thus showed severely reduced traditional medicinal knowledge replaced by an impoverished, highly "globalized" knowledge pertaining to a few mostly nonnative plant species (e.g., *Carica papaya*, *Citrus* spp., and *Aloe vera*).

Conclusions

We have shown that the drivers of language loss documented for communities around the world (45) are, to variable extents, at play in the world's most linguistically diverse nation. The traditional multilingualism in indigenous languages in the present oldest generation has given way to bilingualism with the English-based creole Tok Pisin in an intermediate generation and monolingualism in Tok Pisin, with perhaps English from schooling, in a third generation (46). With Greenberg's language diversity index (the probability that an individual does not share the same language with another randomly selected individual) approaching 0.989 (Dataset S1), the languages of PNG are too localized to be practical for wider communication. Unfortunately, we have shown that ethnobiological knowledge is closely correlated with indigenous language skills and therefore equally at risk.

The factors predicting language and biocultural-knowledge attrition in our models are determined by the factors considered desirable in contemporary PNG society, such as education, cash economy, ease of travel, and skills demanded for employment, or they are a consequence of economic development such as urbanization, which also leads to mixed-language marriages. These powerful forces are making the preservation of traditional knowledge difficult. In 2013, PNG abandoned a decades-long experiment in allowing local communities to deliver early childhood education in local indigenous languages by moving to an English-only plan (47). Furthermore, children often leave their home village to pursue education, which can cause attrition of their indigenous language skills (48). PNG's extraordinary linguistic diversity and overwhelmingly rural population pose a challenge for state-delivered education but have played an important role in the retention of vast biocultural knowledge that exists outside the education system.

The survival of most indigenous languages and traditional knowledge will be determined by factors other than their practicality. On a positive note, PNG communities prize language as a marker of group identity (24). A majority, 88%, of the students fluent in an indigenous language expressed their intention to teach it to their children, but only 8% were motivated by practicality for communication, while the others valued language as an important part of their culture. It is possible that biocultural knowledge is less consciously prized than language skills and therefore even more in danger of disappearing than indigenous languages (41).

New Guinea's share of global linguistic diversity is more than twice as high as its share of biological diversity (5, 17). The nation's linguistic and biological diversity continue to be extensively studied (13, 18) with some sustained efforts at protection (47, 49), but both local and international programs to document and support ethnobiological diversity remain limited (3, 21). A better synergy between traditional biological knowledge and formal biology such as grassroots paraecologist programs could reinvigorate the interest of indigenous communities in their ethnobiological heritage as well as in the preservation of linguistic and biological diversity (17, 21, 40, 41).

Materials and Methods

Language Skills and Ethnobiological Knowledge Variables. We surveyed students attending upper secondary school (grades 11 and 12) at 30 of the 123 secondary schools in PNG from April 6, 2015 to November 14, 2018. The schools were selected to represent both rural and urban locations in the lowland and highland regions from several provinces, comprising areas with both low and high language diversity (*SI Appendix*, Fig. S5 and Table S2). The students completed tests of indigenous language skills and ethnobiological knowledge and a questionnaire on their family background, skills, and lifestyle (Dataset S3). All surveys were voluntary, anonymous, and with informed consent given by all participants. The surveys were approved by the PNG Department of Education and approved by the IRB of the New Guinea Binatang Research Center (BRC_03_15.01.2015). The surveys were conducted at schools and attained 100% participation, eliminating the problem of self-selection, whereby poor speakers may be reluctant to volunteer for language tests (Fig. 1*B*).

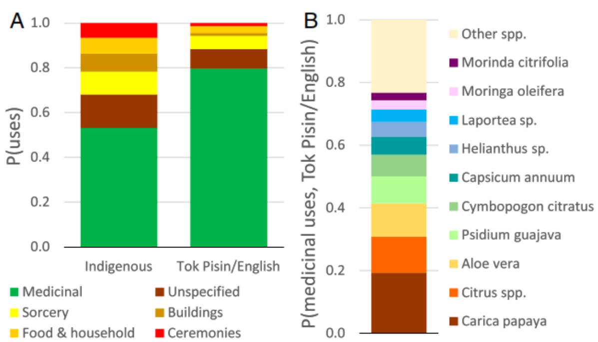


Fig. 4. Language skills and ethnobiological knowledge. (*A*) Indigenous plant use by categories (Hill's diversity $^{1}D = 4.15$ for indigenous and 2.18 for Tok Pisin/English uses). (*B*) The 10 most common plant species listed in Tok Pisin/English medicinal uses. The respondents were asked to freely list up to 10 plant species with their indigenous names and traditional uses (E2). They provided 21,829 responses in indigenous languages (i.e., 35% of the maximum of 10 uses × 6,190 respondents) and an additional 5,458 responses in Tok Pisin/English when they could not name any plant in an indigenous language.

https://doi.org/10.1073/pnas.2100096118

Indigenous language skills were quantified by two variables: L1, the number of body parts, from a set of 24 that included both frequently and rarely used terms, named by students from photographs (50), and L2, the students' self-assessment on a four-point scale: no language skills (0), passive understanding (1), speaking but poorly (2), and fluent language use (3). Students speaking more than one indigenous language were assessed for the language they knew best. Language-skills measures based on self-assessment (L2) can be biased (51). Individual respondents may have different ideas about what it means to be "fluent." Younger people may consider themselves less linguistically fluent than elders because they have less cultural knowledge. However, these potential biases are unlikely to be important, since the L1 and L2 variables are closely correlated in our study (*SI Appendix*, Fig. S6).

Ethnobiological knowledge was quantified by two variables: E1, the number of bird species named in an indigenous language from a set of images of 10 species, and E2, the number of plant species freely listed with their indigenous names and traditional uses other than food (10 species maximum). For birds, the students completed two sets including 10 lowland and 10 montane species, respectively, all geographically widespread. Each selection included a range of species from widely known and easily recognizable ones (e.g., birds of paradise and cassowary species) to more difficult ones. The set with the higher score was used for each student so as not to penalize students from any geographic location. We combined the image identification for birds with free listing for plants in order to obtain more comprehensive ethnobiological information, as each method of data collection has its own strengths and biases (20, 52). The ethnobiological knowledge measures focused on indigenous species names for birds and plants because knowledge of these names is a prerequisite for learning traditional information associated with individual species. Tok Pisin does not have detailed animal or plant taxonomies, and those available in English are not widely used in PNG. For plants, some students listed species by their Tok Pisin or English names only, when they did not know their indigenous names. These data were analyzed separately. Our tests, limited to 10 bird and 10 plant species, did not explore the full scope of ethnobiological knowledge, which often includes several hundred species (20, 43). With their focus on students, they were also not designed to capture improvements of knowledge with age that often take place for people who are immersed in the relevant cultural and natural environment (53).

We used 21 independent variables (details in *SI Appendix*) to explain language skills and ethnobiological knowledge, categorized into four classes.

Class A includes language traits. For language population size (A1), we estimated the number of language users by interpolating or extrapolating the number listed in the *Ethnologue* database (1) to the year 2000 (Dataset S1). For language status (A2 and A3), we used either detailed EGIDS categories (A2) as given for each language in *Ethnologue* (1) or the language status (A3) classified as endangered (EGIDS 6b to 10) or not (EGIDS 1 to 6a). For geographic region (A4), the location of the language in one of the four geographic and administrative regions of PNG (Highlands [1], Momase [2], Southern [3], and Islands [4]) is used as a categorical variable to examine geographic differences in language skills. For elevation (A5), each language was characterized by its median elevation (in meters above sea level, log transformed) obtained from the *Ethnologue* (1) language maps. Concerning Bible translation (A6), Bible translations are typically the only written literature in indigenous languages that are used by their speakers.

Class B includes family socioeconomic traits. For urbanization (B1), the student's childhood place of residence is given as a village (1), a government outpost (2), or a town or city (3). For remoteness (B2), the student's childhood place of residence can be accessed by road (1), boat (no road) (2), plane (no road or boat) (3), or only on foot (4). For parents' education (B3), the highest education reached by either of the parents is given as no school (1), lower primary (first to sixth) grade (2), higher primary (seventh to eighth) grade (3), lower secondary (9th to 10th) grade (4), higher secondary (11th to 12th) grade (5), or any tertiary education (6). For parents' employment (B4), the highest employment category reached by either of the parents is given as subsistence farming (1), cash crop farming (2), or salaried job or small business (3).

Class C includes family language use. For parents' language fluency (C1), the L2 scores were assessed by the respondents for their parents; the higher of the mothers' and fathers' scores was used. Home language use (C2) was given as indigenous language (alone or with other languages, including Tok Pisin and English) (1), Tok Pisin only (2), or English (alone or with Tok Pisin) (3). The parents' languages variable (C3) was given as mother and father speak the same indigenous language (1) or the family is linguistically mixed (0).

Class D includes student traits. Gender (D1) is given as female (1) or male (0). Grade 10 test results are given from English (D2) and Mathematics (D3). For traditional and contemporary technical skills in variables D4 to D6, students self-assessed their skills (as none [0], poor [1], or good [2]) at five traditional tasks (D4), hunting, fishing, growing staple crops, building a house from forest materials, and using plants to treat fever, as well as at two contemporary technical tasks (D5), using a mobile phone and a computer. The difference between traditional and contemporary technical skills was used as an additional explanatory variable (D6).

For the best friend's language variable (D7), the participant's best friend speaks the same (1) or a different (0) indigenous language as the informant. This variable was used as a proxy for the proportion of mixed-language families likely to be formed by the surveyed students in the future (C3), viewed as a predictor of language skills for the generation of the students' children. We compared the D7 values for each surveyed school with the expected proportion of best friends speaking the same language as the informant, with the assumption that students choose their friends at school and do so irrespective of the indigenous language they speak. The teaching indigenous language variable (D8) was given as the intention to teach one's children an indigenous language (yes [1] or no [0]), from those who have the language skills to do so, with a predefined list of five motivations to justify this choice: no, because 1) the indigenous language belongs to an old culture or 2) it is not a useful skill for my child or yes, because 1) everyone in my village/town does it, 2) it is a useful skill for my children, or 3) it is part of my culture. This variable was not used for generalized linear mixed models (GLMMs).

Data Verification. Identification of the indigenous language used by each respondent was often difficult (details in *SI Appendix*). We were able to identify the indigenous language for 6,190 of 8,708 respondents. Both the complete and the verified data sets give similar results for the language skills (L1, L2) and ethnobiological knowledge (E1, E2); only verified data were used in the analysis. We also verified the body part test results, as detailed in the *SI Appendix*.

Language Skills and Ethnobiological Knowledge Analysis. The data used for analysis are provided in Dataset S2. We used GLMMs to assess the effect of the four classes of variables on the language skills of the students. The response variable was the number of correct/incorrect body parts identified by students in their indigenous language (L1). The probability of getting correct responses was modeled as a binomial variable, with students and individual languages treated as random variables in all models. Except for A4, all other potential predictors are either binary or ordinal variables, allowing us to model these variables as numeric (and A1 as natively numeric), with orthogonal polynomials of order $N-1$ representing the number of levels in each variable. This approach is equivalent to representing contrasts in a categorical variable but allows for numeric extrapolation of noninteger values.

We employed a hierarchical model selection approach using the Akaike Information Criterion (AIC) (54) to compare the fit among candidate models. First, we used model selection separately for each class (A through D) of predictor variables. For the variables that had more than one level (except categorical A4), we built models with polynomials of different order, from $N-1$ levels to a simple linear relationship. For each class, we considered all the variable combinations within that class, using different polynomial orders when applicable. When more than one variable represented alternative expression of the same factor (A2 versus A3, D6 versus D4 and D5), we excluded models that included these variables together. In order to make interpretations easier, avoid inflation in the number of candidate models, and limit degrees of freedom in the models, we did not consider interactions among the variables. In the end, we obtained, for each class, one best-performing model with the optimal set of variables belonging to that class (*SI Appendix*, Table S2). Subsequently, we combined the variables from each of these class-specific, best-performing models to test whether different classes of variables acted jointly on language skills. We built these models by combining all the variables from the best-performing model in each class into models with two, three, and all four classes in all possible combinations, again with no interactions (*SI Appendix*, Table S3).

Once we obtained the best-performing, overall model, we investigated the relative role of each class and individual variable by calculating how much the AIC value was increased by removing the focal variable or class from the full model. In case any variable came out with a nonsignificant marginal effect (using a threshold of 2 points of AIC) at this stage, we removed it from the final model, as such loss of effect would be due to a higher predictive power in other correlated variables from another class. In addition, we assessed the direction and shape of the effects for individual predictor variables (Fig. 3). We predicted the response variable while varying each of the predictor variables in the best-performing model across its range, while keeping the other predictors at their original mean values across the whole population of test scores. This procedure was not possible for geographic regions (A4), which is categorical. We kept the A4 values fixed on the most abundant region when predicting the effect of the other variables because an average does not apply to this categorical variable.

We also used the GLMMs to analyze the ethnobiological knowledge of students (E1 and E2). We used the same variables and model-building strategy as for L1, except that we omitted the Language traits (A) class of variables and added language skills (L1) as a new independent variable.

Language-Skills Extrapolation. The empirical relationships among the predictor variables included in the best model were used to extrapolate language skills (L1) for hypothetical populations characterized by values for the model parameters different from the observed parameters: for the 18- to 20-y-olds in PNG at present (Model L1A), characterized by parameters extrapolated 30 y into the future (Model L1B) and assuming PNG reaches the current mean socioeconomic parameters for the lower-middle income countries (55) (Model L1C). We used the estimated parameters for the effects of each variable from the best model described above to predict the response variable for different values of the predictor variables in these populations. Because variable A4 is categorical, we made separate predictions for each geographic region and then made an average prediction by weighting the predicted value for each region by its proportion in the overall population.

In Model L1A, we used parameter values characterizing 18- to 20-y-olds in PNG for urbanization (B1), parents' education (B3), parents' employment (B4), geographic region (A4), and language status (A3) (1, 29, 34, 37) (*SI Appendix*, Table S4). These variables were also used to adjust the remaining variables for which PNG-wide data were not available. For instance, there are no country-wide data for remoteness (B2), but the distribution of remoteness values differs between two levels of urbanization—village and town/city. The remoteness variable was therefore adjusted as a weighted mean between village and town/city values, reflecting the change in the share of village residents from 58% in the original data to 87% in Model L1A. More complex adjustments included several explanatory variables, using distributions of the adjusted variable for all possible combinations of their values. In Model L1A, in addition to remoteness adjusted by urbanization, we adjusted four variables (C2, C3, D4, and D5) by a combination of urbanization and parental education (*SI Appendix*, Table S4). The parameters for the L1B and L1C models extracted from literature (1, 34, 36, 37, 56) and adjusted using other variables appear in *SI Appendix*, Table S4. Finally, we adjusted the proportion of respondents fluent in an indigenous language (L2 = 3) from the student respondents in our study to the entire 18- to 20-y-old cohort in PNG (Model L2A) and used this approach to estimate the proportion of fluent speakers in the next generation, both for students (Model L2B) and the entire 18- to 20-y-old cohort in PNG (Model L2C) (*SI Appendix*, Table S4).

Data Availability. All data used for the analysis are included in the article, the *SI Appendix*, and Datasets S1 and S2.

ACKNOWLEDGMENTS. We thank students, teachers, and heads of the 30 secondary schools that participated in the study; the PNG Department of Education for support; the PNG National Research Institute, particularly G. Kaipu, for permitting the research; and the New Guinea Binatang Research Center for logistical support. G. Luke, M. Sisol, M. Kigl, and E. Messimato provided information on individual languages; K. Kama assisted data collection; and J. Leps advised on statistical analysis. C. Volker commented on the manuscript. The New Guinea Binatang Research Center has provided the ethics oversight of the study, including data collection. The study was supported by the Czech Science Foundation (18-23889S), The European Research Council (669609), The Christensen Fund (2017-10237), and The Darwin Initiative for the Survival of the Species (DIR25S1\100123).

1. D. M. Eberhard, G. F. Simons, C. D. Fennig, Eds., *Ethnologue: Languages of the World* (SIL International, ed. 23, 2020).
2. W. J. Sutherland, Parallel extinction risk and global distribution of languages and species. *Nature* **423**, 276–279 (2003).
3. R. Cámara-Leret, Z. Dennehy, Indigenous knowledge of new Guinea's useful plants: A review. *Econ. Bot.* **73**, 405–415 (2019).
4. L. Maffi, Linguistic, cultural, and biological diversity. *Annu. Rev. Anthropol.* **29**, 599–617 (2005).
5. V. Novotny, P. Drozd, The size distribution of conspecific populations: The peoples of New Guinea. *Proc. Biol. Sci.* **267**, 947–952 (2000).
6. L. Campbell, E. Okura, "New knowledge produced by the *Catalogue of Endangered Languages*" in *Cataloguing the World's Endangered Languages*, L. Campbell, A. Belew, Eds. (Routledge, 2018), pp. 79–84.
7. M. L. Landweer, Methods of language endangerment research: A perspective from Melanesia. *Int. J. Soc. Lang.* **214**, 153–178 (2012).
8. T. Amano *et al.*, Global distribution and drivers of language extinction risk. *Proc. Biol. Sci.* **281**, 20141574 (2014).
9. K. Prochazka, G. Vogl, Quantifying the driving factors for language shift in a bilingual region. *Proc. Natl. Acad. Sci. U.S.A.* **114**, 4365–4369 (2017).
10. L. Bromham, X. Hua, C. Algy, F. Meakins, Language endangerment: A multidimensional analysis of risk factors. *J. Lang. Evol.* **5**, 75–91 (2020).
11. S. Aswani, A. Lemahieu, W. H. H. Sauer, Global trends of local ecological knowledge and future implications. *PLoS One* **13**, e0195440 (2018).
12. T. Furusava, Changing ethnobotanical knowledge of the Roviana people, Solomon Islands: Quantitative approaches to its correlation with modernization. *Hum. Ecol.* **37**, 147–159 (2009).
13. B. Palmer, *The Languages and Linguistics of the New Guinea Area: A Comprehensive Guide* (De Gruyter Mouton, 2017).
14. H. Hammarström, R. Forkel, M. Haspelmath, S. Bank, Glottolog (Version 4.2.1, Max Planck Institute for the Science of Human History, Jena, Germany, 2020). glottolog.org.
15. J. Vaughan, R. Singer, Indigenous multilingualisms past and present. *Lang. Commun.* **62**, 83–90 (2018).
16. S. A. Wurm, "Threatened languages in the Western Pacific area from Taiwan to, and including, Papua New Guinea" in *Language Diversity Endangered*, M. Brenzinger, Ed. (Mouton de Gruyter, 2007), pp. 374–390.
17. V. Novotny, K. Molem, An inventory of plants for the land of the unexpected. *Nature* **584**, 531–533 (2020).
18. V. Novotny, P. Toko, "Ecological research in Papua New Guinean rainforests: Insects, plants and people" in *The State of the Forests of Papua New Guinea 2015. Measuring change over period 2002-2014*, J. E. Bryan, P. L. Shearman, Eds. (University of Papua New Guinea, 2015), pp. 71–85.
19. P. Mühlhäusler, "The development of the life form lexicon in Tok Pisin" in *Degrees of Restructuring in Creole Languages*, I. Neumann-Holzschuh, E. W. Schneider, Eds. (J. Benjamins, 2000), pp. 337–360.
20. B. Berlin, *Ethnobiological classification. Principles of Classification of Plants and Animals in Traditional Societies* (Princeton University, 1992).
21. L. Maffi, E. Woodley, *Biocultural Diversity Conservation. A Global Sourcebook* (Earthscan, 2010).
22. S. Zent, "Processual perspectives on traditional environmental knowledge. Continuity, erosion, transformation, innovation" in *Understanding Cultural Transmission in Anthropology: A Critical Synthesis*, R. Ellen, S. J. Lycett, S. E. Johns, Eds. (Berghahn Books, 2013), pp. 213–265.
23. D. A. Kulick, *Death in the Rainforest. How a Language and a Way of Life Came to an End on Papua New Guinea* (Algonquin Books, 2019).
24. K. M. Sumbuk, "Papua New Guinea's languages: Will they survive?" in *Language Diversity in the Pacific: Endangerment and Survival*, D. D. Cunningham, P. D. E. Ingram, P. K. Sumbuk, Eds. (Multilingual Matters, 2006), pp. 85–96.
25. A. Y. Aikhenvald, Language contact along the Sepik River. *Anthropol. Linguist.* **50**, 1–66 (2008).
26. F. Lüpke, Uncovering small-scale multilingualism. *Crit. Multilingualism Stud.* **4**, 35–74 (2016).
27. A. Y. Aikhenvald, "Language endangerment in the Sepik area of Papua New Guinea" in *Lectures on Endangered Languages: 5. Endangered Languages of the Pacific Rim*, O. Sakiyama, F. Endo, Eds. (ELPR, 2004), pp. 97–142.
28. S. Romaine, *Language, Education, and Development: Urban and Rural Tok Pisin in Papua New Guinea* (Clarendon Press, 1992).
29. Worldometers, Papua New Guinea Population. https://www.worldometers.info/world-population/papua-new-guinea-population/. Accessed 5 March 2020.
30. G. Koczberski, G. N. Curry, B. Imbun, Property rights for social inclusion: Migrant strategies for securing land and livelihoods in Papua New Guinea. *Asia Pac. Viewp.* **50**, 29–42 (2009).
31. M. P. Lewis, G. F. Simons, Assessing endangerment: Expanding Fishman's GIDS. *Rev. Roum. Linguist.* **55**, 103–120 (2010).
32. R. van den Berg, *Scripture Use Research and Ministry* (SIL International, 2020).
33. P. K. Austin, J. Sallabank, "Introduction" in *Cambridge Handbook of Endangered Languages*, P. K. Austin, J. Sallabank, Eds. (Cambridge University, 2011), pp. 3–24.
34. National Statistical Office (NSO), *Papua New Guinea demographic and health survey 2016-18* (NSO, Port Moresby, Papua New Guinea, 2019).
35. S. E. Vollset *et al.*, Fertility, mortality, migration, and population scenarios for 195 countries and territories from 2017 to 2100: A forecasting analysis for the Global Burden of Disease study. *Lancet* **396**, 1285–1306 (2020).
36. United Nations, *World Urbanization Prospects: The 2018 Revision* (United Nations, 2019).
37. National Statistical Office (NSO), *2009-2010 Papua New Guinea Household Income and Expenditure Survey* (NSO, Port Moresby, Papua New Guinea, 2011).
38. A. Si, Patterns in the transmission of traditional ecological knowledge: A case study from Arnhem Land, Australia. *J. Ethnobiol. Ethnomed.* **16**, 52 (2020).
39. E. S. Hunn, *A Zapotec Natural History: Trees, Herbs, and Flowers, Birds, Beasts, and Bugs in the Life of San Juan Gbëë;* (Arizona University Press, 2008).
40. V. Novotny, G. D. Weiblen, S. E. Miller, Y. Basset, "The role of paraecologists in 21st century tropical forest research" in *Methods in Forest Canopy Research*, M. D. Lowman, T. D. Schowalter, J. F. Franklin, Eds. (University of California, 2012), pp. 154–157.
41. I. S. Majnep, R. Bulmer, *Birds of My Kalam Country* (Auckland University & Oxford University, 1977).
42. R. Bulmer, Why is the cassowary not a bird? A problem of zoological taxonomy among the Karam of the New Guinea highlands. *Man (Lond.)* **2**, 5–25 (1967).
43. R. O. Gardner, Plant names of the Kalam (Upper Kaironk Valley, Schrader Range, Papua New Guinea). *Rec. Auckland Mus.* **47**, 5–50 (2010).

44. O. Potterat, M. Hamburger, *Morinda citrifolia* (Noni) fruit–Phytochemistry, pharmacology, safety. *Planta Med.* **73**, 191–199 (2007).
45. P. K. Austin, J. Sallabank, Eds., *The Cambridge Handbook of Endangered Languages* (Cambridge University, 2011). .
46. A. Y. Aikhenvald, "Traditional multilingualism and language endangerment" in *Language Endangerment and Language Maintenance*, D. Bradley, M. Bradley, Eds. (Routledge, 2002), pp. 24–33.
47. P. Paraide, Challenges with the implementation of vernacular and bilingual education in Papua New Guinea. *Contemp. PNG Stud.: DWU Res. J.* **21**, 44–57 (2014).
48. B. Köpke, Neurolinguistic aspects of attrition. *J. Neurol.* **17**, 3–30 (2004).
49. V. M. Adams *et al.*, Scheduling incremental actions to build a comprehensive national protected area network for Papua New Guinea. *Conserv. Sci. Pract.* **3**, e354 (2021).
50. W. O. O'Grady, A. J. Schafer, J. Perla, O.-S. Lee, J. Wieting, A psycholinguistic tool for the assessment of language loss: The HALA Project. *Lang. Doc. Conserv.* **3**, 100–112 (2009).
51. C. Grinevald, M. Bert, "Speakers and communities" in *Cambridge Handbook of Endangered Languages*, P. K. Austin, J. Sallabank, Eds. (Cambridge Univ., 2011), pp. 45–65.
52. V. Reyes-García, N. Martí, T. McDade, S. Tanner, V. Vadez, Concepts and methods in studies measuring individual ethnobotanical knowledge. *J. Ethnobiol.* **27**, 182–203 (2007).
53. J. Koster *et al.*, The life history of human foraging: Cross-cultural and individual variation. *Sci. Adv.* **6**, eaax9070 (2020).
54. K. P. Burnham, D. R. Anderson, *Model Selection and Multimodel Inference. A Practical Information-Theoretic Approach* (Springer, ed. 2, 2002).
55. World Bank, Country Classification. https://datahelpdesk.worldbank.org/knowledgebase/topics/19280-country-classification. Accessed 25 March 2020.
56. World Bank, Data Catalog: Educational Statistics. https://datacatalog.worldbank.org/dataset/education-statistics. Accessed 25 March 2020.

Supporting information

PNAS
www.pnas.org

Supplementary Information for

Language and ethnobiological skills decline precipitously in Papua New Guinea, the world's most linguistically diverse nation

A. Kik*, M. Adamec, A. Y. Aikhenvald, J. Bajzekova, N. Baro, C. Bowern, R. K. Colwell, P. Drozd, P. Duda, S. Ibalim, L. R. Jorge, J. Mogina, B. Ruli, K. Sam, H. Sarvasy, S. Saulei, J. Zrzavy & V. Novotny*

***Corresponding authors:** Alfred Kik Email: akik@prf.jcu.cz and Vojtech Novotny Email: novotny@entu.cas.cz

This pdf file includes:

SI Materials and Methods
Figures S1 to S6
Tables S1 to S7
Legends for Datasets S1 to S3
SI References

Other supplementary materials for this manuscript include the following:

Datasets S1 (Excel), S2 (Excel), S3 (pdf)

Supplementary Methods and Materials

Language skills and ethnobiological knowledge variables

Methodological details for selected variables:

[A] Language traits: [A1] Language population size: The number of language users was estimated by adjusting the number listed in the *Ethnologue* database (1), interpolated or extrapolated to the year 2000 using annual population growth rates for PNG (2). This standardization was necessary, because the *Ethnologue* estimates date from 1971 – 2019 for individual languages, most often using the PNG National Census data from 2000 (3), and the Summer Institute of Linguistics estimates date from 2003 (Dataset S1). [A2] Language status: We used detailed EGIDS categories as given for each language in *Ethnologue* (1): 1 – EGIDS 3, 2 – EGIDS 4, 3 – EGIDS 5, 4 - EGIDS 6a, 5 – EGIDS 6b, 6 – EGIDS 7 to 10. [A5] Elevation: Each language was characterized by its median elevation (in m, log transformed), obtained from the *Ethnologue* (1) language maps overlaid on geographic maps using Zonal Statistics tool ArcGIS Pro on the Shuttle Radar Topography Mission (SRTM) elevation dataset (4) with spatial resolution 3" latitude x 3" longitude. [A6] Bible translation: We used the lists of languages with at least partial Bible translations (1, 5), but we do not have information on the use of these translations by the surveyed students.

[D] Student traits: [D2-D3] Grade 10 test results from English (D2) and Mathematics (D3): 1 – distinction, 2 – credit, 3 – upper pass, 4 – pass or fail. [D6] The scores were summed within traditional (maximum 10 points) and contemporary technical (maximum 4 points) activities, the totals were rescaled to a 0 – 1 range, and the difference between traditional and contemporary technical skills was used as an explanatory variable. [D7] Best friend's language: We compared the observed values for each surveyed school with the expected proportion of best friends speaking the same language as the informant, calculated as $\sum_{i=1}^{n} p_i^2$, where p_i is the proportion of students speaking language *i* in the surveyed school. This probability assumes that students choose their friends at school and do so irrespective of the indigenous language they speak. The overall random expectation of the best friend's language was calculated as the average for all 30 schools surveyed, weighted by their student numbers.

Data verification

Identification of the indigenous language used by each respondent was often difficult. The respondents were often unaware of the name used for their indigenous language by linguists (1) and gave alternative, local names for languages as well as for individual dialects. Further, geographic distribution of many languages in PNG is poorly known, so that language maps remain approximate (1). Villages in PNG also often change their location or name. We therefore integrated information on the language name given by each respondent, the respondent's birthplace, the language and birthplace of the respondent's parents, and the results of the language test naming individual body parts (L1), in order to identify the indigenous language used by the respondent.

We verified the body part test results from 1,990 respondents (32% of the total) speaking the Melpa, Kuman, Enga, and Amele languages (i.e., four of the six languages represented by >100 respondents) with the help of native speakers. The assessment of the responses in other languages was made difficult by the lack of vocabulary lists for many languages (6) and by dialectical differences, which are often poorly documented. Most respondents do not write in their indigenous language, resulting in widely variable spelling in their written responses. The terms for some body parts included in the test may not be widely used in some languages, resulting in particularly high error rates for them. The 47,760 test questions (24 body parts for 1,990 respondents) yielded an answer rate of 81%, including 63% correct answers, 16% answers that referred either to a related body part, or a wider anatomical area (e.g., hand instead of wrist, or toe instead of toenail), and 2% of the answers that were entirely wrong. These data from a few common languages were used to develop a universal protocol applied to all languages. We considered the correct and partly incorrect or vague responses as valid since they reflected some knowledge of the language, as opposed to the entirely incorrect and non-responses. This strategy was also used for the remaining 388 languages, as far as possible. When we were unsure about the correct term, we accepted the response given by a majority of respondents. In languages represented by a single or a few respondents and lacking linguistic information, we accepted the responses provided as valid, since our detailed analysis of the four common languages indicated that this was predominately the case. We used the same approach to verify indigenous bird names in the tests. The indigenous names of plant species that were freely listed were all accepted as correct, since it was impossible to verify them across 392 languages in our data, most of which are ethnobotanically undocumented (7). Our methods of data verification likely somewhat overestimated language skills and ethnobiological knowledge of the respondents by accepting some erroneous responses as valid. On the other hand, many respondents could be unaccustomed to write in their indigenous language, which could have negatively affected their written test results.

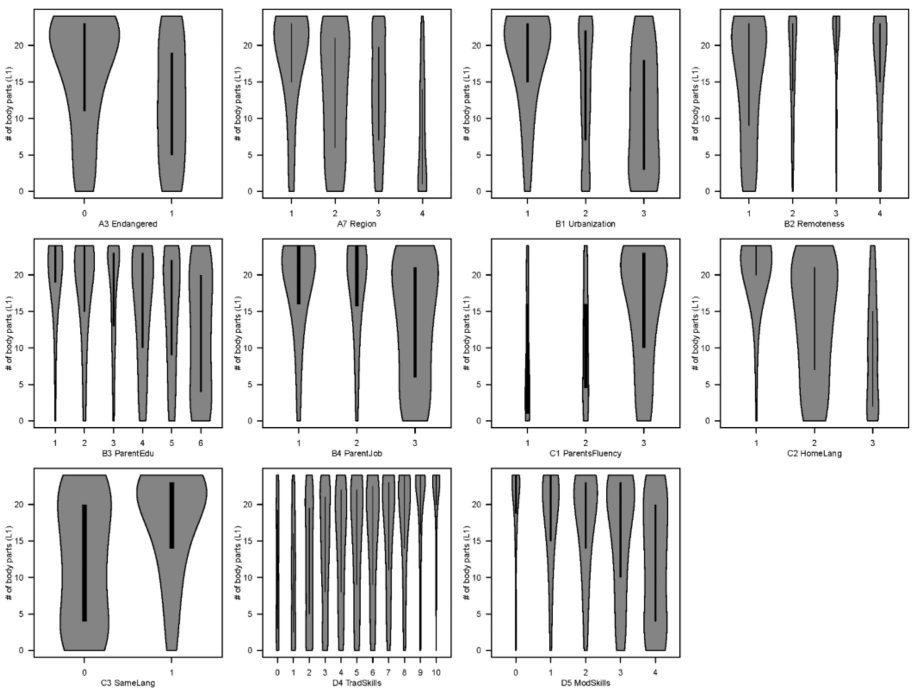


Fig. S1. Effect of the independent variables explaining the indigenous language skills (L1) of students from PNG. Each bar shows the density distribution of the L1 response variable for a given level of the predictor variable, with the width of the bar proportional to the number of students belonging to that class. See Materials and Methods for details on the variables.

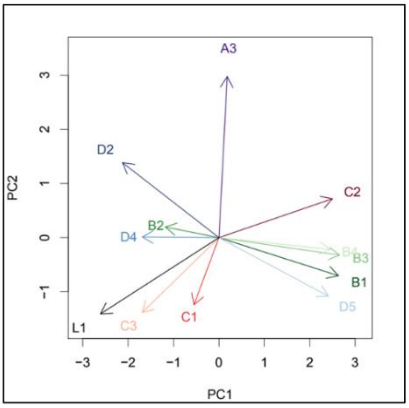


Fig. S2. Correlation of independent variables used to explain language skills. PCA ordination of the 12 independent variables included in the model explaining language skills (L1). All variables were considered numerical, and only linear correlations are visible in this PCA. Variable A4 was excluded as categorical. Arrows represent the direction in which each variable increases along the two PCA axes; their color coding is the same as in Fig. 3. PC1 explained 28.1% and PC2 explained 10.3% of the total variation in the data. See Materials and Methods for the description of variables.

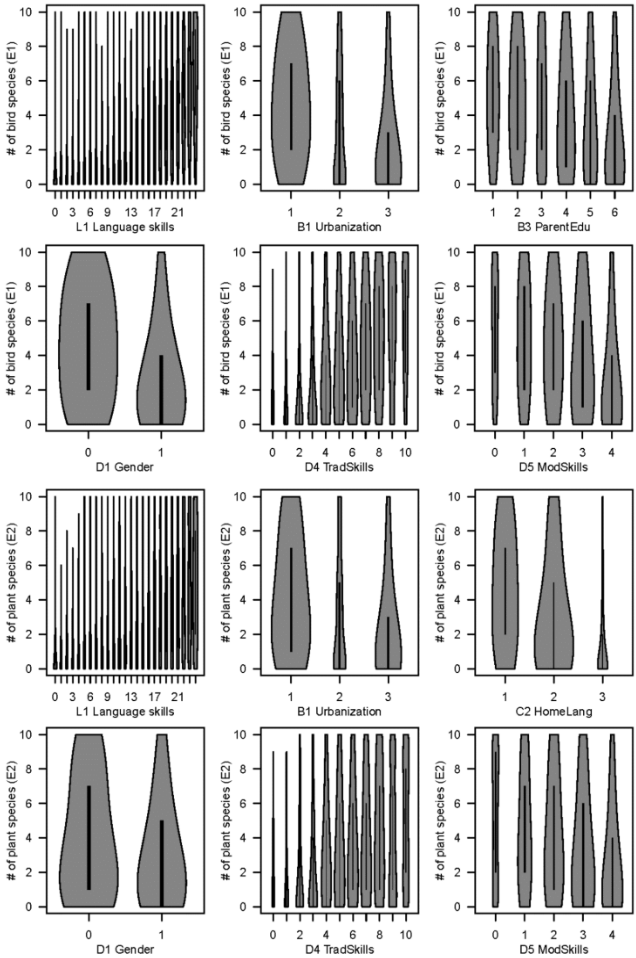


Fig. S3. Effect of the independent variables explaining the ethnobiological knowledge (E1, E2) of students from PNG. Each bar shows the density distribution of the E1 or E2 response variable for a given level of the predictor variable, with the width of the bar proportional to the number of students belonging to that class. See Materials and Methods for details on the variables.

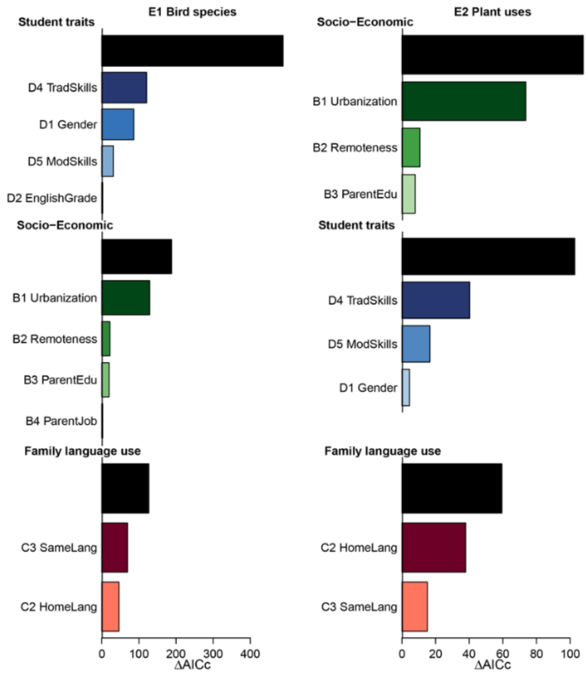


Fig. S4. Effects of language and socio-economic factors on ethnobiological knowledge. Generalized linear mixed models (GLMM) describe variability in the knowledge of bird species (E1, left) and traditional plant uses (E2, right) of students. The models incorporated 11 fixed variables divided into three classes: (B) Socio-economic traits: student's birthplace urbanization (B1) and remoteness (B2), parents' education (B3) and parent's employment (B4); (C) Family language use: parents' language skills (C1), home language use (C2), and whether parents speak the same first language (C3); and (D) Student traits: gender (D1), English skills (D2), traditional skills (hunting, fishing, growing food, house building, medicinal plants) (D4), contemporary technical skills (mobile phone and computer use) (D5). The variables were selected within each class before being included in a global model. The bars show the AIC improvement due to addition of each group (black) and each variable within each group into a model that include all other variables, quantifying the marginal effect of each class/variable. Details on the variables are in Materials and Methods. Only significant variables are shown.

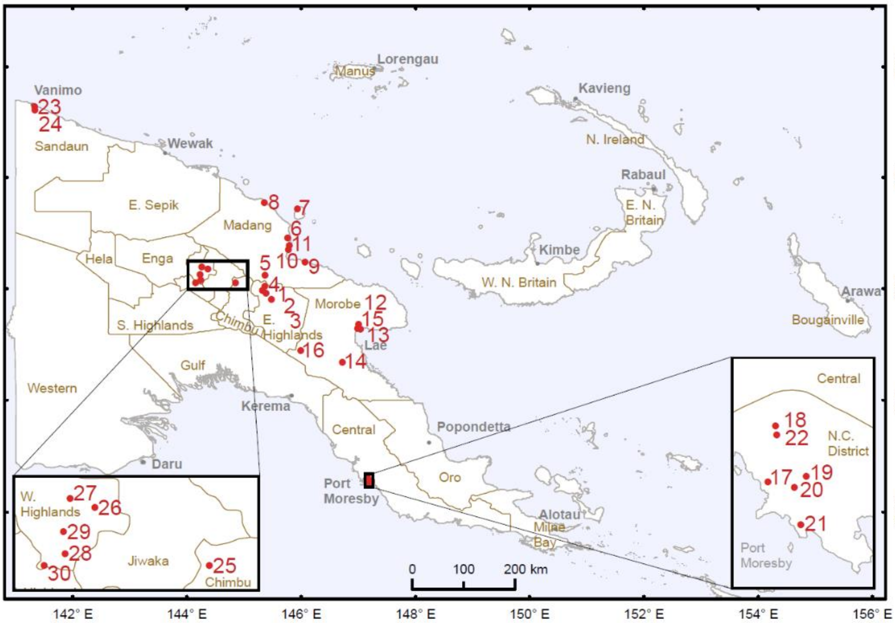


Fig. S5. Location of the 30 secondary schools surveyed in the study. See Table S2 for the details on individual schools.

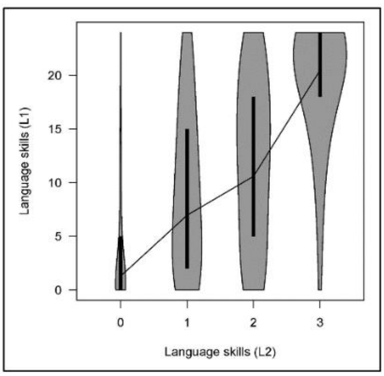


Fig. S6. Correlation between two language skills measures: self-assessed language fluency (L2) and the number of body parts named (L1) for the 6,190 students (Spearman r = 0.58, P < 0.001).

Table S1. Socioeconomic and language parameters for respondents. See Materials and Methods for details of variables A1 - D8. Based on the survey of N = 6,190 secondary school students.

Var#	Variable	Value
A1	Language population size [median, Q1-Q3]	3093 [1350, 8500]
A3	Students speaking endangered languages, %	13.9
A6	Students speaking languages with a Bible translation, %	84.0
B1	Students who spent childhood in a village, %	64.7
B2	Student's childhood residence accessible by road %	80.4
B3	Families having ≥1 parent with secondary of higher education, %	63.2
B4	Families with subsistence agriculture income only, %	30.9
C2	Families using indigenous language at home, %	30.0
C3	Families with parents speaking the same indigenous language, %	63.1
D1	Female students, %	41.0
D4	Students with good hunting skills, %	22.4
D4	Students with good fishing skills, %	39.3
D4	Students with good farming skills, %	67.8
D4	Students with good house building skills, %	28.1
D4	Students with good plant medicinal use skills, %	31.0
D5	Students with good mobile phone use skills, %	67.9
D5	Students with good computer use skills, %	28.3
D7	Students speaking the same indigenous language as their best friend	34.8
D8	Students able and wishing to teach indigenous language to their child	87.7
	Student's age [median, Q1-Q3)	19 [18, 20]
	Student's no. of siblings [median, Q1-Q3]	4 [3, 6]
	Families owning land, %	91.7
	Families owning cash crop plantation, %	52.0
	Families owning forest, %	68.5
	Families with access to electricity, %	53.8

Table S2. Secondary schools surveyed in the study. The number of surveyed students, the number of indigenous languages spoken, and the percentage of students speaking the most common language are listed for each school, numbered as in Fig. S5 showing its geographic location.

#	School	Province	Students	Languages	1st lang %
1	Asaroka Lutheran Secondary	Eastern Highlands	149	27	19
2	Benabena Secondary	Eastern Highlands	223	34	39
3	Goroka Secondary School	Eastern Highlands	44	20	23
4	Kabiufa Secondary	Eastern Highlands	137	27	18
5	Braham Secondary	Madang	104	48	13
6	Good Shepherd Lutheran Secondary	Madang	126	51	15
7	Karkar Secondary	Madang	228	48	28
8	Malala Catholic Upper Secondary	Madang	131	46	13
9	Raikos Lutheran Secondary	Madang	100	33	19
10	Transgogol High	Madang	37	18	35
11	Tusbab Secondary	Madang	205	72	12
12	Bumayong Secondary	Morobe	276	84	7
13	Busu Secondary School	Morobe	227	90	8
14	Grace Memorial Secondary	Morobe	212	62	17
15	Lae National High	Morobe	383	124	7
16	Menyamya Secondary	Morobe	182	34	25
17	Badihagwa Secondary Technical	Nat. Capital Distr.	43	28	9
18	Gerehu Secondary	Nat. Capital Distr.	157	52	11
19	Gordons Secondary	Nat. Capital Distr.	157	62	7
20	Jubilee Catholic Secondary	Nat. Capital Distr.	26	20	8
21	Kila Kila Secondary	Nat. Capital Distr.	74	38	12
22	Port Moresby National High	Nat. Capital Distr.	69	33	10
23	Don Bosco Secondary	Sandaun	117	45	24
24	Vanimo Secondary	Sandaun	173	60	21
25	Kerowagi Secondary	Simbu	495	27	76
26	Kitip Secondary	Western Highlands	346	25	82
27	Kwip Dau Secondary	Western Highlands	301	23	79
28	Mount Hagen Secondary	Western Highlands	483	36	66
29	Paglum Adventist Secondary	Western Highlands	189	35	50
30	Togoba Secondary	Western Highlands	422	17	63

Table S3. Model selection results for the candidate models assessing the role of language-related variables A1 – A6, socio-economic variables B1 – B4, family language use variables C1 – C3, and student-related variables D1 – D6 on the language fluency of students. dAICc = delta corrected Akaike Information Criterion, df = degrees of freedom. All models include Student and Language as random factors on the intercept. Note that D7 and D8 were not used in model building.

Variable class	Models – Student trait variables	dAICc	df
Language traits	A1_LogN.2000 + A3_Endangered + A7_RegCode + A8_LogElevMedian	0	9
Language traits	A1_LogN.2000 + A3_Endangered + A6_PNGbible + A7_RegCode + A8_LogElevMedian	0.72	10
Language traits	A1_LogN.2000. + A2_Status + A6_PNGbible + A7_RegCode + A8_LogElevMedian	3.08	13
Language traits	A3_Endangered + A7_RegCode + A8_LogElevMedian	3.27	8
Language traits	A3_Endangered + A6_PNGbible + A7_RegCode + A8_LogElevMedian	5.18	9
Language traits	A1_LogN.2000 + A3_Endangered + A7_RegCode	6.45	8
Language traits	A3_Endangered + A7_RegCode	6.91	7
Language traits	A6_PNGbible + A7_RegCode + A8_LogElevMedian	20.95	8
Language traits	A1_LogN.2000 + A3_Endangered + A8_LogElevMedian	35.78	6
Language traits	Null (random factors + intercept)	72.68	3
Socio-economic	B1_Urbanization + B2_Isolation^2 + B3_ParentEdu + B4_ParentJob^2	0	9
Socio-economic	B1_Urbanization + B2_Isolation^2 + B3_ParentEdu^2 + B4_ParentJob^2	0.96	10
Socio-economic	B1_Urbanization + B2_Isolation^3 + B3_ParentEdu + B4_ParentJob^2	1.82	10
Socio-economic	B1_Urbanization^2 + B2_Isolation^3 + B3_ParentEdu + B4_ParentJob^2	4.80	11
Socio-economic	B1_Urbanization) + B2_Isolation^2 + B3_ParentEdu^2 + B4_ParentJob	12.07	9
Socio-economic	B1_Urbanization + B2_Isolation + B3_ParentEdu + B4_ParentJob^2	24.23	8
Socio-economic	B1_Urbanization + B2_Isolation^2 + B3_ParentEdu	37.19	7
Socio-economic	B1_Urbanization + B3_ParentEdu + B4_ParentJob^2	64.94	7
Socio-economic	B1_Urbanization + B2_Isolation^2 + B4_ParentJob^2	93.49	8
Socio-economic	B2_Isolation^2 + B3_ParentEdu + B4_ParentJob^2	378.61	8
Socio-economic	Null (random factors + intercept)	992.17	3
Language use	C2_HomeLang^2 + C1_ParentMaxFluency + C3_SameLang	0	7
Language use	C2_HomeLang^2 + C1_ParentMaxFluency^2 + C3_SameLang	1.08	8
Language use	C2_HomeLang + C1_ParentMaxFluency + C3_SameLang	32.04	6
Language use	C2_HomeLang + C3_SameLang)	45.72	5
Language use	C2_HomeLang^2 + C1_ParentMaxFluency	249.60	6
Language use	C3_SameLang	533.92	4
Language use	Null (random factors + intercept)	917.26	3
Student traits	D2_GradeEng^2 + D4_TradSkills + D5_ModSkills	0	7
Student traits	D2_GradeEng^3 + D4_TradSkills + D5_ModSkills	0.94	8
Student traits	D1_Gender + D2_GradeEng^3 + D4_TradSkills + D5_ModSkills	2.08	9
Student traits	D2_GradeEng^3 + D3_GradeMath^3 + D4_TradSkills + D5_ModSkills	4.01	11
Student traits	D1_Gender + D2_GradeEng^3 + D3_GradeMath^3 + D4_TradSkills + D5_ModSkills	4.84	12
Student traits	D2_GradeEng^3 + D6_Trad.Mod	12.58	7
Student traits	D2_GradeEng + D4_TradSkills + D5_ModSkills	13.01	6
Student traits	D1_Gender + D2_GradeEng^3 + D3_GradeMath^3 + D6_Trad.Mod	17.00	11
Student traits	D4_TradSkills + D5_ModSkills	48.06	5
Student traits	D1_Gender + D4_TradSkills + D5_ModSkills	49.46	6
Student traits	D1_Gender + D2_GradeEng^3 + D3_GradeMath^3 + D4_TradSkills	199.85	11
Student traits	D1_Gender + D2_GradeEng^3 + D3_GradeMath^3 + D5_ModSkills	246.61	11
Student traits	Null (random factors + intercept)	750.43	3

Table S4. Model selection results for the candidate models assessing the combined role of the four variable classes A – D included in this study on the language fluency of students. dAICc = delta corrected Akaike Information Criterion, df = degrees of freedom. All models include Student and Language as random factors on the intercept.

Combined Model classes	Combined model variables	dAICc	df
All four classes	B1_Urbanization + B2_Isolation^2 + B3_ParentEdu + B4_ParentJob^2 + D2_GradeEng^2 + D4_TradSkills + D5_ModSkills + C2_HomeLang^2 + C1_ParentMaxFluency + C3_SameLang + A1_LogN.2000. + A3_Endangered + A7_RegCode + A8_LogElevMedian	0	23
All four classes significant	B1_Urbanization + B2_Isolation^2 + B3_ParentEdu + B4_ParentJob^2 + D4_TradSkills + D5_ModSkills + C2_HomeLang^2 + C1_ParentMaxFluency + C3_SameLang + A3_Endangered + A7_RegCode	0.14	19
Socio-Economic + Student	B1_Urbanization + B2_Isolation^2 + B3_ParentEdu + B4_ParentJob^2 + D2_GradeEng^2 + D4_TradSkills + D5_ModSkills + C2_HomeLang^2 + C1_ParentMaxFluency + C3_SameLang	48.56	17
Socio-Economic + Family la	B1_Urbanization + B2_Isolation^2 + B3_ParentEdu + B4_ParentJob^2 + D2_GradeEng^2 + D4_TradSkills + D5_ModSkills + A1_LogN.2000. + A3_Endangered + A7_RegCode + A8_LogElevMedian	146.59	19
Socio-Economic + Family la	B1_Urbanization + B2_Isolation^2 + B3_ParentEdu + B4_ParentJob^2 + C2_HomeLang^2 + C1_ParentMaxFluency + C3_SameLang	200.38	13
Socio-Economic + Student	B1_Urbanization + B2_Isolation^2 + B3_ParentEdu + B4_ParentJob^2 + D2_GradeEng^2 + D4_TradSkills + D5_ModSkills	223.06	15
Student traits + Family lan	D2_GradeEng^2 + D4_TradSkills + D5_ModSkills + C2_HomeLang^2 + C1_ParentMaxFluency + C3_SameLang	329.22	11
Socio-Economic + Languag	B1_Urbanization + B2_Isolation^2 + B3_ParentEdu + B4_ParentJob^2 + A1_LogN.2000. + A3_Endangered + A7_RegCode + A8_LogElevMedian	586.31	15
Socio-Economic	B1_Urbanization + B2_Isolation^2 + B3_ParentEdu + B4_ParentJob^2	644.16	9
Family language use	C2_HomeLang^2 + C1_ParentMaxFluency + C3_SameLang	719.08	7
Student traits	D2_GradeEng^2 + D4_TradSkills + D5_ModSkills C2_HomeLang^2	885.91	7
Language traits	A1_LogN.2000. + A3_Endangered + A7_RegCode + A8_LogElevMedian	1554.97	16
Null	Null (random factors + intercept)	1636.34	3

Table S5. Variables and their values used in the models extrapolating language fluency. The L1 language skills are extrapolated to the entire 18-20-year-old cohort in PNG (L1A model), to the 18-20-year-old cohort in PNG 30 years in the future (L1B), and to the current average socioeconomic parameters for the Lower-Middle Income countries (L1C). Language fluency (L2 = 3) is extrapolated to the to the entire 18-20-year-old cohort in PNG (L2A model), to the next generation of secondary students in PNG (L2B) and the next 18-20-year-old generation in PNG (L2C). See Materials and Methods for the procedure used to generate values for Adjusted variables.

Model	Var#	Variable	Parameter values	Comments	Ref.	Data
L1A	A3	LangStatus	0 = 0.9782, 1 = 0.0218	Distribution of PNG population among endangered/non-endangered languages based on Language size (A1)	(1)	External
L1A	A4	LangRegion	1 = 0.391, 2 = 0.279, 3 = 0.199, 4 = 0.131	Distribution of PNG population among PNG regions, based on Language size (A1)	(1, 8)	External
L1A	B1	Urbanization	1 = 0.869, 3 = 0.131, 2 = not used	Current PNG urbanization rate	(2)	External
L1A	B2	Remoteness	1 = 0.772, 2 = 0.049, 3 = 0.036, 4 = 0.143	Adjusted by Urbanization (B1)		Adjusted
L1A	B3	ParentEdu	1 = 0.453, 2 = 0.354, 3 = 0.049, 4 = 0.076, 5 = 0.019, 6 = 0.049	Education data for 50-54 years age group in PNG	(9)	External
L1A	B4	ParentJob	1 = 0.57, 2 = 0.125, 3 = 0.303	Job structure in PNG 2009-2010	(10)	External
L1A	C1	ParentLang	0 = 0.001, 1 = 0.009, 2 = 0.014, 3 = 0.976	No change from original data		This study
L1A	C2	HomeLang	1 = 0.469, 2 = 0.521, 3 = 0.010	Adjusted by Urbanization (B1) & Parents' education (B3)		Adjusted
L1A	C3	SameLang	0 = 0.240, 1 = 0.760	Adjusted by Urbanization (B1) & Parents' education (B3)		Adjusted
L1A	D2	EnglishGrade		Not used (part of population does not have Gr 10 test)		Not used
L1A	D4	TraditSkills	0 = 0.010, 1 = 0.011, 2 = 0.041, 3 = 0.069, 4 = 0.106, 5 = 0.123, 6 = 0.154, 7 = 0.144, 8 = 0.162, 9 =0.117, 10 = 0.063	Adjusted by Urbanization (B1) & Parents' education (B3)		Adjusted
L1A	D5	ModernSkills	0 = 0.052, 1 = 0.203, 2 = 0.310, 3 = 0.316, 4 = 0.119	Adjusted by Urbanization (B1) & Parents' education (B3)		Adjusted
L1B	A3	LangStatus	0 = 0.922, 1 = 0.078	Distribution of PNG population among endangered/non-endangered languages based on Language size (A1)	(1)	External
L1B	A4	LangRegion	1 = 0.391, 2 = 0.279, 3 = 0.199, 4 = 0.131	Distribution of PNG population among PNG regions, based on Language size (A1)	(1, 8)	External
L1B	B1	Urbanization	1 = 0.76, 3 = 0.24, 2 = not used	Extrapolation for PNG in 2050	(11)	External
L1B	B2	Remoteness	1 = 0.790, 2 = 0.045, 3 = 0.032, 4 = 0.133	Adjusted by Urbanization (B1)		Adjusted
L1B	B3	ParentEdu	1 = 0.254, 2 = 0.333, 3 = 0.100, 4 = 0.190, 5 = 0.057, 6 = 0.066	Education of 30-34 years old	(9)	External
L1B	B4	ParentJob	1 = 0.57, 2 = 0.125, 3 = 0.303	Data for PNG 2009-2010 were used as no trend was apparent over the past 30	(10)	External
L1B	C1	ParentLang	0 = 0.0005, 1 = 0.010, 2 = 0.014, 3 = 0.976	No change from original data		This study
L1B	C2	HomeLang	0 = 0.329, 1 = 0.653, 3 = 0.018	Adjusted by Family language uniformity (C3), Urbanization (B1) and Parents' education (B3)		Adjusted
L1B	C3	SameLang	0 = 0.652, 1 = 0.348	Estimated as the proportion of best friends speaking the same language (D7)		This study
L1B	D2	EnglishGrade		Not used (part of population does not have Gr 10 test)		This study
L1B	D4	TraditSkills	0 = 0.010, 1 = 0.013, 2 = 0.049, 3 = 0.082, 4 = 0.112, 5 = 0.132, 6 = 0.152, 7 = 0.142, 8 = 0.149, 9 =0.104, 10 = 0.055	Adjusted by Urbanization (B1) & Parents' education (B3)		Adjusted
L1B	D5	ModernSkills	0 = 0.038, 1 = 0.167, 2 = 0.287, 3 = 0.343, 4 = 0.165	Adjusted by Urbanization (B1) & Parents' education (B3)		Adjusted
L1C	A3	LangStatus	0 = 0.922, 1 = 0.078	Distribution of PNG population among endangered/non-endangered languages based on Language size (A1)	(1)	External
L1C	A4	LangRegion	1 = 0.391, 2 = 0.279, 3 = 0.199, 4 = 0.131	Distribution of PNG population among PNG regions, based on Language size (A1)	(1, 8)	External
L1C	B1	Urbanization	1 = 0.584, 2 = not used, 3 = 0.416	Lower-middle income countries in 2020	(11)	External
L1C	B2	Remoteness	1 = 0.818, 2 = 0.038, 3 = 0.028, 4 = 0.116	Adjusted by Urbanization (B1)		This study
L1C	B3	ParentEdu	1 = 0.247, 2.5 = 0.430, 4.5 = 0.276, 6 = 0.047	Education attainment in 30-40yrs old population in lower-middle income countries	(12)	External
L1C	B4	ParentJob	1.5 = 0.39, 3 = 0.61	1.5 = work in agriculture, 3 = employment in other sectors	(12)	External
L1C	C1	ParentLang	0 = 0.0005, 1 = 0.010, 2 = 0.014, 3 = 0.976	No change from original data		This study
L1C	C2	HomeLang	0 = 0.269, 1 = 0.702, 3 = 0.029	Adjusted by Family language uniformity (C3), Urbanization (B1) and Parents' education (B3)		Adjusted
L1C	C3	SameLang	0 = 0.652, 1 = 0.348	Estimated as the proportion of best friends speaking the same language (D7)		This study
L1C	D4	TraditSkills	0 = 0.010, 1 = 0.016, 2 = 0.056, 3 = 0.097, 4 = 0.117, 5 = 0.135, 6 = 0.151, 7 = 0.130, 8 = 0.144, 9 =0.093, 10 = 0.051	Adjusted by Urbanization (B1) & Parents' education (B3)		Adjusted
L1C	D5	ModernSkills	0 = 0.049, 1 = 0, 2 = 0.608, 3 = 0.142, 4 = 0.201	Based on access to mobile phone and computer and access to internet	(12)	External

Table S5. Continued

Model	Var#	Variable	Parameter values	Comments	Ref.	Data
L2A	B1	Urbanization	1 = 0.869, 3 = 0.131, 2 = not used	Current urbanization rate	(2)	External
L2A	B3	ParentEdu	1 = 0.453, 2 = 0.354, 3-6 = 0.193	Education data for 50-54 years age group in PNG	(9)	External
L2A	B4	ParentJob	1-2 = 0.695, 3 = 0.305	Job structure in PNG 2009-2010	(10)	External
L2A	C2	HomeLang	1 = 0.467 2-3 = 0.533	Adjusted by Urbanization (B1) & Parents' education (B3)		Adjusted
L2A	C3	SameLang	0 = 0.244, 1 = 0.756	Adjusted by Urbanization (B1) & Parents' education (B3)		Adjusted
L2B	B1	Urbanization	1 = 0.76, 3 = 0.24, 2 = not used	Extrapolation for PNG in 2050	(11)	External
L2B	B3	ParentEdu	1 = 0, 2 = 0, 3 0, 4 = 0, 5 = 0.532, 6 = 0.468	Proportion of secondary school graduates with tertiary education for 25-34 age group in PNG	(9)	External
L2B	C2	HomeLang	1 = 0.306, 2-3 = 0.694	Adjusted by Family language uniformity (C3), Urbanization (B1), Parents' education (B3), and Parent's Language skills (C1) (vernacular language use only for those fluent in it, L2 = 3)		Adjusted
L2B	C3	SameLang	0 = 0.556, 1 = 0.444	The proportion of best friends speaking the same language for those fluent in language (D7)		This study
L2C	B1	Urbanization	1 = 0.76, 3 = 0.24, 2 = not used	Extrapolation for PNG in 2050	(11)	External
L2C	B3	ParentEdu	1 = 0.254, 2 = 0.333, 3 = 0.100, 4 = 0.190, 5 = 0.057, 6 = 0.066	Education of 30-34 years old in PNG	(9)	External
L2C	B4	ParentJob	1 = 0.572, 2 = 0.125, 3 = 0.303	Job structure in PNG 2009-2010 used as no trends in PNG jobs apparent	(11)	External
L2C	C2	HomeLang	1 = 0.388 2-3 = 0.612	Adjusted by Urbanization (B1), Parents' education (B3) and Parent's language skills (C1) (vernacular language use only for those fluent in it, L2 = 3)		Adjusted
L2C	C3	SameLang	0 = 0.297, 1 = 0.703	Adjusted by Urbanization (B1), Parents' education (B3) and Parent's language skills (C1) (vernacular language use only for those fluent in it, L2 = 3)		Adjusted

Table S6. Model selection results for the candidate models assessing the role of socioeconomic variables B1 – B4, family language use variables C1 – C3, and student-related variables D1 – D6 on the knowledge of bird species (E1) and traditional plant use (E2) by students. dAICc = delta corrected Akaike Information Criterion, df = degrees of freedom. All models include Student and Language as random factors on the intercept.

Taxon	Variable class	Models – Student trait variables	dAICc	df
Birds	Socio-economic	B1_Urbanization + B2_Isolation^2 + B3_ParentEdu^2 + B4_ParentJob^2	0	10
Birds	Socio-economic	B1_Urbanization + B2_Isolation^3 + B3_ParentEdu + B4_ParentJob^2	4.60	10
Birds	Socio-economic	B1_Urbanization + B2_Isolation^2 + B3_ParentEdu + B4_ParentJob^2	4.80	9
Birds	Socio-economic	B1_Urbanization^2 + B2_Isolation^3 + B3_ParentEdu + B4_ParentJob^2	4.89	11
Birds	Socio-economic	B1_Urbanization + B2_Isolation^2 + B3_ParentEdu^2 + B4_ParentJob	7.63	9
Birds	Socio-economic	B1_Urbanization + B2_Isolation^2 + B3_ParentEdu	17.15	7
Birds	Socio-economic	B1_Urbanization + B2_Isolation + B3_ParentEdu + B4_ParentJob^2	28.68	8
Birds	Socio-economic	B1_Urbanization + B3_ParentEdu + B4_ParentJob^2	51.05	7
Birds	Socio-economic	B1_Urbanization + B2_Isolation^2 + B4_ParentJob^2	90.28	8
Birds	Socio-economic	B2_Isolation^2 + B3_ParentEdu + B4_ParentJob^2	357.64	8
Birds	Socio-economic	Null (random factors + intercept)	835.38	3
Birds	Language use	C2_HomeLang^2 + C1_ParentMaxFluency^2 + C3_SameLang	0	8
Birds	Language use	C2_HomeLang + C1_ParentMaxFluency + C3_SameLang	2.54	6
Birds	Language use	C2_HomeLang^2 + C1_ParentMaxFluency + C3_SameLang	6.56	7
Birds	Language use	C2_HomeLang + C3_SameLang	8.43	5
Birds	Language use	C2_HomeLang, 2 + C1_ParentMaxFluency, 1	132.04	6
Birds	Language use	C3_SameLang	349.94	4
Birds	Language use	Null (random factors + intercept)	569.16	3
Birds	Student traits	D1_Gender + D2_GradeEng^3 + D4_TradSkills + D5_ModSkills	0	9
Birds	Student traits	D1_Gender + D2_GradeEng^2 + D4_TradSkills + D5_ModSkills	1.99	8
Birds	Student traits	D1_Gender + D2_GradeEng^3 + D3_GradeMath^3 + D4_TradSkills + D5_ModSkills	5.17	12
Birds	Student traits	D1_Gender + D2_GradeEng + D4_TradSkills + D5_ModSkills	19.08	7
Birds	Student traits	D1_Gender + D2_GradeEng^3 + D3_GradeMath^3 + D6_Trad.Mod	22.33	11
Birds	Student traits	D1_Gender + D4_TradSkills + D5_ModSkills	42.13	6
Birds	Student traits	D2_GradeEng^3 + D4_TradSkills + D5_ModSkills	81.35	8
Birds	Student traits	D2_GradeEng^3 + D3_GradeMath^3 + D4_TradSkills + D5_ModSkills	81.96	11
Birds	Student traits	D2_GradeEng^2 + D4_TradSkills + D5_ModSkills	84.53	7
Birds	Student traits	D2_GradeEng + D4_TradSkills + D5_ModSkills	100.34	6
Birds	Student traits	D4_TradSkills + D5_ModSkills	125.79	5
Birds	Student traits	D2_GradeEng^3 + D6_Trad.Mod	162.11	7
Birds	Student traits	D1_Gender + D2_GradeEng^3 + D3_GradeMath^3 + D4_TradSkills	180.34	11
Birds	Student traits	D1_Gender + D2_GradeEng^3 + D3_GradeMath^3 + D5_ModSkills	243.15	11
Birds	Student traits	Null (random factors + intercept)	1066.42	3

Table S6. Continued.

Taxon	Variable class	Models – Student trait variables	dAICc	df
Plants	Socio-economic	B1_Urbanization + B2_Isolation^2 + B3_ParentEdu + B4_ParentJob	0	8
Plants	Socio-economic	B1_Urbanization + B2_Isolation^2 + B3_ParentEdu + B4_ParentJob^2	0.33	9
Plants	Socio-economic	B1_Urbanization + B2_Isolation^2 + B3_ParentEdu^2 + B4_ParentJob	1.49	9
Plants	Socio-economic	B1_Urbanization + B2_Isolation^2 + B3_ParentEdu^2 + B4_ParentJob^2	1.95	10
Plants	Socio-economic	B1_Urbanization + B2_Isolation^3 + B3_ParentEdu + B4_ParentJob^2	2.27	10
Plants	Socio-economic	B1_Urbanization^2 + B2_Isolation^3 + B3_ParentEdu + B4_ParentJob^2	4.27	11
Plants	Socio-economic	B1_Urbanization + B2_Isolation^2 + B3_ParentEdu	5.12	7
Plants	Socio-economic	B1_Urbanization + B2_Isolation + B3_ParentEdu + B4_ParentJob	14.16	7
Plants	Socio-economic	B1_Urbanization + B2_Isolation + B3_ParentEdu + B4_ParentJob^2	14.22	8
Plants	Socio-economic	B1_Urbanization + B3_ParentEdu + B4_ParentJob^2	24.50	7
Plants	Socio-economic	B1_Urbanization + B2_Isolation^2 + B4_ParentJob^2	25.19	8
Plants	Socio-economic	B1_Urbanization + B2_Isolation^2 + B4_ParentJob	27.28	7
Plants	Socio-economic	B2_Isolation^2 + B3_ParentEdu + B4_ParentJob^2	181.05	8
Plants	Socio-economic	Null (random factors + intercept)	392.61	3
Plants	Language use	C2_HomeLang^2 + C1_ParentMaxFluency + C3_SameLang	0	7
Plants	Language use	C2_HomeLang + C3_SameLang	0.57	5
Plants	Language use	C2_HomeLang^2 + C1_ParentMaxFluency^2 + C3_SameLang	1.70	8
Plants	Language use	C2_HomeLang + C1_ParentMaxFluency + C3_SameLang	1.72	6
Plants	Language use	C2_HomeLang^2 + C1_ParentMaxFluency	37.32	6
Plants	Language use	+C3_SameLang	185.97	4
Plants	Language use	Null (random factors + intercept)	263.85	3
Plants	Student traits	D1_Gender + D2_GradeEng^2 + D4_TradSkills + D5_ModSkills	0	8
Plants	Student traits	D1_Gender + D2_GradeEng^3 + D4_TradSkills + D5_ModSkills	0.25	9
Plants	Student traits	D1_Gender + D2_GradeEng^3 + D3_GradeMath^3 + D4_TradSkills + D5_ModSkills	1.79	12
Plants	Student traits	D1_Gender + D2_GradeEng^3 + D3_GradeMath^3 + D6_Trad.Mod	2.63	11
Plants	Student traits	D2_GradeEng^2 + D4_TradSkills + D5_ModSkills	5.28	7
Plants	Student traits	D2_GradeEng^3 + D4_TradSkills + D5_ModSkills	5.31	8
Plants	Student traits	D2_GradeEng^3 + D3_GradeMath^3 + D4_TradSkills + D5_ModSkills	6.66	11
Plants	Student traits	D1_Gender + D2_GradeEng + D4_TradSkills + D5_ModSkills	6.70	7
Plants	Student traits	D1_Gender + D4_TradSkills + D5_ModSkills	11.44	6
Plants	Student traits	D2_GradeEng + D4_TradSkills + D5_ModSkills	11.68	6
Plants	Student traits	D2_GradeEng^3 + D6_Trad.Mod	13.18	7
Plants	Student traits	D4_TradSkills + D5_ModSkills	16.85	5
Plants	Student traits	D1_Gender + D2_GradeEng^3 + D3_GradeMath^3 + D5_ModSkills	94.18	11
Plants	Student traits	D1_Gender + D2_GradeEng^2 + D4_TradSkills	94.81	7
Plants	Student traits	D1_Gender + D2_GradeEng^3 + D3_GradeMath^3 + D4_TradSkills	96.51	11
Plants	Student traits	Null (random factors + intercept)	369.48	3

Table S7. Model selection results for the candidate models assessing the combined role of the four variable classes A – D on the knowledge of bird species (E1) and traditional plant use (E2) by students. dAICc = delta corrected Akaike Information Criterion, df = degrees of freedom. All models include Student and Language as random factors on the intercept.

Taxon	Combined Model classes	Combined model variables	dAICc	df
Birds	Socio-Economic + Student	L1_BodyParts^2 + B1_Urbanization + B3_ParentEdu^2 + D1_Gender + D4_TradSkills + D5_ModSkills	0	11
Birds	Socio-Economic + Student	L1_BodyParts^2 + B1_Urbanization + B2_Isolation^2 + B3_ParentEdu^2 + B4_ParentJob^2 + D1_Gender + D2_GradeEng^2 + D4_TradSkills + D5_ModSkills	3.30	17
Birds	Socio-Economic + Student	L1_BodyParts^2 + B1_Urbanization + B2_Isolation^2 + B3_ParentEdu^2 + B4_ParentJob^2 + D1_Gender + D2_GradeEng^2 + D4_TradSkills + D5_ModSkills + C2_HomeLang^2 + C1_ParentMaxFluency^2 + C3_SameLang	4.10	22
Birds	Student traits + Family lan	L1_BodyParts^2 + D1_Gender + D2_GradeEng^2 + D4_TradSkills + D5_ModSkills + C2_HomeLang^2 + C1_ParentMaxFluency^2 + C3_SameLang	44.70	15
Birds	Socio-Economic + Family la	L1_BodyParts^2 + B1_Urbanization + B2_Isolation^2 + B3_ParentEdu^2 + B4_ParentJob^2 + C2_HomeLang^2 + C1_ParentMaxFluency^2 + C3_SameLang	387.30	17
Birds	Language skills	L1_BodyParts^2	572.70	5
Birds	Socio-Economic + Student	B1_Urbanization + B2_Isolation^2 + B3_ParentEdu^2 + B4_ParentJob^2 + D1_Gender + D2_GradeEng^2 + D4_TradSkills + D5_ModSkills	1467.70	15
Birds	Student traits	D1_Gender + D2_GradeEng^2 + D4_TradSkills + D5_ModSkills	1799.80	9
Birds	Socio-Economic	B1_Urbanization + B2_Isolation^2 + B3_ParentEdu^2 + B4_ParentJob^2	2038.40	9
Birds	Family language use	C2_HomeLang^2 + C1_ParentMaxFluency^2 + C3_SameLang	2299.60	6
Birds	Null	Null (random factors + intercept)	2866.20	3
Plants	Socio-Economic + Student	L1_BodyParts^2 + B1_Urbanization + D1_Gender + D4_TradSkills + D5_ModSkills + C2_HomeLang	0	10
Plants	Socio-Economic + Student	L1_BodyParts^2 + B1_Urbanization + B2_Isolation^2 + B3_ParentEdu + B4_ParentJob + D1_Gender + D2_GradeEng^2 + D4_TradSkills + D5_ModSkills + C2_HomeLang + C3_SameLang	5.20	17
Plants	Socio-Economic + Student	L1_BodyParts^2 + B1_Urbanization + B2_Isolation^2 + B3_ParentEdu + B4_ParentJob + D1_Gender + D2_GradeEng^2 + D4_TradSkills + D5_ModSkills	10.10	15
Plants	Student traits + Family lan	L1_BodyParts^2 + B1_Urbanization + B2_Isolation^2 + B3_ParentEdu + B4_ParentJob + D1_Gender + D2_GradeEng^2 + D4_TradSkills + D5_ModSkills + C2_HomeLang + C3_SameLang	28.00	12
Plants	Socio-Economic + Family la	L1_BodyParts^2 + B1_Urbanization + B2_Isolation^2 + B3_ParentEdu + B4_ParentJob + D1_Gender + D2_GradeEng^2 + D4_TradSkills + D5_ModSkills + C2_HomeLang + C3_SameLang	62.00	12
Plants	Socio-Economic + Student	L1_BodyParts^2 + B1_Urbanization + B2_Isolation^2 + B3_ParentEdu + B4_ParentJob + D1_Gender + D2_GradeEng^2 + D4_TradSkills + D5_ModSkills + C2_HomeLang + C3_SameLang	408.60	15
Plants	Socio-Economic	L1_BodyParts^2 + B1_Urbanization + B2_Isolation^2 + B3_ParentEdu + B4_ParentJob + D1_Gender + D2_GradeEng^2 + D4_TradSkills + D5_ModSkills + C2_HomeLang + C3_SameLang	601.00	9
Plants	Student traits	L1_BodyParts^2 + B1_Urbanization + B2_Isolation^2 + B3_ParentEdu + B4_ParentJob + D1_Gender + D2_GradeEng^2 + D4_TradSkills + D5_ModSkills + C2_HomeLang + C3_SameLang	622.90	9
Plants	Family language use	L1_BodyParts^2 + B1_Urbanization + B2_Isolation^2 + B3_ParentEdu + B4_ParentJob + D1_Gender + D2_GradeEng^2 + D4_TradSkills + D5_ModSkills + C2_HomeLang + C3_SameLang	730.00	6
Plants	Language skills	L1_BodyParts^2 + B1_Urbanization + B2_Isolation^2 + B3_ParentEdu + B4_ParentJob + D1_Gender + D2_GradeEng^2 + D4_TradSkills + D5_ModSkills + C2_HomeLang + C3_SameLang	861.50	4
Plants	Null	Null (random factors + intercept)	992.10	3

Dataset S1 Legend

Population size of PNG languages in year 2000.

Dataset S2 Legend

Data for the independent and dependent variables for individual respondents, used for the GLMM analyses.

Dataset S3 Legend

Questionnaire used for data collection.

SI References

1. D. M. Eberhard, G. F., Simons, C. D. Fennig, Eds., *Ethnologue: Languages of the World* (SIL International, ed. 23, 2020).
2. Worldometers, *Papua New Guinea Population* (March 2020); https://www.worldometers.info/world-population/papua-new-guinea-population/.
3. National Statistical Office (NSO), *Papua New Guinea 2000 Census: Final Figures* (NSO, Port Moresby, 2002).
4. A. Jarvis, H. I. Reuter, A. Nelson, E. Guevara, Hole-filled seamless SRTM data V4. (Int. Ctr. Trop. Agric. CIAT (September 2020); http://srtm.csi.cgiar.org.
5. PNG Bible Translation Association (PNGBTA), *Papua New Guinea Scriptures* (March 2020); https://png.bible/.
6. S. J. Greenhill, *TransNewGuinea.org, a Database of the Languages of New Guinea* March 2020); http://transnewguinea.org/.
7. R. Cámara–Leret, Z. Dennehy, Indigenous knowledge of New Guinea's useful plants: a review, *Econ. Bot.* **73**, 405–415 (2019).
8. H. Hammarström, R. Forkel, M. Haspelmath, S. Bank, Sebastian, *Glottolog 4.2.1*. (Max Planck Inst. Science of Human History, Jena (March 2020); http://glottolog.org.
9. National Statistical Office (NSO), *Papua New Guinea Demographic and Health Survey 2016-18* (NSO, 2019).
10. National Statistical Office (NSO). *2009-2010 Papua New Guinea Household Income and Expenditure Survey*, (NSO, 2011).
11. United Nations, *World Urbanization Prospects: The 2018 Revision*, (United Nations, 2019).
12. World Bank, *Data Catalog: Educational Statistics* (March 2020); https://datacatalog.worldbank.org/dataset/education-statistics.

Language and ethnobiological skills decline precipitously in Papua New Guinea, the world's most linguistically diverse nation

A. Kik*, M. Adamec, A. Y. Aikhenvald, J. Bajzekova, N. Baro, C. Bowern, R. K. Colwell, P. Drozd, P. Duda, S. Ibalim, L.R. Jorge, J. Mogina, B. Ruli, K. Sam, H. Sarvasy, S. Saulei, G.D.Weiblen, J. Zrzavy, V. Novotny*

***Corresponding authors:** Alfred Kik Email: akik@prf.jcu.cz and Vojtech Novotny Email novotny@entu.cas.cz

Dataset S1. Questionnaire used for data collection.

Welcome to the survey of tokples language skills and ethno-biological knowledge in the Madang Province

Thank you for taking part in the survey

Papua New Guinea has the highest number of languages in the world. However, nobody knows how these languages are passed on the new generation of Papua New Guineans. Please, take a short test and help us find out! This study is a project by **Alfred Kik**, based at the New Guinea Binatang Research Center in Madang and the University of PNG in Port Moresby.

Please circle one or several correct answers to each question, or fill the information needed on dotted line: ....

Example: are you a student? [yes] [no]

Your personal information (all information is anonymous, without your name)

1. I am a **[boy]** **[girl]** (circle correct answer)

2. My year of birth .... (make a guess if you are not sure)

4. I was born in the village or town: ....
District .... Province ....

5. I spent most of my pre-school years in the village or town: ....
It is (circle one answer):

[my parent's village]

[my mother's village]

[my father's village]

[another village]

[government station]

[provincial town or city]

[overseas]

6. If you spent pre-school years in a village or a government station, did it have:
(circle correct answer)

road access by car: [yes] [no]

airstrip: [yes] [no]

boat access by river/sea: [yes] [no]

access ONLY by walking: [yes] [no]

electricity: [yes] [no]

7. My family is now living in the village or town: .... It is:

[my parent's village]

[my mother's village]

[my father's village]

[another village]

[government station]

[provincial town or city] [overseas]

8. Does your family own land? **[yes] [no]** If yes, do you own land with:

undisturbed forest - big bush: [yes] [no]

logged forest: [yes] [no]

cash crop plantation (coffee, coconut, cocoa, oil palm): [yes] [no]

food gardens: [yes] [no]

grassland/kunai: [yes] [no]

settlement area: [yes] [no]

9. I have .... sisters and .... brothers
(sharing at least one parent, including adopted ones)

10. My grade 10 results (circle your grade for each subject):

English: [distinction] [credit] [upper pass] [pass] [fail]

Mathematics: [distinction] [credit] [upper pass] [pass] [fail]

Science: [distinction] [credit] [upper pass] [pass] [fail]

Social science: [distinction] [credit] [upper pass] [pass] [fail]

11. Do you know how to:

hunt animals in forest: [well] [a little] [no]

catch fish: [well] [a little] [no]

plant gardens: [well] [a little] [no]

build village house: [well] [a little] [no]

make a mumu: [well] [a little] [no]

use plants to treat fever: [well] [a little] [no]

use mobile phone: [well] [a little] [no]

use computer: [well] [a little] [no]

12. What language do you use most of the time in your home?

[English]

[Tok pisin]

[Tok ples]

13. Is your best friend speaking the same tokples as you?

[same]

[different]

[one of us do not speak any tokples]

[both of us do not speak any tokples]

14. What field have you streamed into?

[Science]

[Social science]

Your mother

1. She was born in the village (her asples): ....
District .... Province ....

2. The name of her tokples (or the name of the village where it is spoken): ....
or circle: **[do not know]**

3. She speaks tokples (circle one answer):
[very well]
[poorly]
[does not speak it but can understand]
[does not speak or understand it at all]

4. Her highest completed education (circle one answer):
[no school]
[elementary school up to grade ....]
[primary school up to grade ....]
[secondary school up to grade ....]
[university certificate] [university diploma] [BSc] [postgraduate]

5. Her present or past jobs (circle one or several answers):
[caring for family/subsistence farming]
[cash crop farming]
[salaried job (write what job): ....]
[own business (write what business): ....]

Your father

1. He was born in the village (his asples): ....
District .... Province ....

2. The name of his tokples (or the name of the village where it is spoken): ....
or circle: **[do not know]**

3. He speaks tokples (circle one answer):
[very well]
[poorly]
[does not speak it but can understand]
[does not speak or understand it at all]

4. His highest completed education (circle one answer):
[no school]
[elementary school up to grade ....]
[primary school up to grade ....]
[secondary school up to grade ....]
[university certificate] [university diploma] [BSc] [postgraduate]

5. His present or past jobs (circle one or several answers):
[caring for family/subsistence farming]
[cash crop farming]
[salaried job (write what job): ....]
[own business (write what business): ....]

Your language skills:

1. Does your mother and father speak the same tokples? **[yes] [no]**

2. I speak my mother's tokples (circle one answer):

[very well]

[poorly]

[do not speak it but can understand]

[do not speak or understand it at all]

3. I speak my my father's tokples (circle one answer):

[very well]

[poorly]

[do not speak it but can understand]

[do not speak or understand it at all]

4. I speak also another tokples: **[yes] [no]** If yes, then:
Tokples name or the name of the village where spoken: ....
I speak it:

[very well]

[poorly]

[do not speak it but can understand]

[do not speak or understand it at all]

5. Will you teach tokples to your children? (circle one or several answers)

[no because I do not speak it myself]

[no because it is not a useful skill for my children]

[no because it belongs to an old culture that is now out of date]

[yes because everybody in my village/town area does it]

[yes because it is a useful skill for my children]

[yes because it is a part of my culture]

Language test

We will show you 24 body parts. See how many of them you can name in tokples!
If you speak more than one tokples, use the tokples language you know best. If you do not speak any tokples, circle **[I do not know]** in all cases.

The name of the tokples language used (or the name of the village where it is spoken):

.... or circle: **[do not know]**

Body part No. 1

English: Ear

Tokples name: .... or circle: [do not know]

Body part No 2

English: Ankle

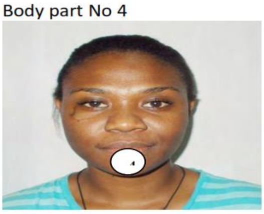
Tokples name:...or circle [do not know]

Body part No **3**

English: Eye

Tokples name:...or circle [do not know]

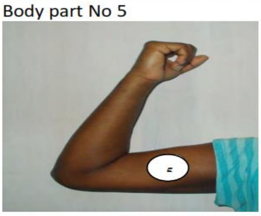
Body part No 4



English: Chin

Tokples name:...or circle [do not know]

Body part No 5



English: Bicep

Tokples name:...or circle [do not know]

Body part No 6

English: Eyebrow

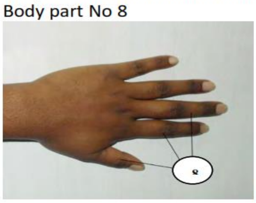
Tokples name:……………………………………………………………or circle [do not know]

Body part No 7

English: Calf

Tokples name:……………………………………………………………or circle [do not know]

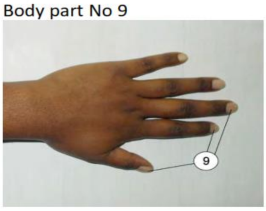
Body part No 8



English: Fingers

Tokples name:……………………………………………………………or circle [do not know]

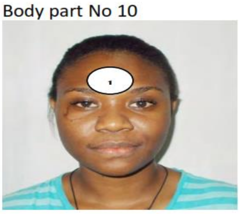
Body part No 9



English: Fingernail

Tokples name:……………………………………………………………or circle [do not know]

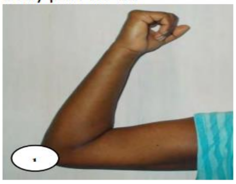
Body part No 10



English: Forehead

Tokples name:……………………………………………………………or circle [do not know]

Body part No 11



English: Elbow

Tokples name:……………………………………………………………or circle [do not know]

Body part No 12

English: Neck

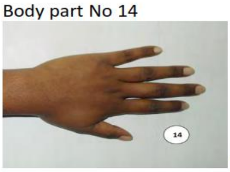
Tokples name:……………………………………………………………or circle [do not know]

Body part No 13

English: Eyelid

Tokples name:……………………………………………………………or circle [do not know]

Body part No 14



English: Hand

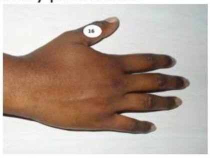
Tokples name:……………………………………………………………or circle [do not know]

Body part No 15

English: Head

Tokples name:……………………………………………………………or circle [do not know]

Body part No 16



English: Thumb

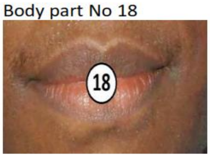
Tokples name:……………………………………………………………or circle [do not know]

Body part No 17

English: Heel

Tokples name:……………………………………………………………or circle [do not know]

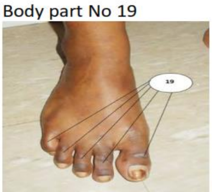
Body part No 18



English: Lips

Tokples name:……………………………………………………………or circle [do not know]

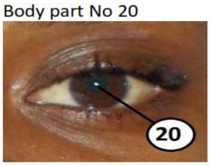
Body part No 19



English: Toe

Tokples name:……………………………………………………………or circle [do not know]

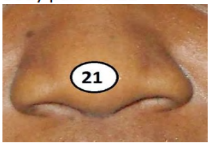
Body part No 20



English: Pupil

Tokples name:……………………………………………………………or circle [do not know]

Body part No 21



English: Nose

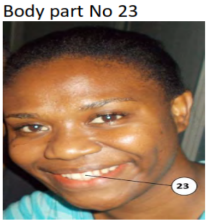
Tokples name:……………………………………………………………or circle [do not know]

Body part No 22

English: Toenails

Tokples name:……………………………………………………………or circle [do not know]

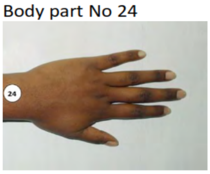
Body part No 23



English: Teeth

Tokples name:……………………………………………………………or circle [do not know]

Body part No 24



English: Wrist

Tokples name:……………………………………………………………or circle [do not know]

Birds test

We will show you 20 species of PNG birds from lowlands (nambis), and 20 species from the Highlands. You can choose either **lowland** or **highland** species, depending on which birds you know better. You can also try both groups and we will use the results from the group where you achieved better results.

Please write tokples name for each bird species (or circle [I do not know] option).
Use the same tokples language as you used for the language test.
If you do not know tokples name, try at least Tok Pisin or English

Highlands birds

Bird species No. 1

Scientific name: *Aepypodius arfakianus*

Tokples name: .... or circle: [do not know]

Tok Pisin or English name ....

Bird species No. 2

Scientific name: *Casuarius bennetti*

Tokples name: .... or circle: [do not know]

Tok Pisin or English name ....

Bird species No. 3

Scientific name: *Astrapia stephaniae*

Tokples name: .... or circle: [do not know]

Tok Pisin or English name ....

Bird species No. 4

Scientific name: Peltop montanus

Tokples name: .... or circle: [do not know]

Tok Pisin or English name ....

Bird species No. 5

Male Female

Scientific name: Alisterus chloropetrus

Tokples name: .... or circle: [do not know]

Tok Pisin or English name ....

Bird species No. 6

Scientific name: *Chaetorhynchus papuensis*

Tokples name: .... or circle: [do not know]

Tok Pisin or English name ....

Bird species No. 7

Scientific name: *Rhipidura albolimbata*

Tokples name: .... or circle: [do not know]

Tok Pisin or English name ....

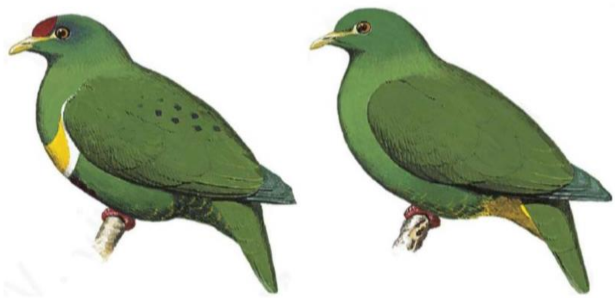
Bird species No. 8

Scientific name: *Accipiter soloensis*

Tokples name for species : ....or circle: [do not know]

Tok Pisin or English name species ....

Bird species No. 9



Male Female

Scientific name: *Ptilinopus pulchellus*

Tokples name: .... or circle: [do not know]

Tok Pisin or English name ....

Bird species No. 10

Scientific name: *Aegotheles insignis*

Tokples name: .... or circle: [do not know]

Tok Pisin or English name ....

Lowlands birds:

Bird species No. 1

Scientific name: *Talegalla jobiensis*

Tokples name: .... or circle: [do not know]

Tok Pisin or English name ....

Bird species No. 2

Scientific name: *Casuarius unappendiculatus*

Tokples name: .... or circle: [do not know]

Tok Pisin or English name ....

Bird species No. 3

Scientific name: *Paradisaea minor*

Tokples name: .... or cir

Tok Pisin or English name ....

Bird species No. 4

Scientific name: *Peltops blainvillii*

Tokples name: .... or circle: [do not know]

Tok Pisin or English name ....

Bird species No. 5

Scientific name: *Lorius lorry*

Tokples name: .... or circle: [do not know]

Tok Pisin or English name ....

Bird species No. 6

Scientific name: *Dicrurus bracteatus*

Tokples name: .... or circle: [do not know]

Tok Pisin or English name ....

Bird species No. 7

Scientific name: *Rhipidura threnothorax*

Tokples name: .... or circle: [do not know]

Tok Pisin or English name ....

Bird species No. 8

Scientific name: *Accipiter fasciatus*

Tokples name: .... or circle: [do not know]

Tok Pisin or English name ....

Bird species No. 9

Scientific name: *Ptilinopus ornatus*

Tokples name: .... or circle: [do not know]

Tok Pisin or English name ....

Bird species No. 10

Scientific name: *Caprimulgus macrurus*

Tokples name: .... or circle: [do not know]

Tok Pisin or English name ....

Plants test

List up to 10 plant species which you know and can use for medicinal, sorcery, or other traditional use. Write the tokples name of each plant (or at least Tok Pisin or English if you do not know tokples name), and describe its use.

	Tokples plant name	Tok Pisin/English name	Plant use (medicinal, sorcery, other traditional, but not food)
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

CHAPTER II

Hunting skills and ethnobiological knowledge among the young, educated Papua New Guineans: Implications for conservation

[*Global Ecology and Conservation*: https://doi.org/10.1016/j.gecco.2023.e02435]

(IF = 3.97)

Global Ecology and Conservation 43 (2023) e02435

Contents lists available at ScienceDirect

Global Ecology and Conservation

journal homepage: www.elsevier.com/locate/gecco

Hunting skills and ethnobiological knowledge among the young, educated Papua New Guineans: Implications for conservation

Alfred Kik [a,b,*], Pavel Duda [a], Jarmila Bajzekova [a,b], Nigel Baro [c], Redley Opasa [c], Gibson Sosanika [e], Leonardo R. Jorge [b], Paige West [d], Katerina Sam [a,b], Jan Zrzavy [a], Vojtech Novotny [a,b]

[a] Faculty of Sciences, University of South Bohemia, Ceske Budejovice, Czech Republic
[b] Biology Centre, Czech Academy of Sciences, Ceske Budejovice, Czech Republic
[c] New Guinea Binatang Research Center, Madang, Papua New Guinea
[d] Barnard College, Columbia University, New York, USA
[e] Bulolo University College, Papua New Guinea University of Technology, Morobe, Papua New Guinea

A R T I C L E I N F O

Keywords:
Biodiversity conservation
Ethnobiological knowledge
Hunting skills
Education
Indigenous communities
Tropical forests

A B S T R A C T

Hunting, as a component of traditional indigenous livelihoods, can play either positive or negative role in biodiversity conservation by maintaining traditional lifestyles that are conducive to conservation or by endangering vulnerable hunted species. Quantitative data on changes in hunting skills in indigenous communities driven by education, employment, and other lifestyle changes are lacking. Here we assess hunting skills of young people in Papua New Guinea (PNG). We use a sample of 7818 secondary school students, representing 15% of the most educated individuals in their age cohort. Students self-assessed their hunting skills as none (34% of respondents), poor (46%), and good (20%). Male students reported significantly higher hunting skills than female students. Hunting skills were positively correlated with knowledge of local bird species and with other traditional skills (growing food, using medicinal plants, building houses). They were negatively correlated with math and English skills, as well as with the transportation accessibility of the village/town where the students grew up. Students who grow up in town reported significantly lower hunting skills than those who grew up in village. These results show that students' hunting skills are already low, and the trends in their socio-cultural drivers predict a further decline in the future. The increasing disconnection from the natural environment and the declining attractiveness of hunting as prestigious activity for the young and educated people are part of a broader trend of loss of ethnobiological knowledge in PNG's indigenous communities. While it may reduce hunting pressure on some endangered species, it may also remove traditional incentives for conservation in rainforest-dwelling communities.

* Correspondence to: Faculty of Sciences, University of South Bohemia, Branisovska 1760, 370 05 Ceske Budejovice, Czech Republic.
E-mail address: akik@prf.jcu.cz (A. Kik).

https://doi.org/10.1016/j.gecco.2023.e02435
Received 22 October 2022; Received in revised form 12 March 2023; Accepted 12 March 2023
Available online 13 March 2023

1. Introduction

1.1. The benefits of hunting

Hunting plays numerous roles in the indigenous communities of rainforest dwellers in the tropics. It is a part of cultural heritage, a way to enhance personal prestige, a source of food, raw materials, and trophies, a source of income, and a sport and leisure activity (Brashares et al., 2011; Luz et al., 2017; Milner-Gulland and Bennett, 2003; Nielsen et al., 2018). A conservative projection by Nielsen et al. (2018) indicates that more than 150 million households in Latin America, Asia, and Africa rely to some extent on wild meat for subsistence or as a source of income. Although hunting is widespread in agricultural rural communities, it generally accounts for a relatively small portion of income and diet. This is the case in rainforest communities from PNG (Mack and West, 2005) or the Yanomamo from the Amazon who spend as much time hunting as growing food in their gardens, although the gardens provide 80–90% of their food (Chagnon, 2012). However, the extent of hunting and its benefits may vary across countries (Nielsen et al., 2017, 2018).

PNG has high forest cover, 78% of the land area (Gamoga et al., 2021), low population density of 20 persons per km^2, and a predominantly rural population, with 87% of the population living in villages (Worldometers, 2020). The diversity and biomass of larger animals that can be hunted for food is low in New Guinea's marsupial-dominated forests (Cuthbert, 2010; Mack and West, 2005). Hence, Mack and West (2005) argue that hunted animals in PNG should be referred to as "wild meat" because there is little or no market for it and the animals are killed mainly for consumption by the hunter and his family, as opposed to game or "bushmeat" where the hunted animals are killed to generate income. Demand for wild meat from urban populations is also limited (Mack and West, 2005). Culturally important species such as cassowaries, crocodiles, pythons, and tree kangaroos are used to pay bride prices or for other traditional payments (Mack and West, 2005; Saulei and Aruga, 1994). A greater number of species are hunted to be used as trophies, and as ornaments and to obtain materials for costumes for traditional dances and ceremonies (Supuma, 2018).

1.2. Increasing hunting pressure in PNG

Traditional hunting in PNG has often been made sustainable through a combination of taboo forest areas or taboo hunting seasons with inefficient hunting techniques, usually using bows and arrows (Supuma, 2018). Many conservation-friendly traditional practices are grounded in traditional belief systems (West and Brockington, 2006) but may no longer be observed or effective due to cultural change, including the spread of Christianity in PNG (Jacka, 2010; Raymond, 2007; Robbins, 1995; Smith and Wishnie, 2000).

Hunting in PNG may already be unsustainable in many places or is becoming so due to increased hunting pressure from a rapidly growing population (Cuthbert, 2010; Mack and West, 2005; Nugi and Whitmore, 2020). Lifestyle changes in PNG are accompanied by unprecedented population growth of $>$ 2% per year, which has tripled the population over the past 50 years (Worldometers, 2020). These changes may alter the way wildlife are used and managed and threaten some hunted species (Godoy et al., 2005; Shen et al., 2012). Fortunately, hunting methods remain largely traditional, without the use of firearms that is common in many other countries. In the absence of large animals that can be hunted for wild meat, with the important exception of introduced wild pigs (Ayalew et al., 2011), a few larger species such as tree kangaroos and cassowaries, as well as long-billed echidnas, cuscuses, wallabies, ringtails, and others, could be hunted to local extinction (Cuthbert, 2010). The effects of hunting may be exacerbated by low reproductive rates of the long-beaked echidna, tree kangaroos, cuscuses, and other marsupial species (Cuthbert, 2010).

With over 97% of PNG's indigenous population owning land (Armitage, 2001), there is virtually no government control over hunting, even in protected areas. The Faunal Act of 1996 lists protected bird and mammal species, including all birds of paradise and tree kangaroo (*Dendrolagus*) species, but lacks a system of enforcement and monitoring (Shearman and Bryan, 2015).

1.3. Lifestyle changes divert interest in hunting

Changing lifestyles, including new employment opportunities (Gill et al., 2012) or the introduction of alternative sources of income, such as growing coffee, vanilla, or other cash crops, may reduce the attractiveness of hunting (Sirén and Parvinen, 2015; Vasco and Sirén, 2016), which can be perceived as laborious and unprofitable by comparison (Williams and Knight, 2021). Conservation projects can introduce alternative sources of meat or income to achieve a reduction in hunting activities (Williams and Knight, 2021).

Hunting skills are often replaced by educational achievement as a source of personal prestige in rural communities (Luz, 2015). Hunting as a source of entertainment increasingly competes with sports, such as football and rugby, and with online entertainment. This is fueled by the expansion of mobile phone signal coverage (Foster & Horst, 2018). These factors may be exacerbated by urbanization, as well as increased accessibility of village communities through the expanding road network (Gray et al., 2015; Vasco and Sirén, 2016). Loss of regular contact with the natural environment and loss of traditional ecological knowledge, including detailed information on wildlife ecology, may lead to abandonment of hunting but also make traditional habitat management and wildlife conservation less effective (Aswani et al., 2018; Kik et al., 2021). For example, traditional knowledge of bird taxonomy, ecology, and behavior may be useful for both hunting and conservation management.

Given the ambiguous relationship between hunting and nature conservation, the ongoing change of the way of life of indigenous peoples in PNG can have either negative or positive effect on the survival of hunted species. Therefore, it is important to quantify the extent of that change, especially among the younger people, and to examine the relationship between hunting and ethnobiological knowledge. At present, there is only one quantitative study of hunting sustainability in PNG (Cuthbert, 2010) and a few anthropological studies of individual rural communities (Nugi and Whitmore, 2020; Sillitoe, 2001; Williams and Knight, 2021; Van Den Bergh et al., 2013; Mack and West, 2005). In order to fill this knowledge gap, we conducted a countrywide survey among young, educated

Papua New Guineans. We aim to (1) assess their self-reported hunting skills, (2) assess socio-cultural drivers of hunting skills, and (3) investigate the relationship between hunting skills and ethnobiological knowledge as well as other traditional skills.

2. Materials and methods

2.1. Student survey

We conducted a survey that included sociodemographic characteristics, family background, level of language proficiency, traditional skills including hunting, and ethnobiological knowledge of secondary school students (grades 11 and 12, i.e., two senior years in the 4-year secondary education) in PNG. The survey was conducted in English, the official language of education, from 14 April 2015–14 November 2018. It included thirty rural and urban secondary schools (24% of the country's total) representing a culturally diverse sample of students speaking 392 languages from all of PNG's provinces (Fig. 1 *R*). Students were gathered in a common room (e.g., a dining hall) where they completed the questionnaire anonymously within one hour (Fig. 1 *L*). Students received small gifts such as pens for their participation. Although participation was voluntary, all students took the survey, which minimized the risk of bias among students with lower interest in hunting who might not want to participate in other settings. The survey was approved by the Education Departments of the Provincial Governments and the Institutional Review Board of the New Guinea Binatang Research Center (BRC_03_15/01/2015). All participants provided informed consent before participating in the survey.

2.2. Variable choice

We used selected questions from a comprehensive questionnaire (Document S1) to examine the hunting skills of students and their drivers. The dependent variable "hunting skills" was based on the question "Do you know how to hunt animals in the forest?", which was a Likert-type item scored on a three-point scale (0 "no hunting skills", 1 "poor hunting skills", 2 "good hunting skills") (Table S3). Similarly scored responses to questions about skills in fishing, growing food, building a house from traditional forest materials, and treating fever with medicinal plants were combined into a single continuous predictor variable called *traditional skills*. Here we have taken the sum of the scores of each traditional skill listed above for each respondent. Other predictor variables were *gender* (male or female), *urbanization*, i.e., where the student lived during childhood, coded as village (1) or town or city (2), *remoteness*, i.e., whether the student's home was accessible by road (1), only by boat (2), only by plane (3), or only on foot (4), *parental education*: the highest education attained by a parent is reported as no school (1), lower primary (first through sixth grades) (2), higher primary (seventh through eighth grades) (3), lower secondary (9th through 10th grades) (4), higher secondary (11th through 12th grades) (5), or any tertiary education (6), *parents' employment*: the highest employment category attained by a parent is reported as subsistence farming (1), cash crop farming (2), or salaried job or small business (3) were averaged into a single continuous variable, *modern skills*: the students' skills in using the telephone and computer were averaged into a single continuous variable, and students' lower secondary (grade 10) *math and English scores*, distinction (1), credit (2), upper pass (3), and pass or fail (4), were averaged into a single continuous variable.

Students also identified two groups of 10 bird species that are geographically widespread, one from montane regions and one from lowland regions, in their local language. Each group included a range of species that are widely known and easily recognized (e.g., cassowary), as well as species that are difficult to identify. For each student, the higher value of the two species groups was used to minimize bias due to the student's region of origin.

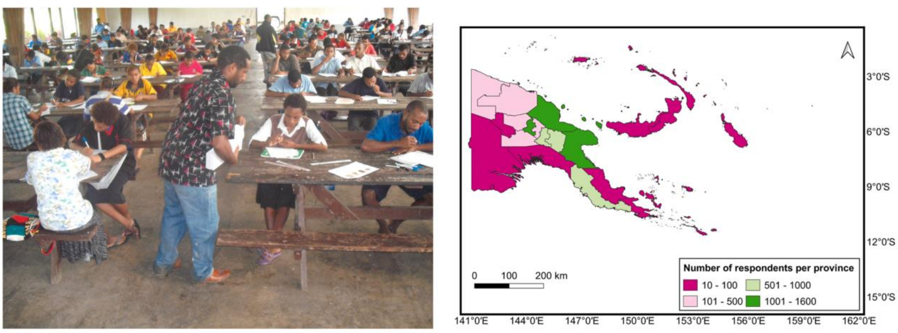


Fig. 1. Ethnobiological skills test administered at Brahman secondary school in 2015 (*L*) and PNG map showing the number of students surveyed (*R*).

2.3. Statistical analysis

We tested the drivers of hunting skills, using the variables described in the above section as predictors. Our analysis requires ordinal approaches, namely logistic regressions, due to the non-linear and ordered nature of the dependent variable. Because the proportionality assumption (the Brant test) for gender was violated (Table S1), we used a partial proportional odds model to examine the explanatory variables associated with hunting skill ratings (Peterson and Harrell Jr, 1990). The vglm function from the VGAM package was used to estimate the model (Yee, 2010). Each variable was normalised before fitting the model. Odds ratio estimates (OR) and 95% confidence intervals (CIs) were used to interpret the results (Sengeh et al., 2020; Suri et al., 2019). The analysis yielded two odds ratios for the gender variable (none vs. poor/good [OR_1] and none/poor vs. good [OR_2]) due to violation of the proportional odds assumption (Williams, 2006). For the variables that did not violate the assumption, a single OR was reported. A p-value of < 0.05 was defined as statistically significant for all tests. We performed model selection to determine the best-fitting combinations of explanatory variables using the Akaike Information Criterion (AIC). We intentionally omitted interactions to avoid inflation in the number of models considered and to limit the degrees of freedom in the models. The simplest model with the lowest ΔAIC was selected for the report (Burnham and Anderson, 2004) (Table S2). The data used for the analysis can be found in Supporting Information Dataset S1. All analyses were performed in R version 4.0.5 (R Core Team, 2021).

3. Results

We sampled 8708 participants but excluded 890 (10.2%) partially completed questionnaires with missing values. The remaining 7818 respondents were used for analysis. They were 58.1% male and 41.9% female, with an average age of 19 years. Overall, 33.9% of the students reported no hunting skills, 45.8% reported poor hunting skills, and 20.3% reported good hunting skills (Table 2).

Male students reported significantly higher hunting skills as well as better knowledge of bird and other traditional skills than female students (Fig. 2, Table 1 – 2, S4).

Hunting skills were higher among students who had grown up in a village than among those who had grown up in urban areas, and more remote locations were also associated with higher hunting skills. In addition, hunting skills were positively correlated with other traditional skills as well as knowledge of bird species and negatively correlated with grade 10 math and English scores (Fig. 2).

Gender violated the proportional odds assumption and therefore has two odds ratios. Odds ratio 1 (OR_1) for none vs. poor and good hunting skills; Odds Ratio 2 (OR_2) for none and poor vs. good hunting skills.

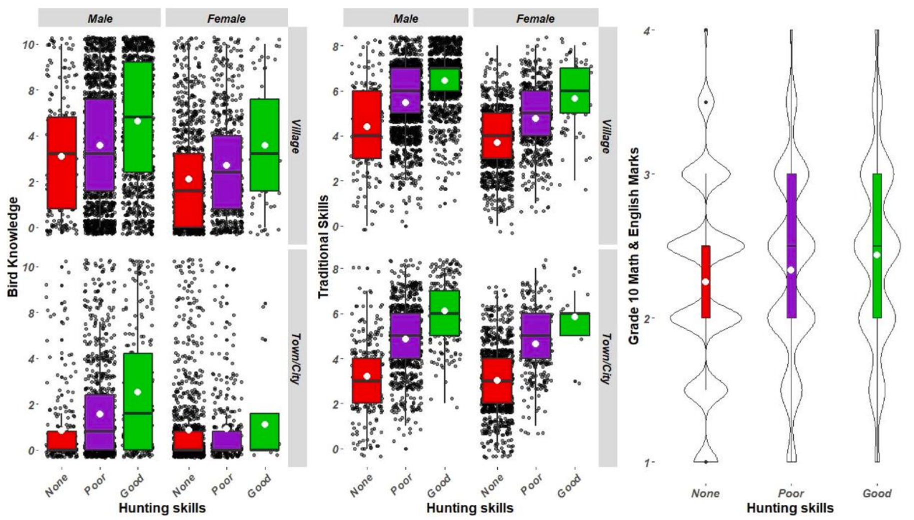


Fig. 2. Bird knowledge (*L*) and traditional skills (*C*) at different levels of hunting skills, broken down by gender and urbanization. *R*: Grade 10 proficiency (1–4, from best to worst) for different levels of hunting skills. Data points (individual students) added to boxplots (median with 1st and 3rd quartiles, mean marked by a white circle).

Table 1
Results of the partial proportional odds model: factors influencing hunting skills.

Predictor	OR (CI)	P-value
Urbanization	0.71 (0.63–0.79)	< 0.001
Remoteness	1.11 (1.05–1.16)	< 0.001
Bird knowledge	1.34 (1.26–1.40)	< 0.001
Traditional skills	3.10 (2.89–3.29)	< 0.001
Grade 10 marks	1.08 (1.03–1.14)	0.002
Gender		
OR_1	0.08 (0.07–0.10)	< 0.001
OR_2	0.13 (0.10–0.16)	< 0.001

Table 2
Number (n) and % of responses, or mean (standard deviation) response for individual states of the studied variables.

		Hunting skills score		
Characteristics	**Total**	**None**	**Poor**	**Good**
Hunting skills score, n (%)		2881 (33.9)	3899 (45.8)	1729 (20.3)
Urbanization				
Village, n (%)	5445 (64.3)	1399 (49.6)	2528 (66.6)	1402 (83.5)
Town/City, n (%)	3025 (35.7)	1420 (50.4)	1267 (33.4)	277 (16.5)
Remoteness				
Road access, n (%)	6839 (81.6)	2389 (86.6)	3101 (82.2)	1242 (73.4)
Boat, n (%)	346 (4.1)	81 (2.9)	170 (4.5)	85 (5)
Air, n (%)	218 (2.6)	40 (1.5)	92 (2.4)	84 (5)
Walking only, n (%)	982 (11.7)	250 (9.1)	411 (10.9)	282 (16.7)
Gender				
Male, n (%)	4899 (58.1)	479 (17)	2762 (73.1)	1568 (95.2)
Female, n (%)	3531 (41.9)	2347 (83.1)	1016 (26.9)	80 (4.9)
Bird knowledge, mean (SD)	3.28 (3.26)	1.94 (2.59)	3.36 (3.16)	5.26 (3.38)
Traditional skills, mean (SD)	4.7 (1.9)	3.4 (1.5)	5.1 (1.5)	6.3 (1.3)
Grade 10 marks, mean (SD)	2.2 (0.8)	2.2 (0.8)	2.3 (0.8)	2.4 (0.7)

4. Discussion

To our knowledge, this is the first study to examine the hunting skills of young, educated people in the face of rapid socioeconomic and cultural change in PNG and in a tropical developing country in general. Because hunting is an almost exclusively male activity in PNG, as has been documented here and elsewhere (Dwyer and Minnegal, 1991; Mack and West, 2005), we primarily discuss factors influencing male students' hunting skills. However, they are virtually identical to the drivers identified for female students.

4.1. Shifting interest from traditional subsistence skills

Our study shows that only one-third of male students have good hunting skills, indicating that many have shifted their interest away from subsistence hunting. This is however true only for the 15% of young people in PNG who attend secondary school (National Bureau of Statistics, 2019) and represent the educated segment of the young population.

Williams and Knight (2021) evaluated the impact of a tree kangaroo conservation program in selected remote communities in PNG and found that improvements in local agriculture, education, and health care led to a decrease in hunting activity. The accessibility of domestic animals and store-purchased food has replaced the need for wild meat.

The low attractiveness of hunting in contemporary PNG can be explained in part by limited markets for bushmeat, with few larger animals available for hunting and small towns in PNG that are often difficult to access from the countryside. The situation in PNG contrasts with the Indonesian part of New Guinea, where markets created by Indonesian transmigrants increase the economic benefits of selling wild meat (Pangau-Adam et al., 2012; Pattiselanno et al., 2020).

Hunting provides limited nutrition because the success rate of hunting is generally low (Williams and Knight, 2021). Therefore, hunting is relatively easy to replace with improvements in agriculture, especially breeding of domestic animals. Such situations make hunting a less promising option and discourage skilled hunters and families from teaching their children to hunt, which is critical for developing hunting skills at a young age (Lew-Levy et al., 2017; Ryan and Shaw, 2011).

4.2. Education is valued more than hunting

The focus is now on formal education, which is seen as more prestigious than traditional skills such as hunting and as a promising gateway to employment and cash income, allowing to purchase food, including tinned fish and meat, cooking oil and rice, rather than hunting for wild meat (Gray et al., 2015; Vasco and Sirén, 2016; Williams and Knight, 2021). Our study showed that students who performed well in math and English were poor hunters, confirming our hypothesis that there is a trade-off between investing time in formal education and academic achievement and investing in traditional subsistence skills such as hunting (Luz et al., 2015, 2017). This also suggests that hunting skills may be higher among young people with only primary education than among the secondary school students surveyed here.

The other traditional skills were correlated with hunting skills, likely due to the same lifestyle drivers. It is possible that there is a more direct relationship between knowledge of birds and hunting skills, as both are acquired during long time spent in rainforests. Not surprisingly, the acquisition of traditional knowledge about wildlife and its practical application in hunting is higher in forests and remote villages (Gichuli and Terer, 2001; Majnep and Bulmer, 1977).

4.3. Threats to hunted species remain

The apparent shift of interest in traditional subsistence skills and ethnobiological knowledge noted in our study is based on only the 15% of young people who attend secondary school. Higher levels of hunting skills are expected particularly in remote rural areas with more traditional lifestyles (Pangau-Adam et al., 2012; Luz, 2017). Growing populations may therefore exert greater hunting pressure in remote rainforests than in the past. At the same time, these areas are most likely of great conservation importance. For example, subsistence hunting is the most important threat to tree kangaroo species in PNG (Beehler et al., 2021a). The threat of unsustainable hunting of tree kangaroos led to the establishment of two protected areas in PNG focused on their conservation (Beehler et al., 2021b). Both were able to reduce hunting pressure by providing alternative benefits to indigenous communities, including improved income opportunities, health and education services. Interestingly, these modernization trends were not viewed by indigenous communities as negatively affecting their culture (Williams and Knight, 2021).

The case study of tree kangaroos in PNG may be an example of a more general trend of increasing hunting pressure in remote rural areas due to a combination of the remaining attractiveness of hunting and growing populations, while the importance of hunting is decreasing in more urbanized areas where local people are losing interest in the activity because it is no longer seen as economically rewarding or prestigious. This trend may continue as the proportion of young people with secondary or tertiary education in PNG is expected to increase to 31% by 2050 (National Statistics Office, 2019).

4.4. Hunting and attitudes towards conservation

Maintaining animal populations for hunting may also be one of the incentives for rainforest conservation in indigenous communities. Impacts on wildlife are among the greatest concerns about rainforest logging. Incentives for applying modern methods of conservation may also include traditional beliefs and customs (Henning, 2015) and expectations of better material conditions and services (Novotny, 2010). However, political support for conservation increases with education and wealth, both within populations (Baranzini et al., 2010) and across countries (McClanahan and Rankin, 2016). Thus, support for conservation may peak in remote indigenous communities, where it is positively associated with hunting and other traditional lifestyle activities, and then in majority-educated urban populations, with the transition between the two characterized by lower support for conservation.

In summary, our study finds that hunting skills among the young, educated population in PNG are already very low. Although our results do not indicate that subsistence hunting is being abandoned, our results do suggest that while hunting may be on the rise in remote rural areas and becoming a problem for conservation, the more educated segment of the young population appears to be turning its interest away from hunting and pursuing various other activities that provide food, income, prestige, and entertainment traditionally supplied by hunting.

Contributors

A.K and V.N designed research; A.K and V.N performed research; A.K and L.J analyzed the data; A.K, V.N, P.D, P.W, R.O, G.S, L.J, K.S, J.B and J.Z interpreted the data and wrote the paper. All authors gave final approval for publication.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We are grateful to Jimmy Moses for his statistical advice. We thank the PNG education department and New Guinea Binatang Research Center for supporting this study. We also thank the ethnobiological research team in PNG for their assistance in filed survey. This study was supported by the Czech Science Foundation (18–23889 S), The European Research Council (669609) and The Darwin Initiative for the Survival of the Species (DIR25S1\100123).

References

Armitage, L. (2001). Customary land tenure in Papua New Guinea: Status and prospects. Brisbane: Queensland University of Technology. Retrieved May 9, 2022, from http://dlc. dlib. indiana. edu/archive/00001043/00/armitage. pdf.

Aswani, S., Lemahieu, A., Sauer, W.H.H., 2018. Global trends of local ecological knowledge and future implications. PloS One 13, e0195440.
Ayalew, W., Danbaro, G., Dom, M., Amben, S., Besari, F., Moran, C., Nidup, K., 2011. Genetic and cultural significance of indigenous pigs in Papua New Guinea and their phenotypic characteristics. Anim. Genet. Resour. /Resour. Génétiques Anim. /Recur. Genéticos Anim. 48, 37–46.
Baranzini, A., Faust, A.-K., Huberman, D., 2010. Tropical forest conservation: attitudes and preferences. For. Policy Econ. 12, 370–376.
Beehler, B.M., Kemp, N., Shearman, P.L., 2021a. Threats to New Guinea's tree kangaroos. In: Dabek, L., et al. (Eds.), Tree Kangaroos. Science and Conservation. Elsevier, London, pp. 41–49.
Beehler, B.M., Kemp, N., Shearman, P.L., 2021b. Opportunities for tree kangaroo conservation on the island of New Guinea. In: Dabek, L., et al. (Eds.), Tree Kangaroos. Science and Conservation. Elsevier, London, pp. 129–134.
Brashares, J.S., Golden, C.D., Weinbaum, K.Z., Barrett, C.B., Okello, G.V., 2011. Economic and geographic drivers of wildlife consumption in rural Africa. Proc. Natl. Acad. Sci. 108, 13931–13936.
Burnham, K.P., Anderson, D.R., 2004. Multimodel inference: understanding AIC and BIC in model selection. Sociol. Methods Res. 33 (2), 261–304.
Chagnon, N.A., 2012. The Yanomamo. Boston USA, 6th ed. Cengage Learning, p. 336.
R. Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.
Cuthbert, R., 2010. Sustainability of hunting, population densities, intrinsic rates of increase and conservation of Papua New Guinean mammals: A quantitative review. Biol. Conserv. 143 (8), 1850–1859. https://doi.org/10.1016/j.biocon.2010.04.005.
Dwyer, P.D., Minnegal, M., 1991. Hunting in lowland, tropical rain forest: Towards a model of non-agricultural subsistence. Hum. Ecol. 19 (2), 187–212. https://doi.org/10.1007/BF00888745.
Foster, R.J., Horst, H.A. (Eds.), 2018. The Moral Economy of Mobile Phones: Pacific Islands Perspectives. Australian National University Press, Canberra.
Gamoga, G., Turia, R., Abe, H., Haraguchi, M. & Iuda, O. (2021). The Forest Extent in 2015 and the Drivers of Forest Change Between 2000 and 2015 in Papua New Guinea: Deforestation and Forest Degradation in Papua New Guinea. Case Studies in the Environment, 5(1), 1442018. https://doi.org/10.1525/cse.2021.1442018.
Gichuli, N. & Terer, T. (2001). Significance of indigenous knowledge and values of birds in promoting biodiversity conservation in Kenya. *Significance*, *9*, 2.
Gill, D.J.C., Fa, J.E., Rowcliffe, J.M., Kümpel, N.F., 2012. Drivers of change in hunter offtake and hunting strategies in sendje, Equatorial Guinea. Conserv. Biol. 26 (6), 1052–1060. https://doi.org/10.1111/j.1523-1739.2012.01876.x.
Godoy, R., Reyes-García, V., Byron, E., Leonard, W.R., Vadez, V., 2005. The effect of market economies on the well-being of indigenous peoples and on their use of renewable natural resources. Annu. Rev. Anthropol. 34 (1), 121–138. https://doi.org/10.1146/annurev.anthro.34.081804.120412.
Gray, C.L., Bozigar, M., Bilsborrow, R.E., 2015. Declining use of wild resources by indigenous peoples of the Ecuadorian Amazon. Biol. Conserv. 182, 270–277. https://doi.org/10.1016/j.biocon.2014.12.022.
Henning, B.M., 2015. Market-Based conservation in Melanesia: contrasting expectations of landowners and conservationists. Conserv. Soc. 13 (3), 299–310.
Jacka, J. (2010). The spirits of conservation: Ecology, Christianity, and resource management in highlands Papua New Guinea. Journal for the Study of Religion Nature and Culture, 4(1), 24.
Kik, A., Adamec, M., Aikhenvald, A.Y., Bajzekova, J., Baro, N., Bowern, C., Colwell, R.K., Drozd, P., Duda, P., Ibalim, S., Jorge, L.R., Mogina, J., Ruli, B., Sam, K., Sarvasy, H., Saulei, S., Weiblen, G.D., Zrzavy, J., Novotny, V., 2021. Language and ethnobiological skills decline precipitously in Papua New Guinea, the world's most linguistically diverse nation. Proc. Natl. Acad. Sci. 118 (22) https://doi.org/10.1073/pnas.2100096118.
Lew-Levy, S., Reckin, R., Lavi, N., Cristóbal-Azkarate, J., Ellis-Davies, K., 2017. How do hunter-gatherer children learn subsistence skills? Hum. Nat. (Hawthorn, N. Y.) 28 (4), 367–394. https://doi.org/10.1007/s12110-017-9302-2.
Luz, A.C., Guèze, M., Paneque-Gálvez, J., Pino, J., Macía, M.J., Orta-Martínez, M., Reyes-García, V., 2015. How does cultural change affect indigenous peoples' hunting activity? An empirical study among the Tsimane' in the Bolivian Amazon. Conserv. Soc. 13 (4), 382–394.
Luz, A.C., Paneque-Gálvez, J., Guèze, M., Pino, J., Macía, M.J., Orta-Martínez, M., Reyes-García, V., 2017. Continuity and change in hunting behaviour among contemporary indigenous peoples. Biol. Conserv. 209, 17–26. https://doi.org/10.1016/j.biocon.2017.02.002.
Mack, A.L., and West, P. (2005). Ten thousand tonnes of small animals: wildlife consumption in Papua New Guinea, a vital resource in need of management. Resource Management in Asia-Pacific Working Paper No. 61. Resource Management in Asia-Pacific Program, Research School of Pacific and Asian Studies, Australian National University, Canberra.
Majnep, I.S., Bulmer, R., 1977. Birds of my Kalam country. Oxford University Press, USA.
McClanahan, T.R., Rankin, P.S., 2016. Geography of conservation spending, biodiversity, and culture. Conserv. Biol. 30, 1089–1101.
Milner-Gulland, E.J., Bennett, E.L., 2003. Wild meat: the bigger picture. Trends Ecol. Evol. 18, 351–357.
National Bureau of Statistics (2019). Papua New Guinea demographic and health survey 2016–18, NSO, Port Moresby, Papua New Guinea.
Nielsen, M.R., Pouliot, M., Meilby, H., Smith-Hall, C., Angelsen, A., 2017. Global patterns and determinants of the economic importance of bushmeat. Biol. Conserv. 215, 277–287. https://doi.org/10.1016/j.biocon.2017.08.036.
Nielsen, M.R., Meilby, H., Smith-Hall, C., Pouliot, M., Treue, T., 2018. The importance of wild meat in the global south. Ecol. Econ. 146, 696–705. https://doi.org/10.1016/j.ecolecon.2017.12.018.
Novotny, V., 2010. Rainforest conservation in a tribal world: why forest dwellers prefer loggers to conservationists. Biotropica 42, 546–549.
Nugi, G., Whitmore, N., 2020. More dead than alive: Harvest for ceremonial headdresses threatens Pesquet's Parrot in Papua New Guinea. Emu - Austral Ornithol. 120 (2), 156–161. https://doi.org/10.1080/01584197.2019.1676162.
Pangau-Adam, M., Noske, R., Muehlenberg, M., 2012. Wildmeat or bushmeat? Subsistence hunting and commercial harvesting in Papua (West New Guinea), Indonesia. Hum. Ecol. 40 (4), 611–621. https://doi.org/10.1007/s10745-012-9492-5.
Pattiselanno, F., Lloyd, J.K.F., Sayer, J., Boedhihartono, A.K., Arobaya, A.Y.S., 2020. Wild meat trade chain on the bird's head peninsula of West Papua Province, Indonesia. J. Ethnobiol. 40 (2), 202–217. https://doi.org/10.2993/0278-0771-40.2.202.
Peterson, B., Harrell Jr., F.E., 1990. Partial proportional odds models for ordinal response variables. J. R. Stat. Soc.: Ser. C. (Appl. Stat.) 39 (2), 205–217. https://doi.org/10.2307/2347760.
Raymond, H., 2007. The ecologically noble savage debate. Annu. Rev. Anthropol. 36, 177–190.
Robbins, J., 1995. Dispossessing the spirits: christian transformations of desire and ecology among the urapmin of Papua New Guinea. Ethnology 34 (3), 211–224. https://doi.org/10.2307/3773824.
Ryan, E.L., Shaw, B., 2011. Improving hunter recruitment and retention. Hum. Dimens. Wildl. 16 (5), 311–317.
Saulei, S.M., Aruga, J.A., 1994. The status and prospects of non-timber forest products development in Papua New Guinea. Commonw. For. Rev. 73 (2), 97–105.
Sengeh, P., Jalloh, M.B., Webber, N., Ngobeh, I., Samba, T., Thomas, H., Nordenstedt, H., Winters, M., 2020. Community knowledge, perceptions and practices around COVID-19 in Sierra Leone: a nationwide, cross-sectional survey. BMJ Open 10 (9), e040328. https://doi.org/10.1136/bmjopen-2020-040328.
Shearman, P. & Bryan, J.E. (2015). The State of the Forests of Papua New Guinea 2014: Measuring change over the period 2002–2014. University of Papua New Guinea. https://openresearch-repository.anu.edu.au/handle/1885/104074.
Shen, X., Li, S., Chen, N., Li, S., McShea, W.J., Lu, Z., 2012. Does science replace traditions? Correlates between traditional Tibetan culture and local bird diversity in Southwest China. Biol. Conserv. 145 (1), 160–170. https://doi.org/10.1016/j.biocon.2011.10.027.
Sillitoe, P., 2001. Hunting for conservation in the Papua New Guinea Highlands. Ethnos 66 (3), 365–393. https://doi.org/10.1080/00141840120095140.
Sirén, A., Parvinen, K., 2015. A spatial bioeconomic model of the harvest of wild plants and animals. Ecol. Econ. 116, 201–210. https://doi.org/10.1016/j.ecolecon.2015.04.015.
Smith, E.A., Wishnie, M., 2000. Conservation and Subsistence in Small-Scale Societies. Annu. Rev. Anthropol. 29 (1), 493–524. https://doi.org/10.1146/annurev.anthro.29.1.493.
Supuma, M. (2018). Endemic birds in Papua New Guinea's montane forests: Human use and conservation. (PhD Thesis, James Cook University). Retrieved from https://researchonline.jcu.edu.au/58743/1/JCU_58743-supuma-2018-thesis.pdf.

Suri, M.R., Dery, J.L., Pérodin, J., Brassill, N., He, X., Ammons, S., Gerdes, M.E., Rock, C., Goldstein, R.E.R., 2019. U.S. farmers' opinions on the use of nontraditional water sources for agricultural activities. Environ. Res. 172, 345–357. https://doi.org/10.1016/j.envres.2019.02.035.
Van Den Bergh, M.O., Kusters, K., Dietz, A.T., 2013. Destructive attraction: factors that influence hunting pressure on the Blue Bird-of-paradise Paradisaea rudolphi. Bird Conservation International 23 (2), 221–231.
Vasco, C., Sirén, A., 2016. Correlates of wildlife hunting in indigenous communities in the Pastaza province, Ecuadorian Amazonia. Anim. Conserv. 19 (5), 422–429. https://doi.org/10.1111/acv.12259.
West, P., Brockington, D., 2006. An anthropological perspective on some unexpected consequences of protected areas. Conserv. Biol. 20, 609–616.
Williams, H.F., Knight, A., 2021. Barriers and benefits to tree kangaroo conservation in Papua New Guinea. J. Nat. Conserv. 60, 125972 https://doi.org/10.1016/j.jnc.2021.125972.
Williams, R., 2006. Generalized ordered logit/partial proportional odds models for ordinal dependent variables. Stata J. 6 (1), 58–82. https://doi.org/10.1177/1536867×0600600104.
Worldometers (2020). Papua New Guinea Population. Retrieved April 29, 2022, from https://www.worldometers.info/world-population/papua-new-guinea-population/.
Yee, T.W., 2010. The VGAM package for categorical data analysis. J. Stat. Softw. 32 (10), 1–34.

Support information

Table S1: Brant test of parallel regression assumption using the 5 percent level of significance.

Variable	**P-value**
Urbanization	0.67
Remoteness	0.16
Gender	**0**
Bird knowledge	0.06
Traditional skills	0.27
Grade 10 marks	0.29

Note: A significant test statistic provides evidence that the parallel regression assumption has not been fulfilled

Table S2. Model selection of partial proportional odds models (*K* = number of estimated parameters; LogL = log-likelihood; ΔAIC, difference in AIC values between each model and the best model; ω_i, Akaike weight). Codes listed under Model structure are given in S3.

Model	Model structure	Ranking	K	LogL	AIC	ΔAIC	ω_i
6	HUN~URB+REM+GEN+BIR+TRA+GRA	1	14	-5430.12	10888.3	0	0.43
8	HUN~URB+REM+GEN+BIR+TRA+GRA+MOS+PAR	2	18	-5426.49	10889.07	0.77	0.29
7	HUN~URB+REM+GEN+BIR+TRA+GRA+MOS	3	16	-5428.62	10889.32	1.02	0.26
5	HUN~URB+REM+GEN+BIR+TRA	4	12	-5435.42	10894.89	6.59	0.02
4	HUN~URB+REM+GEN+BIR	5	10	-6125.71	12271.45	1383.15	0
3	HUN~URB+REM+GEN	6	8	-6240.43	12496.89	1608.59	0
2	HUN~URB+REM	7	6	-7863.72	15739.45	4851.15	0
1	HUN~URB	8	4	-7883.77	15775.55	4887.25	0

Table S3. Overview of independent and dependent variables

Variable	Description	Type	Levels
Response variable			
Hunting skills (HUN)	Rating of hunting skills in a three-point scale	Ordinal	1 = None 2 = Poor 3 = Good
Explanatory variables			
Urbanization (URB)	Describes where a student attends preschool	Binary	1 = Village 2 = Town/City
Remoteness (REM)	Specifies how students access their childhood place of residence	Categorical	1 = Access by road 2 = Access by boat 3 = Access by air

			4=Access by walking
Gender (GEN)	The gender the participant identifies with	Binary	0 = Male 1 = Female
Bird knowledge (BIR)	10 lowland or 10 montane spp.	Quantative	-
Traditional skills (TRA)	Describes traditional skills: house building, fishing, gardening, plant use	Quantative	-
Parent's education & job (PAR)	Specifies parent's level of education and employment background	Quantative	-
Modern skills (MOS)	Student's computer & phone usage skills	Quantative	-
Grade 10 marks (GRA)	Student's grade 10 maths & English scores	Quantative	-

Table S4. Mean with standard deviation and median for the surveyed variables

Variables	*Grade 10 marks*			*Traditional skills*			*Bird knowledge*		
Urbanization	Mean	SD	Median	Mean	SD	Median	Mean	SD	Median
Village	2.37	0.74	2.5	5.2	1.7	5	4.2	3.22	4
Town	2.04	0.77	2	4.09	1.8	4	1.56	2.51	0
Remoteness									
Road	2.21	0.76	2.5	4.73	1.82	5	3.02	3.17	2
Boat	2.41	0.74	2.5	5.16	1.73	5	3.99	3.21	3
Air	2.44	0.66	2.5	4.97	1.62	5	5.74	3.43	6
Walk	2.45	0.75	2.5	5.1	1.79	5	4.34	3.28	4
Gender									
Male	2.27	0.75	2.5	5.49	1.65	6	4.08	3.4	4
Female	2.23	0.78	2.5	3.83	1.56	4	2.16	2.65	1

CHAPTER III

Language skills and ethnobiological knowledge in the young and educated Indigenous Melpa speakers in Papua New Guinea

[Manuscript]

Language skills and ethnobiological knowledge in the young and educated Indigenous Melpa speakers in Papua New Guinea

Alfred Kik[1,2*], Pavel Duda[1], Jarmila Bajzeková[,2], Karl Kama[3], Leonardo R. Jorge[2], Vojtěch Novotný [1,2]

Affiliations

[1]Faculty of Sciences, University of South Bohemia, České Budějovice, Czech Republic

[2]Biology Centre, Czech Academy of Sciences, České Budějovice, Czech Republic

[3]New Guinea Binatang Research Center, Madang, Papua New Guinea

*Corresponding author (akik@prf.jcu.cz)

Abstract

Indigenous populations are rapidly losing their languages and with them, their culture, including traditional knowledge of nature, passed down orally from generation to generation. Here we examine knowledge of birds and plants among the young and educated cohort of the Melpa Indigenous people of Papua New Guinea and seek to understand the main causes of the decline in this knowledge. We show that although the young, educated Melpa speakers remain fluent in their native language, they are losing their ethnobiological knowledge. We have uncovered the gaps in bird knowledge, including culturally important ones such as birds of paradise. Knowledge of traditionally used plant species is also limited, with a total of 117 species listed by 1,313 respondents. Nearly half of the plant uses listed by respondents concerned non-native plant species. The identified drivers of the decline in Melpa language proficiency and ethnobiological knowledge include urbanization, the use of Neo-Melanesian pidging and English at home, mixed language marriages, and the decline in traditional skills caused by lifestyle changes. These socioeconomic trends are largely endogenous, reflecting the choices and aspirations of the Melpa people. Therefore, the ongoing loss of traditional knowledge is difficult to reverse.

Keywords: ethnozoology, ethnobotany, birds, traditional plant use, language skills

Introduction

Traditional ethnobiological knowledge that is culture-specific and is passed down orally from generation to generation is vulnerable to changes in lifestyle. The preservation of Indigenous languages and the wealth of information they convey ultimately depends on the attitudes of young speakers of these languages towards it. Recent lifestyle changes, particularly the increased focus on formal education and limited contact with the natural world among young peoples, may lead to a rapid decline in the use of Indigenous languages and consequent disappearance of traditional knowledge (Hughes, Richardson, and Lumber 2018; Soga and Gaston 2016; Kik et al. 2023). We argue that the survival of biocultural diversity will ultimately depend not on the last pockets of isolated communities in remote rural areas, but rather on the attitudes of educated and urban segments of these Indigenous populations, and whether they maintain Indigenous traditions and remain connected to their natural environment (Hunn 2002).

The island of New Guinea is characterized by an extraordinary diversity of plant and animal species as well as languages (Stepp, Castaneda, and Cervone 2005). New Guinea is the world's largest hotspot of linguistic diversity with over 1000 Indigenous languages (Eberhard, Simons, and Fennig 2021). Indigenous peoples are mostly rural and practice swidden agriculture. They also hunt and collect wild plants for cultural, economic, and medicinal uses in the mostly rainforest environments. These peoples have therefore developed a deep understanding of their extremely species-rich environment (Cámara–Leret and Dennehy 2019; Douglass et al. 2021). Natural history knowledge of plants and animals is rooted in Indigenous taxonomy, i.e., naming systems for plants and animals that were developed independently in each language. New Guinea is therefore an island of a thousand plant and animal taxonomies (Cámara-Leret et al. 2020; CEPA 2019).

New Guineans have been hunting birds and harvesting their eggs for at least 18,000 years (Douglass et al. 2021). Contemporary uses of bird species range from food to a variety of cultural uses, including the use of feathers of birds of paradise, parrots, and cassowaries, or beaks of hornbills as body ornaments, or the use of live cassowaries as bride price (e.g., Healey 1993; Mack and West 2005; Saulei and Aruga 1994). Birds also feature in local myths and legends and traditional beliefs (Slone 2001). Parrots and hornbills are often kept as pets. Indigenous taxonomies of bird species are generally very detailed and largely consistent with modern species concepts, although the higher classification of birds into species groups can be based on morphology, ecology, mythology, or combination thereof, and therefore differ greatly from Linnean taxonomy and classification (Majnep and Bulmer 1977).

New Guinea is the floristically richest island in the world, with 13,634 named plant species (Cámara-Leret et al. 2020). Each of the New Guinean languages has developed its own system of plant taxonomy, focusing on conspicuous or useful species. Detailed ethnobotanical studies document several hundred plant species named and used by each Indigenous culture (Gardner 2010; Hays 1979; Milliken 1992). Medicinal uses of plants dominate ethnobotanical records from New Guinea, followed by four use categories of similar importance: Medicine, construction, food, and tools (Cámara–Leret and Dennehy 2019). Information on traditional oral plant use has yet to be documented in the scientific literature (Camara-Leret and Dennehy 2019).

Currently, the cultural diversity of Indigenous peoples of New Guinea and the world is threatened by the forces of cultural and economic globalization (Kik et al. 2021; Stepp, Castaneda, and Cervone 2005). Globally, 25% of languages are at risk of extinction by the end of the century (Bromham et al. 2022), with the risk being particularly high in the tropics (Amano Tatsuya et al. 2014). The endemic languages of New Guinea account for 15% of the world's linguistic diversity (Eberhard, Simons, and Fennig 2021). These languages are essential for the preservation of oral traditional ecological knowledge (Cámara-Leret and Bascompte 2021). The loss of this knowledge would have negative impacts on Indigenous communities, including their health, food security, and environmental management.

We have documented widespread and rapid declines in language proficiency and traditional ethnobiological knowledge among secondary school students in Papua New Guinea (PNG) (Kik et al. 2021; Kik et al. 2023). Here we focus on the Melpa language, one of the largest PNG languages of the Trans-New Guinea language family. Melpa is spoken in the Western Highlands Province (WHP) by more than 100,000 people. Unlike many PNG languages, Melpa is not endangered, as it is vigorously used (Eberhard, Simons, and Fennig 2021). However, even populations speaking languages that are not threatened may lose their traditional knowledge due to changes in lifestyle (Hunn 2008; Si 2020).

Here we investigate whether such knowledge decline occurs in a large and seemingly healthy Indigenous language such as Melpa. We assess language skills and ethnobiological knowledge of Melpa-speaking secondary school students, as well as the socioeconomic and cultural factors that might be responsible for it. We focus on secondary school students, who currently comprise only 15% of the young generation in PNG, since we can expect that in a few generations, secondary education will become widespread in this country.

Materials and methods

Survey methods

We analyzed data from an anonymous questionnaire survey designed to assess the ethnobiological knowledge and Indigenous language skills of upper secondary school students (grades 11 and 12, i.e., two senior years in the 4-year secondary education in PNG) in 30 rural and urban secondary schools in PNG. The survey took place between 14 April 2015 and 14 November 2018. The survey was developed and conducted in English (the official language of education). The work was conducted with ethical permission from the Education Department of the respective provinces and the Ethics Board New Guinea Binatang Research Center (BRC_03_15.01.2015). Permission was also obtained from the principals of each school.

Students were gathered in one location, such as a dining hall, and anonymously completed a 24-page questionnaire within one hour. The purpose and importance of the survey were clearly explained to the students. Participation was voluntary, but generally all students wanted to participate. All participants gave their informed consent.

Melpa language

We limited our analysis to the Melpa language, one of the five largest Indigenous languages in PNG spoken by over 100,000 people living in an area of about 2,500 km^2 in the Western Highlands Province, mainly between 1,300 and 1,900 m a.s.l. Mt. Hagen (population 40,000), the third largest urban settlement in PNG is located in this area (Eberhard, Simons, and Fennig 2021). The region where Melpa is spoken has been occupied for at least 40,000 years and contains one of the oldest records of early agriculture, dating to 10,000 years ago (Golson and Gardner 1990; Howley 2008). The first contact of the Melpa people with the outside world occurred very late, during M. Leahy's expedition in 1933 (Leahy 1991).

Melpa is regularly used in daily life and is classified as "vigorous" in the Ethnologue language database (Eberhard, Simons, and Fennig 2021). It is member of the Chimbu–Wahgi branch of the Trans New Guinea language family and has three recognized dialects: Temboka, Northern Melpa, and Central Melpa. It is used as a second language by Bo-Ung and Kyaka speaking people in the Western Highlands Province and Umbu-Ungu spoken people in the Southern Highlands. Almost the entire Melpa population also speaks Neo-Melanesian pidgin (a lingua franca in PNG), while English is the official language of education from elementary school to university.

We selected the Melpa language because it is a relatively large language and was the best represented language in our PNG survey. The 1,313 respondents were primarily from the five secondary schools in Western Highlands Province (Kitip, Kwip Dau, Paglum, Togoba, and Mt. Hagen Secondary Schools), but also 18 other secondary schools across the country. This allowed us to examine language proficiency and ethnobiological knowledge patterns in a single language in detail, as opposed to a broad cross-language analysis by Kik et al. (2021). Alfred Kik, the principal author, is a native Melpa speaker, which gave a better understanding of the data collected.

Language skills and ethnobiology knowledge

The questionnaire included personal, socioeconomic, lifestyle, and economic information, followed by tests of language skills and ethnobiological knowledge about birds and plants (Supplementary Document 1). We used photo-elicitation, a commonly used method to effectively capture participants' knowledge through the use of pictures (Bignante 2010; Van Auken, Frisvoll, and Stewart 2010). For the bird knowledge test (E1), we provided high-quality color photographs of 10 widespread montane species, ranging from those that are widely known and easily recognized to those that were difficult to identify, and asked participants to write the names in Melpa.

The plant knowledge test (E2) was based on free enumeration. Students were asked to name ten plant species in the Melpa language that are traditionally used and are not staple foods. Students who were unable to list 10 species either left some entries blank or named plants in Neo-Melanesian pidgin or English. These entries were excluded from the analysis.

We classified the named plants into 10 groups according to their intended use: medicine, food, construction (e.g., houses, bridges), firewood, myths/beliefs (e.g., wild bananas are believed to be planted by spirits), weapons and tools, drugs, personal ornaments, and other uses. We also noted the plant part used, its life form (herb, shrub, tree, palm, climber, epiphyte), and whether it is native to New Guinea.

The names of plant species and their uses in Melpa were verified by Alfred Kik, a native Melpa speaker, in collaboration with several knowledgeable Melpa informants. Plant taxonomy was reviewed using the Dynamic Checklist of Flora of New Guinea (Cámara-Leret et al. 2020) and plant specialist Tiberius Jimbo of the PNG Forest Research Institute.

Students' language proficiency (L1) was assessed by their knowledge of Melpa terms for a set of 24 human body parts, ranging from more to less frequently used in conversation based on their color photographs and English names. We also asked students to self-assess their own Melpa language proficiency (L2) on a four-point scale: no language proficiency (0), passive comprehension (1), speaking but poorly (2), and speaking fluently (3). We also asked them to rate their parents' language skills on the same scale.

Drivers of language skills and ethnobiological knowledge

We examined the influence of linguistic, socioeconomic, and lifestyle factors on the loss of language proficiency and ethnobiological knowledge. We applied the PNG-wide analysis of Kik et al. (2021), which included 392 languages, to the Melpa language only to examine whether the factors driving skill loss in the inter-language study remain important also within a single language. We included 13 of the total 21 independent variables used by Kik et al. (2021) that were relevant to the Melpa language. The original 21 variables were divided into four classes: (A) language traits (not used here for monolingual analysis), (B) socioeconomic traits, (C) family language use, and (D) student traits (see Kik et al. (2021) for methodological details). The traits used in the present analysis are discussed in more detail below.

Socioeconomic traits (B): birthplace urbanization (B1) refers to the student's childhood residence, coded as village (1) or town/city (2); remoteness (B2) defined according to whether the student's residence was accessible by road (1), only by boat (2), only by plane (3), or only on foot (4); parents' education (B3) refers to the highest education attained by a parent, coded as no school (1), lower primary (first through sixth grades) (2), higher primary (seventh through eighth grades) (3), lower secondary (ninth to 10th grade) (4), higher secondary (11th to 12th grade) (5), or tertiary education (6); parents' employment (B4) used the highest employment category achieved by a parent, coded as subsistence farming (1), cash crop farming (2), or salaried employment or small business (3).

Language use in the family (C): parents' language proficiency (C1) the higher of mother's and father's proficiency as assessed by the respondent using the L2 score; language use at home (C2) coded as Melpa language (alone or in combination with other languages, including Neo-Melanesian pidgin and English) (1), exclusively Neo-Melanesian pidgin (2), or English (alone or in combination with Neo-Melanesian pidgin) (3); same first language (C3) refers to both mother and father speaking Melpa (1) or only one of them (0).

Student traits (D): Gender (D1) coded as male (0) or female (1); student's grade 10 scores in mathematics (D2) and English (D3) coded as distinction (1), credit (2), upper pass (3), and pass or fail (4); student's traditional skills (hunting, fishing, growing food, building houses, and medicinal plants) (D4) and contemporary technical skills (mobile phone and computer use) (D5) were each coded as none (0), poor (1), or good (2). The difference between these two variables was used as another variable (D6).

Data analysis

Our access to Melpa speakers, including one of the authors (Alfred Kik), allowed us to evaluate student responses in detail. For the bird names, for example, we could ignore spelling errors (e.g., writing Kigrama instead of Kei Raima for cassowary) which were very common because most Melpa speakers are not used to writing in their language. We also divided the answers into four categories: correct, near correct, correct general category, and incorrect. For example, Kei Rama is the correct Melpa expression for cassowary, while Kei, meaning bird, was accepted as a general name. A name for a bird species that resembled the correct species in color and appearance was classified as "near correct." We also accepted identifications at the bird genus level as correct, e.g., Kei Raima refers to all three species of cassowary (Jaun-Holderegger, Lehnert, and Lindemann-Matthies 2022). In the quantitative analyses, correct responses were assigned 3 points, nearly correct responses were assigned 2 points, general terms were assigned 1 point, and incorrect responses and English and Neo-Melanesian pidgin responses were assigned 0 points. This finer classification of responses was used in all tests of language proficiency and ethnobiological knowledge, unlike in Kik et al. (2021), where similar information could not be obtained for all 392 languages. All analyses were conducted in R version 4.2.0 (R Core Team 2022). The data used for the analysis can be found in Supporting Information Supplementary Dataset 1.

We used GLMM models to assess the effects of the three groups of variables on students' language proficiency and ethnobiological knowledge. The response variable (L1) was modeled as a binomial, with students treated as random variables in all models. All predictors are either binary or ordinal variables, so we were able to model these variables as numerical. We performed hierarchical model selection using the Akaike Information Criterion (AIC) to compare the fit among candidate models. First, we performed model selection for each class (B to D) of predictor variables separately. For each class, we considered all variable combinations within that class. We did not consider interactions between variables. Finally, for each class, we obtained the best model with the optimal set of variables belonging to that class. We then combined the variables from each of these class-specific best models to test whether different classes of variables jointly affected language proficiency. We built these models by combining all variables from the model with the best performance in each class into models with two and three classes in all possible combinations, again without interactions. Once we obtained the best-performing, overall model, we examined the relative role of each class and each variable by calculating how much the AIC score increased when the focal variable or class was removed from the full model.

Results

Ethnobiological knowledge: birds

We analyzed data from 1,313 Melpa speakers (57% of boys and 43% of girls, median age 19 years). We obtained 5,074 responses, i.e., a response rate of 39%, for the identification of 10 bird species. Among them, 38% were correct Melpa identifications, 19% were near correct responses, 31% of responses named other than the correct bird names, and 10% were incorrect responses. Most students were able to identify the cassowary (*Casuarius bennetti*) (86%), followed by the morphologically distinct owlet-nightjar (*Aegotheles insignis*). Only 15% of respondents were able to identify the culturally important bird of paradise, the Stephanie's astrapia (*Astrapia stephaniae*) (Figure 1). The Papuan King Parrot (*Alisterus chloropetrus*) was almost never correctly named but had a high rate of near-correct and general identifications.

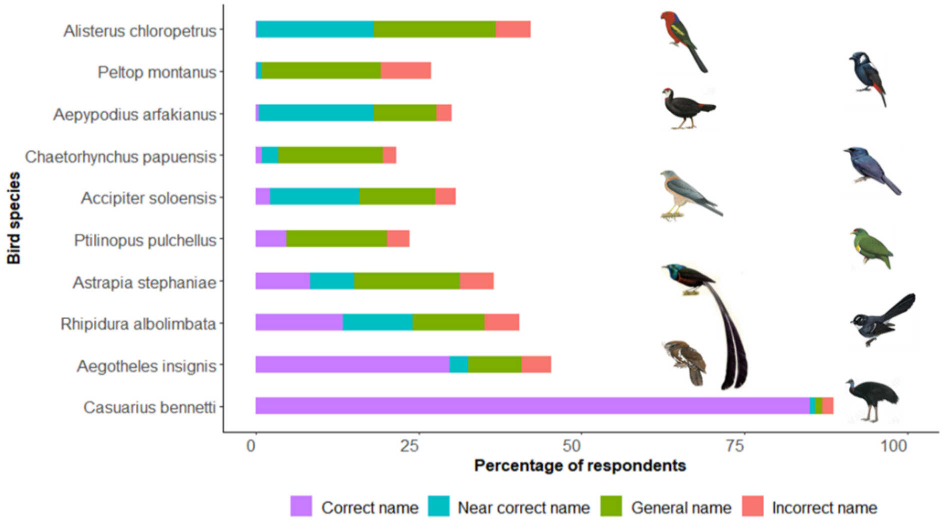


Figure 1. Identification of bird species in the Melpa language. The rest of the respondents made no attempt to identify the species or wrote the name in Neo-Melanesian pidgin or English.

Ethnobiological knowledge: plants

We received 6,609 responses on the traditional use of plants (50% response rate), including 62% (n = 4,074) responses that provided correct Melpa names of plants at genus or species levels (Supplementary Figure 1B), 4% responses with general plant names, and 8% incorrect or unclear responses. A total of 117 different plant taxa, either species or genera, were named by respondents, including 12 taxa each reported by > 100 respondents (Supplementary Table 1). *Laportea decumana* (Roxb.) was mentioned most frequently (n = 514), followed by *Cordyline* spp. (295), *Capsicum frutescens* (220), *Citrus* spp. (217), and *Zingiber officinale* (201). The listed plants are dominated by herbaceous species, which are overrepresented compared to the flora of New Guinea. In contrast, epiphytes are underrepresented among the listed species (Figure 2A). Plant uses reported by Melpa students are broadly similar to those reported in published information from various ethnic groups in New Guinea, with medicinal uses most frequently cited, followed by construction and food uses (Figure 2B). Leaves are by far the most commonly used plant part (64%), followed by fruits (32%), stems (20%), and wood (20%) (Supplementary Figure 1A). A large proportion of the listed plant species (35%) are not native to PNG flora (Supplementary Figure 2A). The proportion of non-native species uses approaches 50% (Supplementary Figure 2B).

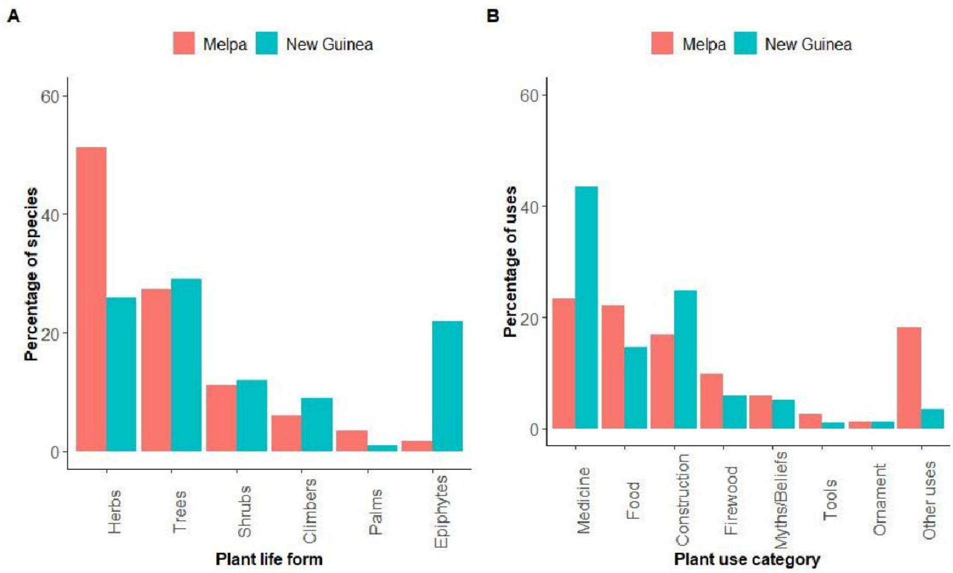


Figure 2. Life forms of the 117 plant taxa listed by the Melpa-speaking students (blue) and the distribution of life forms in the flora of New Guinea (Cámara-Leret et al. 2020) (A) and the type of traditional use of the plant species listed by the Melpa-speaking students (blue) and listed for all New Guinea ethnic groups studied (Cámara-Leret and Dennehy 2019) (B). Note that some plant species have multiple uses.

Assessment of language skills

Students gave 20,751 responses (66% response rate) in the language proficiency (L1) assessment. These responses were 80% correct (Figure

3). Three-quarters of the body parts tested were named correctly at a rate of ≥80%. The eyebrow and chin had a small proportion of correct responses but a large proportion of nearly correct responses, whereas students performed poorly in naming the eyelid, pupil, and wrist (Figure 3).

According to the respondents' self-assessment of language proficiency (L2), only 0.6% of the respondents lacked the language completely, 5.7% could only understand it, 11.7% could speak it poorly, and 82.0% were fluent in Melpa. For both L1 and L2 language proficiency, Melpa was in the top quartile of 110 PNG languages in the Kik et al. (2021) survey with ≥10 respondents (Figure 4). In contrast, Melpa speakers' knowledge of birds and plants was not exceptional and was only slightly above the median (Figure 4).

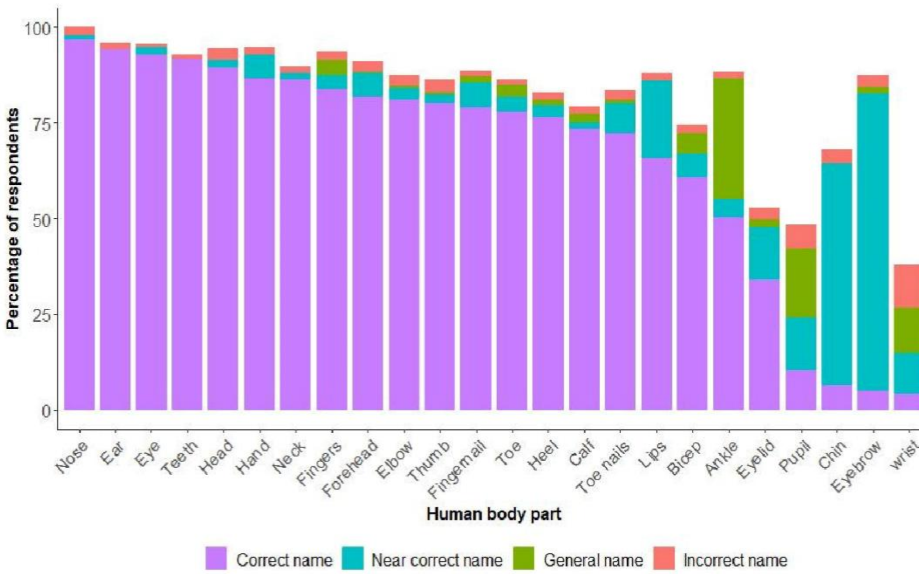


Figure 3. The proportion of each body part mentioned by respondents in the Melpa language. The rest of the respondents did not attempt to identify the body part.

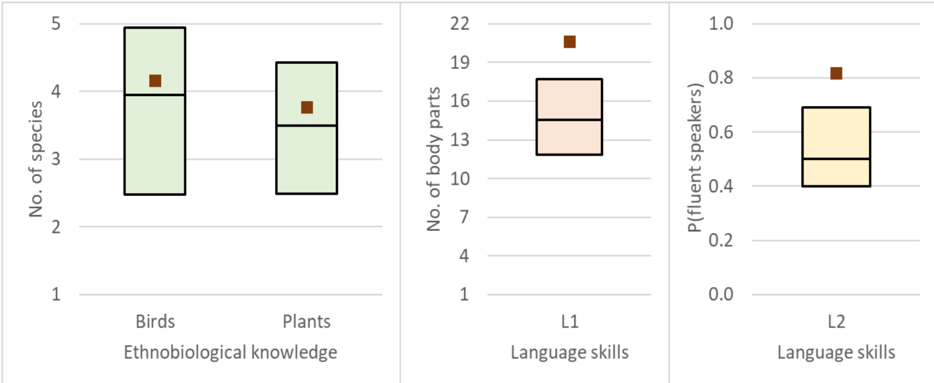


Figure 4. The median, 1st, and 3rd quartiles for the number of bird and plant species named, the number of body parts named (L1), and the proportion of fluent speakers (L2) for 110 PNG languages with ≥10 respondents in Kik et al. (2021) and for the Melpa language (squares).

Predictors of language skills and ethnobiological knowledge

The results of the GLMMs showed that socioeconomic factors were the most important predictors of language proficiency, especially urbanization and parent's employment (Figure 5). Students who spent their childhood in the village (77% of respondents) had better language skills than students who grew up in a town or city. In addition, traditional skills were positively correlated, and English grades were negatively correlated with Melpa language skills. Finally, it was important whether student's family spoke Melpa (53% of families), and not Neo-Melanesian pidgin (45%) or English (2%) at home. It was also important whether both parents spoke Melpa (72% of families) or only one of them did. Parental proficiency in Melpa was a less important factor, as most of the Melpa-speaking parents were fluent in the language. No other variables, including gender, math grades, contemporary technical skills, or parent's education, were significant predictors of language proficiency (Figure 5).

A Pearson correlation showed that students' self-reported language skills (L2) were positively correlated with their bird knowledge (E1, $r_{1297} = 0.3$, p ≤ 0.001) and plant knowledge (E2, r $_{1297}$ = 0.2, p ≤ 0.001). The GLMM models documented an overwhelming importance of language proficiency (L1) in determining ethnobiological knowledge about birds and plants (Figure 5). Bird knowledge was significantly better in boys than in girls, whereas plant knowledge was positively correlated with traditional skills and negatively correlated with students' contemporary technical skills (Figure 5).

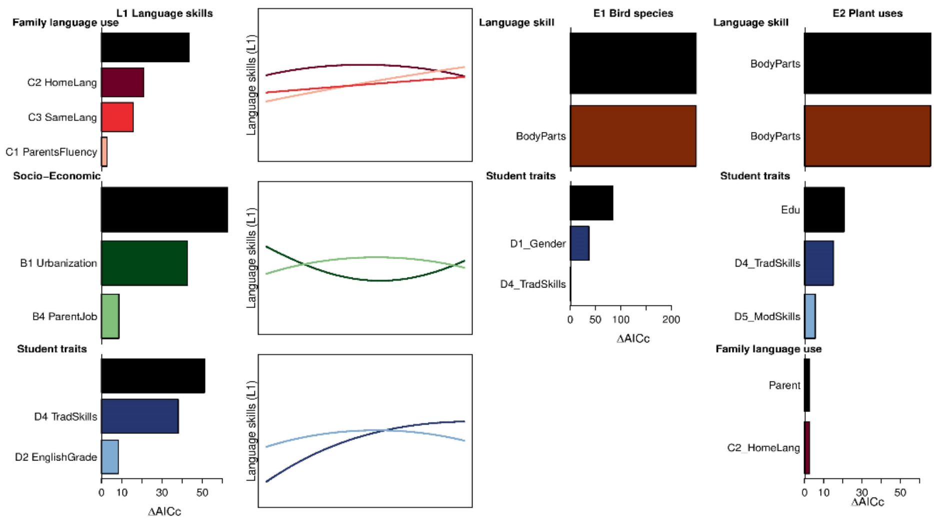


Figure 5. Effects of language use, socioeconomic factors, and student traits on language proficiency and ethnobiological knowledge among Melpa-speaking students. GLMMs describe variability in language proficiency (L1) and knowledge of bird species (E1) and traditional plant use (E2). The bars show the AIC improvement that results when each group (black) and each variable within each group is added to a model that includes all other variables and quantifies the marginal effect of each class/variable. The line plots show the shape of the effect of each variable over its range, while holding the other variables constant. Only significant (P < 0.05) variables are shown.

Discussion

Knowledge of bird and plant species depends on general language skills, but the ability to identify particular species also reflects how people interact with their natural environment and the value of these species (Cox and Gaston 2018; Lindemann-Matthies 2005; Pilgrim et al. 2008).

Melpa students' overall knowledge of birds was quite low. Only one species, the cassowary, was correctly named by its vernacular name by the majority of students and only 2-3 other species were correctly or nearly correctly identified by at least a quarter of the students. This is in line with other studies done in PNG (Frye, Balar, and Si 2022; Kik et al. 2021) and elsewhere (Dallimer et al. 2012; Pam, Zeitlyn, and Gosler 2018) that also reported limited knowledge of birds. The hypothesis that birds that have economic and cultural significance are easily identified and named (Agnihotri and Si 2012; Schlegel and Rupf 2010) was supported in part by the high recognition rate of the cassowary. On the other hand, the Princess Stephanie's astrapia (*Astrapia stephaniae*) was surprisingly little known despite the importance of its feathers that are still commonly used as body adornments and featuring in myths (Healey 1993; Supuma 2018). Notably, the three most frequently named birds tend to live near human settlements, while the lesser-known birds, including the astrapia, are restricted to less disturbed rainforests. A similar bias toward anthropogenic environments in traditional knowledge has been recognized previously (Enzensberger et al. 2022; Mikołajczak et al. 2021). Conspicuous species tend to have higher recognition rates (Enzensberger et al. 2022; Schlegel and Rupf 2010), but this trend was not evident in our results, as illustrated by low recognition of the mountain peltops (*Peltop montanus*). Cultural factors may have played a role in the high recognition rate of owlet-nightjar (*Aegotheles insignis*), which is thought to carry the spirits of dead, likely because is often found near cemeteries as it prefers forest clearings.

Considering that nearly half of the world's bird species are facing population declines (Lees et al. 2022), many ethnobiological studies may be influenced by the increasing rarity of the species. However, this explanation is less likely for PNG, where the ecosystems are still well-preserved. The causes of the decline in bird knowledge are probably mostly socioeconomic. Language skills are obviously a prerequisite for ethnobiological knowledge, and these are being lost due to urbanization and the decline of traditional lifestyle and traditional skills. In particular, PNG students' interest in hunting is declining (Kik et al. 2023). We hypothesize that the better knowledge of birds among male than female Melpa students reflects the impact of hunting, which has always been a male-dominated activity in PNG. Low awareness of the Princess Stephanie astrapia in particular may indicate a decline in cultural knowledge and activities, including traditional dances or wealth exchange, among younger generations, as this is one of the most commonly hunted and traded species used for traditional headdresses in the PNG highlands (Supuma 2018).

A traditional plant taxonomy may include up to 500 species (Gardner 2010), while the collective effort of more than a thousand students has resulted in a total of 117 plant taxa. The free listing of only 10 species may have resulted in each student focusing on a few most commonly used plants, but despite this potential bias, our data show that plant knowledge among Melpa students is limited. The average of six species listed per respondent shows that many students were unable to complete the list of 10 species. Such poor ethnobotanical knowledge is not unusual (Campos et al. 2012; Gosler and Tilling 2022; O’Brien 2010).

Compared to the composition of the flora of New Guinea (Cámara-Leret et al. 2020), plant use was disproportionately focused on herbaceous plants, while epiphytes were, unsurprisingly, rarely mentioned. Vascular epiphytes are perhaps the most abundant plants in the montane forests, accounting for about 35% of the floral diversity of tropical forests (Nieder, Prosperi, and Michaloud 2001). They may contain potentially useful secondary chemical compounds, but their inaccessibility makes them an underutilized life form worldwide. Melpa students cited medicinal use as the most important category, which is consistent with other studies (Ahmed et al. 2015; Cámara–Leret and Dennehy 2019; Quinlan et al. 2016; Yaseen et al. 2015).

The high proportion of plant taxa and their uses that refer to non-native plants is a striking feature of our survey. These are mainly food plants (chilli pepper, citrus, and guava as the top three non-native taxa), but also medicinal plants such as *Bryophyllum pinnatum* or edible species that are also used for medicinal purposes, such as papaya leaves. Other studies have reported on the openness and adaptability of local taxonomies and their cross-cultural ability to accommodate new, often non-native species (Cámara-Leret and Dennehy 2019; Kik et al. 2021).

The native species stinging tree, *Laportea decumana* (Roxb.), is the most frequently mentioned plant, apparently because of its numerous medicinal uses, such as treating body aches, fatigue, headaches, stomach aches, joint and muscle pain (Cámara–Leret and Dennehy 2019; Jorim et al. 2012; WHO 2009), as well as because it is common along forest trails and can sting painfully (Lindemann-Matthies 2005). Its leaves, when added to food, are thought to increase dogs' aggressiveness and thus their ability to protect homes and property. The second most mentioned plant, *Cordyline* spp. is traditionally planted to mark land boundaries, an important function in the country where customary land ownership is recognized but often unmapped and unrecorded (Barrau 1965; Sheridan 2016). It is also used in medicine (WHO 2009) and as body decoration in traditional dances. Also, in Melpa culture, important vows (e.g., not to get involved in tribal fights, not to remarry, etc.) are sealed with planting cordyline. The third most frequently mentioned native plant, ginger (*Zingiber* spp.), is not only edible but also often used as protection against sorcery.

Picture-based language tests are one of the most efficient and useful methods for measuring language ability (Brouwer, Johannessen, and Clausen 2019; Cheung, Hartley, and Monaghan 2022). Our tests show a high level of language proficiency among Melpa students, which correlates well with their self-assessment of language proficiency. Students were largely familiar with most common terms for body parts, and only two terms (pupil and wrist) were not correctly or nearly correctly named by the majority of respondents. Certain body parts were systematically confused with an adjacent part (chin with jaw, eyebrow with eyelid). The Melpa language is spoken by a relatively large population in a densely populated area with a large urban center, Mt. Hagen, and is therefore used for general communication. Despite the strength of the Melpa language, our analysis shows the same factors influencing language proficiency as in many other PNG languages (Kik et al. 2021). This suggests that even large and commonly vigorously used languages are not immune to the strong socioeconomic factors that threaten all Indigenous languages, particularly in the tropics (Amano Tatsuya et al. 2014). These include increasing urbanization, declining traditional life skills, formal education obtained in non-native another language, employment, mixed-language marriages, and declining language use at home. These trends point to an uncertain future for the Melpa language as well, as PNG moves forward in economic development and education.

Our analysis of the Melpa language as part of a broader study of PNG languages (Kik et al. 2021) has shown that ethnobiological knowledge can be easily lost, even if the language itself remains strong. It is likely the majority of the young Melpa population that live in villages and do not attend secondary school have better ethnozoological and ethnobotanical knowledge. However, we expect secondary education to spread rapidly in PNG, as it has in other countries, so our study gives an indication of future trends for the Melpa population in general. The threats to traditional biological and cultural knowledge are well known. They were recently addressed in the Warning to Humanity on Threats to Indigenous and Local Knowledge Systems (Fernández-Llamazares et al. 2021). This analysis identified external threats to Indigenous communities, including land and cultural appropriation, oppression, and assimilation. However, while the Melpa people and Papua New Guineans in general are in control of their land, culture, and lifestyle, their traditional knowledge is declining nonetheless as a consequence of powerful internal factors, including economic and lifestyle choices and aspirations of the Melpa people.

Acknowledgements

We are grateful to Put Aiya, Tengdui Aiya, Pelga Eti, Susan Dupai, and Kerin Koi for advice in interpreting the Melpa language responses. Tiberius Jimbo for verifying names of plant species. We thank the Education Department of PNG Government and the New Guinea Binatang Research Center for approving and supporting this study. This study was supported by the Czech Science Foundation (18–23889 S), The European Research Council (669609) and The Darwin Initiative for the Survival of the Species (DIR25S1\100123).

References Cited

Agnihotri, S., and A. Si. 2012. Solega Ethno-Ornithology. *Journal of Ethnobiology* 32: 185–211. DOI:10.2993/0278-0771-32.2.185.

Ahmed, N., A. Mahmood, A. Mahmood, Z. Sadeghi, and M. Farman. 2015. Ethnopharmacological Importance of Medicinal Flora from the District of Vehari, Punjab Province, Pakistan. *Journal of Ethnopharmacology* 168: 66–78. DOI: 10.1016/j.jep.2015.02.048.

Amano, T., B. Sandel, H. Eager, E. Bulteau, J. Svenning, B. Dalsgaard, C. Rahbek, R. G. Davies, and W. J. Sutherland. 2014. Global Distribution and Drivers of Language Extinction Risk." *Proceedings of the Royal Society B: Biological Sciences* 281: 20141574. DOI: 10.1098/rspb.2014.1574.

Barrau, J. 1965. Witnesses of the Past: Notes on Some Food Plants of Oceania. *Ethnology* 4: 282–294. DOI:10.2307/3772988.

Bignante, E. 2010. The Use of Photo-elicitation in Field Research. *EchoGéo*, 11. DOI: 10.4000/echogeo.11622.

Bromham, L., R. Dinnage, H. Skirgård, A. Ritchie, M. Cardillo, F. Meakins, S. Greenhill, and X. Hua. 2022. Global Predictors of Language Endangerment and the Future of Linguistic Diversity. *Nature Ecology & Evolution* 6: 163–73. DOI: 10.1038/s41559-021-01604-y.

Brouwer, C. E., C. M. Johannessen, and M. C. Clausen. 2019. Understanding the Meaning Potential of Pictures in Speech and Language Assessment. *RASK–International journal of language and communication* 49: 105-127.

Cámara-Leret, R., and J. Bascompte. 2021. Language Extinction Triggers the Loss of Unique Medicinal Knowledge. *Proceedings of the National Academy of Sciences* 118. DOI: 10.1073/pnas.2103683118.

Cámara–Leret, R., and Z. Dennehy. 2019. Indigenous Knowledge of New Guinea's Useful Plants: A Review1. *Economic Botany* 73: 405-415. DOI: 10.1007/s12231-019-09464-1.

Cámara-Leret, R., D. G. Frodin, F. Adema, C. Anderson, M. S. Appelhans, G. Argent, S. A. Guerrero, et al. 2020. New Guinea Has the World's Richest Island Flora. *Nature* 584: 579–83. DOI: 10.1038/s41586-020-2549-5.

Campos, C. M., S. Greco, J. J. Ciarlante, M. Balangione, J. B. Bender, J. Nates, and P. Lindemann-Matthies. 2012. Students' Familiarity and Initial Contact with Species in the Monte Desert (Mendoza, Argentina). *Journal of Arid Environments* 82: 98–105. DOI: 10.1016/j.jaridenv.2012.02.013.

Cheung, R. W., C. Hartley, and P. Monaghan. 2022. Receptive and Expressive Language Ability Differentially Support Symbolic Understanding over Time: Picture Comprehension in Late Talking and Typically Developing Children. *Journal of Experimental Child Psychology* 214: 105305. DOI: 10.1016/j.jecp.2021.105305.

Conservation & Environment Protection Authority of Papua New Guinea (CEPA). 2019. Papua New Guinea 6th National Report to the Convention on Biological Diversity. Conservation and Environment Protection Authority, Papua New Guinea.

Cox, D. T. C., and K. J. Gaston. 2018. Human–Nature Interactions and the Consequences and Drivers of Provisioning Wildlife. *Philosophical Transactions of the Royal Society B: Biological Sciences* 373: 20170092. DOI: 10.1098/rstb.2017.0092.

Dallimer, M., K. N. Irvine, A. M. J. Skinner, Z. G. Davies, J. R. Rouquette, L. L. Maltby, P. H. Warren, P. R. Armsworth, and K. J. Gaston. 2012. Biodiversity and the Feel-Good Factor: Understanding Associations between Self-Reported Human Well-Being and Species Richness. *BioScience* 62: 47–55. DOI:

10.1525/bio.2012.62.1.9.

Douglass, K., D. Gaffney, T. J. Feo, P. Bulathsinhala, A. L. Mack, M. Spitzer, and G. R. Summerhayes. 2021. Late Pleistocene/Early Holocene Sites in the Montane Forests of New Guinea Yield Early Record of Cassowary Hunting and Egg Harvesting. *Proceedings of the National Academy of Sciences* 118: e2100117118. DOI:10.1073/pnas.2100117118.

Eberhard, D. M., G. F. Simons, and C. D. Fennig, eds. 2021. Ethnologue: Languages of the World. Twenty-fourth edition. Dallas, Texas: SIL International. [online] URL: http://www.ethnologue.com.

Enzensberger, P., B. Schmid, T. Gerl, and V. Zahner. 2022. Robin Who? Bird Species Knowledge of German Adults. *Animals* 12: 2213. DOI: 10.3390/ani12172213.

Fernández-Llamazares, Á., D. Lepofsky, K. Lertzman, C. G. Armstrong, E. S. Brondizio, M. C. Gavin, P. O. Lyver, et al. 2021. Scientists' Warning to Humanity on Threats to Indigenous and Local Knowledge Systems. *Journal of Ethnobiology* 41: 144–69. DOI: 10.2993/0278-0771-41.2.144.

Frye, H., S. Balar, and A. Si. 2022. Experiences with Remote Linguistic-ethnobiological Fieldwork on Bird Names in the Qaqet Language of Papua New Guinea. *Language Documentation & Conservation* 16.

Gardner, R. O. 2010. Plant Names of the Kalam (Upper Kaironk Valley, Schrader Range, Papua New Guinea). *Records of the Auckland Museum* 47: 5–50.

Golson, J., and D. S. Gardner. 1990. Agriculture and Sociopolitical Organization in New Guinea Highlands Prehistory. *Annual Review of Anthropology* 19: 395–417.

Gosler, A. G., and S. M. Tilling. 2022. Knowledge of Nature and the

Nature of Knowledge: Student Natural History Knowledge and the Significance of Birds. *People and Nature* 4: 127–42. DOI: 10.1002/pan3.10265.

Hays, T. E. 1979. Plant Classification and Nomenclature in Ndumba, Papua New Guinea Highlands. *Ethnology* 18: 253–70. DOI: 10.2307/3773377.

Healey, C. 1993. Folk Taxonomy and Mythology of Birds of Paradise in the New Guinea Highlands. *Ethnology* 32: 19.

Howley, P. 2008. A Short Study of Melpa Prehistory. *Contemporary PNG Studies* 9: 1-17.

Hughes, J., M. Richardson, and R. Lumber. 2018. Evaluating Connection to Nature and the Relationship with Conservation Behaviour in Children. *Journal for Nature Conservation* 45: 11–19. DOI: 10.1016/j.jnc.2018.07.004.

Hunn, E. S. 2002. Evidence for the Precocious Acquisition of Plant Knowledge by Zapotec Children. *Ethnobiology and Biocultural Diversity* 604: 13.

Hunn, E. S. 2008. *A Zapotec Natural History: Trees, Herbs, and Flowers, Birds, Beasts, and Bugs in the Life of San Juan Gbʻʻ*. University of Arizona Press.

Jaun-Holderegger, B., H. Lehnert, and P. Lindemann-Matthies. 2022. Knowledge and Perception of Common Local Wild Plant and Animal Species by Children and Their Teachers – a Case Study from Switzerland. *International Journal of Science Education* 44: 1318–35. DOI: 10.1080/09500693.2022.2076949.

Jorim, R.Y., S. Korape, W. Legu, M. Koch, L. R. Barrows, T. K. Matainaho, and P. P. Rai. 2012. An Ethnobotanical Survey of Medicinal Plants Used in the Eastern Highlands of Papua New Guinea. *Journal of Ethnobiology and Ethnomedicine* 8: 47.

DOI:10.1186/1746-4269-8-47.

Kik, A., M. Adamec, A. Y. Aikhenvald, J. Bajzekova, N. Baro, C. Bowern, R. K. Colwell, et al. 2021. Language and Ethnobiological Skills Decline Precipitously in Papua New Guinea, the World's Most Linguistically Diverse Nation. *Proceedings of the National Academy of Sciences* 118. DOI: 10.1073/pnas.2100096118.

Kik, A., P. Duda, J. Bajzekova, N. Baro, R. Opasa, G. Sosanika, L. R. Jorge, et al. 2023. Hunting Skills and Ethnobiological Knowledge among the Young, Educated Papua New Guineans: Implications for Conservation. *Global Ecology and Conservation* 43: e02435. DOI: 10.1016/j.gecco.2023.e02435.

Leahy, M. J. 1991. *Explorations Into Highland New Guinea, 1930-1935*. University of Alabama Press.

Lees, A. C., L. Haskell, T. Allinson, S. B. Bezeng, I. J. Burfield, L. M. Renjifo, K. V. Rosenberg, A. Viswanathan, and S. H. M. Butchart. 2022. State of the World's Birds. *Annual Review of Environment and Resources* 47: 231–60. DOI: 10.1146/annurev-environ-112420-014642.

Lindemann-Matthies, Petra. 2005. 'Loveable' Mammals and 'Lifeless' Plants: How Children's Interest in Common Local Organisms Can Be Enhanced through Observation of Nature. *International Journal of Science Education* 27: 655–77. DOI: 10.1080/09500690500038116.

Mack, A.L., and P. West. 2005. Ten Thousand Tonnes of Small Animals: Wildlife Consumption in Papua New Guinea, a Vital Resource in need of Management. Resource Management in Asia-Pacific Working Paper No. 61. Resource Management in Asia-Pacific Program, Research School of Pacific and Asian Studies, Australian National University, Canberra.

Majnep, I. S., and R. Bulmer. 1977. *Birds of My Kalam Country*. Oxford University Press, USA.

Mikołajczak, K., A. C. Lees, J. Barlow, F. Sinclair, O. Trindade de Almeida, A. C. Souza, and L. Parry. 2021. Who Knows, Who Cares? Untangling Ecological Knowledge and Nature Connection among Amazonian Colonist Farmers. *People and Nature* 3: 431–45. DOI: 10.1002/pan3.10183.

Milliken, W. 1992. Ethnobotany of the Yali. *Royal Botanic Garden, Endiburgh*, 4–6.

Nieder, J., J. Prosperi, and G. Michaloud. 2001. Epiphytes and Their Contribution to Canopy Diversity. *Plant Ecology* 153: 51–63. DOI: 10.1023/A:1017517119305.

O'Brien, C. M. 2010. Do They Really 'Know Nothing'? An Inquiry into Ethnobotanical Knowledge of Students in Arizona, USA. *Ethnobotany Research Applications* 8:035-047. [online] URL: http://hdl.handle.net/10125/20998.

Pam, G., D. Zeitlyn, and A. Gosler. 2018. Ethno-Ornithology of the Mushere of Nigeria: Nigeria: Children's Knowledge and Perceptions of Birds. *Ethnobiology Letters* 9: 48–64.

Pilgrim, S. E., L. C. Cullen, D. J. Smith, and J. Pretty. 2008. Ecological Knowledge Is Lost in Wealthier Communities and Countries. *Environmental Science & Technology* 42: 1004–9. DOI: 10.1021/es070837v.

Quinlan, M. B., R. J. Quinlan, S. K. Council, and J. W. Roulette. 2016. Children's Acquisition of Ethnobotanical Knowledge in a Caribbean Horticultural Village. *Journal of Ethnobiology* 36: 433–56. DOI: 10.2993/0278-0771-36.2.433.

R. Core Team. 2022. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. [online] URL: https://www.R-project.

Saulei, S. M., and J. A. Aruga. 1994. The Status and Prospects of Non-Timber Forest Products Development in Papua New Guinea. *The Commonwealth Forestry Review* 73: 97–105.

Schlegel, J., and R. Rupf. 2010. Attitudes towards Potential Animal Flagship Species in Nature Conservation: A Survey among Students of Different Educational Institutions. *Journal for Nature Conservation* 18: 278–90. DOI: 10.1016/j.jnc.2009.12.002.

Sheridan, M. 2016. Boundary Plants, the Social Production of Space, and Vegetative Agency in Agrarian Societies. *Environment and Society* 7: 29–49. DOI: 10.3167/ares.2016.070103.

Si, A. 2020. Patterns in the Transmission of Traditional Ecological Knowledge: A Case Study from Arnhem Land, Australia. *Journal of Ethnobiology and Ethnomedicine* 16: 52. DOI: 10.1186/s13002-020-00403-2.

Slone, T. H., ed. 2001. *One Thousand One Papua New Guinean Nights: Tales form 1972-1985.* Vol. 1. Masalai Press, 2001.

Soga, M., and K. J. Gaston. 2016. Extinction of Experience: The Loss of Human–Nature Interactions. *Frontiers in Ecology and the Environment* 14: 94–101.

Stepp, J. R., H. Castaneda, and S. Cervone. 2005. Mountains and Biocultural Diversity. *Mountain Research and Development* 25: 223–27.

Supuma, M. 2018. Endemic Birds in Papua New Guinea's Montane Forests: Human Use and Conservation. PhD Thesis, James Cook University. Available at: https://doi.org/10.25903/5d0194ca93995. Accessed on June 12, 2023.

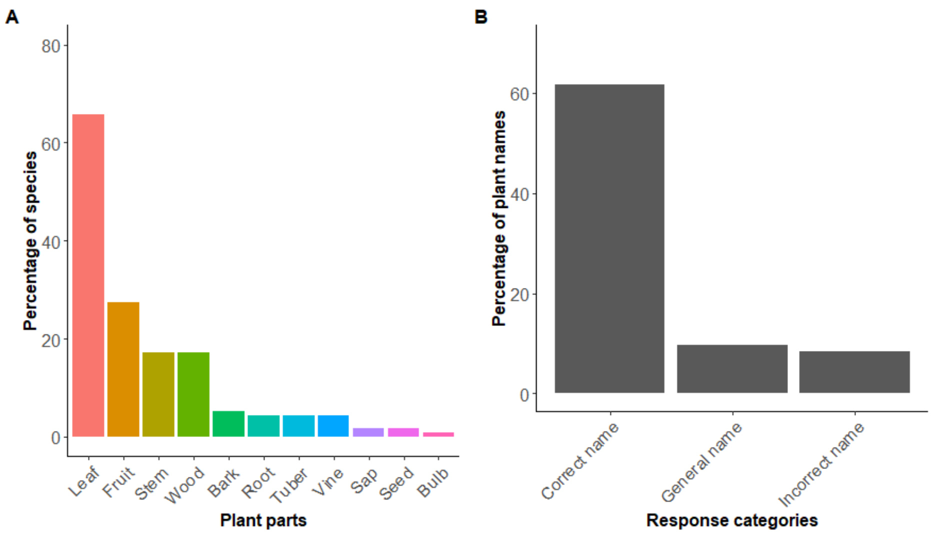
Van Auken, P. M., S. J. Frisvoll, and S. I. Stewart. 2010. Visualising

Community: Using Participant-Driven Photo-Elicitation for Research and Application. *Local Environment* 15: 373–88. DOI: 10.1080/13549831003677670.

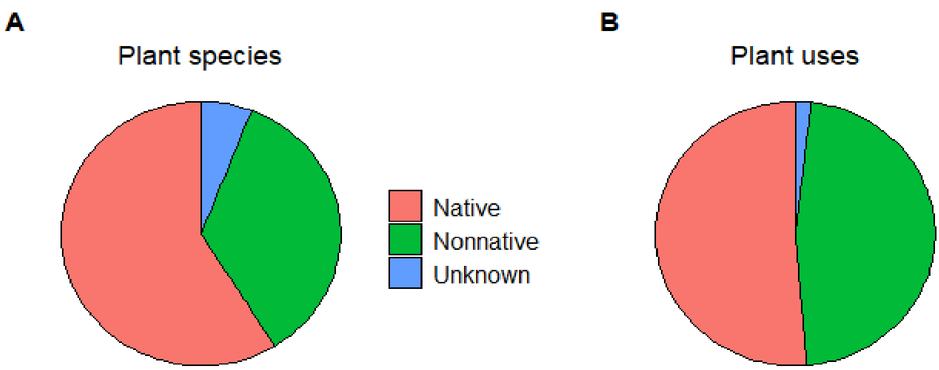
World Health Organization (WHO). 2009. *Medicinal Plants in Papua New Guinea: Information on 126 Commonly Used Medicinal Plants in Papua New Guinea*. WHO Regional Office for the Western Pacific.

Yaseen, G., M. Ahmad, M. Zafar, S. Sultana, S. Kayani, A. A. Cetto, and S. Shaheen. 2015. Traditional Management of Diabetes in Pakistan: Ethnobotanical Investigation from Traditional Health Practitioners. *Journal of Ethnopharmacology* 174: 91–117. DOI: 10.1016/j.jep.2015.07.041.

Supporting information



Supplementary Figure 1. The frequency of usage of individual plant parts from the traditionally used species listed by Melpa-speaking students (A) and the accuracy of traditional plant names listed by Melpa-speaking students. Plant species names (B).



Supplementary Figure 2. The number of traditionally used plant species

(A) and their individual uses (B), classified by the origin of the plant species: native to New Guinea, non-native, and of uncertain status. Note that some plant species have multiple uses.

Supplementary Table 1. The 117 traditionally used plant species listed by Melpa-speaking students. Count: number of students that mentioned the plant, from the total of 1,313 students tested; Scientific name: some local names could not be linked with botanical species; Origin: native or non-native species; Use category: Co = construction, Dr = drug, Fi = firewood, Fo = food, MB = myth/belief, Me = medicine, Or = ornamental, Ou = other use, TW = tools/weapons; Parts used: B = Bark, F = fruit, L = leaf, R = root, S = stem, Sa = Sap, Se = seed, T= tuber, V = vine, W = Wood, WP = whole plant.

Vernacular name	Count	Common name	Scientific name	Origin	Life Form	Use Category	Part
Nunt	514	Stinging tree	*Laportea decumana*	Native	Herb	Me	L
Pulga kaia	295	Ti plant	*Cordyline* spp.	Native	Shrub	Co, Me, MB, Or	S, L
Lombo	220	Chilli pepper	*Capsicum frutescens*	Non-native	Herb	Fo, Me	F
Muli	217	Mandarin/Orange	*Citrus* spp.	Non-native	Shrub	Fo, Me	F,L
Kupna	201	Ginger	*Zingiber officinale*	Native	Herb	Fo, Me, MB	R, L
Towa/rua	192	Banana	*Musa* spp.	Native	Herb	Fo, Me, Ou	F, L, S,
Gomba	180	Guava	*Psidium guajava*	Non-native	Shrub	Fo, Me	F/L
Apra mapra	159	Miracle leaf	*Bryophyllum pinnatum*	Non-native	Shrub	Me, MB	L
Oka/Gai	137	Sweet potato	*Ipomoea batatas*	Non-native	Herb	Fo, Me, Ous	T, L
Pamba	127	Fern	*Asplenium* spp.	Native	Shrub	Fo, Me, Ou	L, S
Angumb	122	Kunai grass	*Imperata cylindrica*	Native	Herb	Co, Ou	L
Popo	119	Pawpaw leaf	*Carica papaya*	Non-native	Tree	Fo, Me, Ou	L, F, Se
Kowa mungalg	87	Bamboo	*Schizostachyum* spp.	Native	Herb	Co, TW, Ou	S

Kumaia	87	Wild sugarcane	*Saccharum spontaneum*	Native	Herb	Co, TW, Ous	S
Me	86	Taro	*Colocasia esculenta*	Non-native	Herb	Fo, Me, Ou	R, L
Po	83	Sugarcane	*Saccharum officinarum*	Native	Herb	Fo, Me, Ou	S, L
Nde kaipa	82	Casuarina tree	*Casuarina* spp.	Native	Tree	Co, Fi, MB, Ou	W, B, L
Kim weka	74	Aibika	*Abelmoschus manihot*	Native	Shrub	Fo, Me	L
Kalip	67	Peanut	*Arachis hypogaea*	Non-native	Herb	Fo, Me	See, L
Titik	67	Lemongrass	*Cymbopogon citratus*	Non-native	Herb	Me, Ou	L
Bengabanga	64	Blackjacks	*Bidens pilosa*	Non-native	Herb	Me, Ou	L
Kuki daka	44	Pepper	*Piper* spp.	Non-native	Tree	Co, Me, Ou	L, S
Knapa	42	Corn	*Zea mays*	Non-native	Herb	Fo, Ou	F, L, S
Op	42	Yam	*Dioscorea* spp.	Non-native	Herb	Fo, Ou	T, V
Kim kun	41	Water dropwort	*Oenanthe javanica*	Native	Herb	Fo, Me	L
Golg	33	Sugarcane	*Saccharum officinarum*	Native	Herb	Co, TW, Ou	S
Kim kengepa	33	Mushroom plant	*Rungia* spp.	Native	Shrub	Fo, Me, Ou	L

Neka	33	Marita	*Pandanus conoideus*	Native	Tree	Fo, Me, Ou	F, L, S
Brus	30	Passion/granadilla fruit	*Passiflora spp.*	Non-native	Climber	Fo, Me	F, V
Bata	27	Avocado	*Persea americana*	Non-native	Tree	Co,Fi, Fo, Ou	F, W, L
Kopi	26	Coffee	*Coffea arabica*	Non-native	Tree	Co, Ou	W, F, L
Eta rarau	25	General weeds	N/A	N/A	Herb	Fo, Me, Ou	L, WP
Bandi	21	Cassava	*Manihot esculenta*	Non-native	Shrub	Fo, Ou	T, S, L
Minba	21	Highland breadfruit	*Ficus dammaropsis*	Native	Tree	Fi, Fo, Ou	L, S, Sa, F
Eta aiwai	19	Horseweed	*Conyza* spp.	Non-native	Herb	Me, Ou	L, WP
Am	18	Karuka nut	*Pandanus julianettii*	Native	Tree	Co, Fo, Ou	S, L, F
Mui	18	Palmgrass	*Setaria palmifolia*	Native	Herb	Fo, Ou	S, L
Kengel	15	Giant reed	*Arundo donax*	Non-native	Herb	Co, MB, TW	S
Kaspel	14	Potato	*Solanum tuberosum*	Non-native	Herb	Fo, Ou	T
Lepa	14	Agave plants	*Agave* spp.	Non-native	Herb	Me, Ou	L
Pulg pint	14	Bracken fern	*Pteridium aquilinum*	Native	Herb	Ou	L

Kim gitam	13	Black nightshade	*Solanum nigrum*	Native	Herb	Fo, Me	L, F
Tupralg	13	Cucumber	*Cucumis sativus*	Non-native	Climber	Fo, Me	F
Nde kwang	12	Japanese chinquapin	*Castanopsis cuspidata*	Native	Tree	Co, Fi, Ou	W, L, F
Nde waima	12	Pine tree	*Pinus* spp.	Non-native	Tree	Co, Fi, Ou	W, B
Kim kapis	12	Cabbage	*Brassica oleracea*	Non-native	Herb	Fo, Me	L
Rok mara	11	Marijuana	*Cannabis sativa*	Non-native	Herb	Me, Dr	L
Wei pen	10	N/A	N/A	Native	Tree	Or	F
Binap	10	Pineapple	*Ananas comosus*	Non-native	Herb	Fo, Ou	F
Nde kraip	10	N/A	N/A	Native	Tree	Co, Fi	W
Buna	10	Geonoma palm	*Geonoma* spp.	Native	Palm	Co	S, L
Koma	10	Moss	*Bryophyta*	Native	Epiphyte	Co, Or	WP
Oma Kan	9	N/A	N/A	Native	Climber	Ou	V
Aniani	8	Onion/Galic	*Allium* spp.	Non-native	Herb	Fo, Me	Bu, L
Ant plaua	8	Mexican sunflower	*Tithonia diversifolia*	Non-native	Shrub	Me	L

Nde pokta	8	N/A	N/A	Native	Tree	Co, Fi, Ou	W, B, L
Nde wantep	8	N/A	N/A	Native	Tree	Co, Fi	W, B
Postri	8	Gum tree	*Eucalyptus*	Native	Tree	Co, Fi	W, B, L
Kim kund	7	Joseph's coat	*Amaranthus tricolor*	Native	Herb	Fo, Me	L
Rok Brus	7	Tobacco	*Nicotiana tabacum*	Native	Herb	Dr	L
Kim sako	7	Choko	*Sechium edule*	Non-native	Herb	Fo	F, L, R
Mumbil	6	Berries	*Rubus* spp.	Native	Shrub	Fo	F
Gorgor	6	Gorgor	*Zingiber* spp.	Native	Herb	Fo, Me	L, F
Bangen	5	Pumpkin	*Cucurbita* spp.	Non-native	Herb	Fo	L, F
Nde malt	5	N/A	N/A	Native	Tree	Co, Fi, MB	W, B
Gu tamb	5	N/A	N/A	Native	Herb	Me	WP/L
Kim kimbi	5	N/A	N/A	Native	Herb	Fo, Me	WP, L
KimkKris	5	Watercress	*Nasturtium officinale*	Non-native	Herb	Fo	WP
Mara omong	5	N/A	N/A	Native	Tree	Co, Ou	L

Nde kilua	4	N/A	N/A	Native	Tree	Co	W
Nde krup (ro)	4	N/A	N/A	Native	Tree	Co, Fi, Me	W, Sa
Gramba ka	4	N/A	N/A	Native	Climber	Co	V
Kengna yara	4	N/A	N/A	Native	Herb	Co	WP/L
Kim kora	4	Kapiak	*Ficus copiosa*	Native	Tree	Fo, Fi, Me	L, WP
Kopen kima	4	Bread fruit	*Artocarpus altilis*	Native	Tree	Fo, MB	L, F
Plaua tumb	4	American senna	*Senna hebecarpa*	Non-native	Herb	Ou	WP, L
Capera mera	3	N/A	N/A	Native	Herb	Me	L
Nde neng	3	N/A	N/A	Native	Shrub	Fi, MB, Dr	L, WP
Poilg	3	Crabgrass	*Digitaria* spp.	Native	Herb	Ou	WP
Yalga	3	Palm	*Palm* spp.	Native	Palm	Co, Dr, TW	L, S, F
Alo vera	2	Alo vera	*Alo vera*	Non-native	Herb	Me	L
Nde marmar	2	Marmar (Rain tree)	*Samanea* spp.	Non-native	Tree	Co, Fi, Me	W, L
Nde nap	2	N/A	*Casuarina* spp.	Native	Tree	Co, Fi, TW	W

Goiminga	2	Sponge gourd	*Luffa aegyptiaca Mill.*	Native	Climber	Fo, MB	F
Kemb tank	2	N/A	N/A	Native	Herb	Me	WP
Kupna krai	2	Ginger	*Zingiber* spp.	Native	Herb	MB	R, L
Kur kim	2	Thick head	*Crassocephalum crepidioides*	Non-native	Herb	Me	L
Kur towa	2	Wild banana	*Musa* spp.	Native	Herb	Fo, MB	L, F
Kur weka	2	Wild aibika	*Abelmoschus* spp.	Native	Shrub	Me, MB	L
Mong tamb	2	N/A	N/A	Native	Herb	Me	L
Punt	2	Winged bean	*Psophocarpus tetragonolobus*	Native	Herb	Fo, Me	L, TR
Tamto	2	Tomato	*Solanum* spp.	Non-native	Herb	Fo	F
beage mong	1	Beans	N/A	N/A	Climber	Fo, Me	L, Se
Bin bari	1	Lima bean	*Phaseolus lunatus*	Non-native	Herb	Fo	L, Se
Bin pee	1	Garden pea	*Pisum sativum*	Non-native	Herb	Fo	Se
Buai	1	Areca nut	*Areca catechu*	Native	Palm	Co, MB, Dr	F, L
Nde bun	1	N/A	N/A	Native	Tree	Co, Fi	W

Nde katel	1	White oak	*Castanopsis acuminatissima*	Native	tree	Co, Fi	W
Nde kumbalg	1	N/A	N/A	N/A	Tree	Co, Fi	W
Nde mara	1	N/A	N/A	Native	Tree	Co, Fi	W
Nde melek	1	N/A	N/A	Native	Tree	Co, Fi, Ou	W, L
Nde Olka	1	Sand olive	*Dodonaea angusifolia*	Native	Tree	Co, Fi	W
Kera tamto	1	Tree tomato	*Cyphomandra betacea*	Non-native	Tree	Fo, Me, Ou	F, L
Kim kambilga	1	Scurvy weed	*Commelina* spp.	Native	Herb	Fo, Me	WP
Kokonut	1	Coconut	*Cocos nucifera*	Native	Palm	Co, Fi, Me	S, L, F
kombla oui	1	Grass	N/A	Native	Herb	Me	L
Kung hera	1	Napier grass	*Pennisetum purpureum*	Non-native	Herb	Ou	L
Kupulg	1	N/A	N/A	Native	Herb	Co	WP
Kurup ro	1	N/A	N/A	Native	Tree	Co, Fi, Me	L, S
Ming tepa	1	Calabash gourd	*Lagenaria siceraria*	Native	Herb	Fo, Ou	F
Mint	1	Mint	*Mentha* spp.	Non-native	Herb	Fo, Me	L

Mongalkan	1	N/A	N/A	Native	Climber	Me	V
Noni	1	Noni	*Morinda citrifolia*	Native	Tree	Me	F
Numa nama	1	N/A	N/A	Native	Herb	Ou	L
Ropen	1	Pitpit	*Saccharum edule*	Native	Herb	Co, Fo	F, S
Takam	1	Pandan Ikan	*Benstonea* spp.	Native	Epiphytic	Co	L

CHAPTER IV

Decline in language proficiency and ethnobiological knowledge in major linguistic hotspots: West Africa and New Guinea

[Manuscript]

Decline in language proficiency and ethnobiological knowledge in major linguistic hotspots: West Africa and New Guinea

Alfred Kik[A,B,C], Aku N. Neku[D], Francis L. Ewome[E], Leonardo R. Jorge[B], Liliane Hodieb[F], Jeff Good[G], Jarmila Bajzekova[A,B], Tomas Albrecht[H,I], Katerina Sam[A,B], Alexandra Y. Aikhenvald[J], Pavel Drozd[K], Pavel Duda[A], Hannah Sarvasy[L] & Vojtech Novotny[A,B,*]

[A]Faculty of Sciences, University of South Bohemia, Ceske Budejovice, Czech Republic.

[B]Biology Centre, Czech Academy of Sciences, Ceske Budejovice, Czech Republic.

[C]New Guinea Binatang Research Center, Madang, Papua New Guinea.

[D]Department of Linguistics and African Languages, University of Bamenda, Bamenda, Cameroon.

[E]Venture Trips, Bokwango, Buea, Cameroon.

[F]National Institute of Oriental Languages and Civilizations, Paris, France

[G]Department of Linguistics, University at Buffalo, Buffalo, USA.

[H]Faculty of Sciences, Charles University, Praha, Czech Republic.

[I]Institute of Vertebrate Biology, Czech Academy of Sciences, Brno, Czech Republic.

[J]MARCS Institute for Brain, Behaviour and Development, Western Sydney University, Penrith, Australia.

[K]Faculty of Sciences, University of Ostrava, Ostrava, Czech Republic.

[*]Corresponding author, Email: novotny@entu.cas.cz

Author Contributions: A.K. and V.N. designed research with input from F.L.E., T.A. and K.S.; A.N.N. and F.L.E. performed research; L.R.J. contributed analytic tools and led the analysis; J.B. managed the data; all authors interpreted the data and contributed to writing the paper, led by V.N.

Competing Interest Statement: The authors declare no competing interests.

Classification: Social Sciences: Anthropology and Biological Sciences: Anthropology

Abstract

With 872 languages, West Africa is the second largest hotspot of language diversity in the world, surpassed only by New Guinea (1,065 languages). Together, these regions comprise more than a quarter of the world's languages. We analyze individual-level parameters of family language use, socioeconomic status, life skills, and language traits as factors influencing language proficiency and ethnobiological knowledge for 831 students in Cameroon who speak 65 languages (24% of the country's total) and compare them with data from 6,190 students speaking 392 languages in Papua New Guinea (PNG). We show that only 54% of Cameroonian students are fluent in indigenous languages compared to 92% of their parents. Urbanization, traditional skills, and language use in the home predicted students' language proficiency, which in turn was strongly correlated with their ethnobiological knowledge of birds and plants. Drivers of language proficiency were nearly identical in Cameroon and PNG, but PNG students had better ethnobiological knowledge than Cameroon students across all levels of language proficiency. The rapid decline in language proficiency and ethnobiological knowledge in both language hotspots is likely to continue in the future, particularly due to increasing urbanization and globalization in both countries, which in PNG is also leading to an increasing proportion of linguistically mixed families.

Keywords: ethnobiology, language attrition, language endangerment, Cameroon, Papua New Guinea

Introduction

A majority of the ~7,000 existing languages are spoken by small populations in the tropics (Hua et al. 2019). The two largest tropical hotspots that host more languages than predicted based on their climate and landscape geography (Hua et al. 2019) are: the island of New Guinea, with 1,065 languages, and West Africa, where three countries, Nigeria, Cameroon, and Chad, host a combined 872 languages (Eberhard et al. 2020). Nearly half of all languages are considered threatened, and these are overrepresented in the tropics, where language communities are much smaller on average (Eberhard et al. 2020, Campbell & Okura 2018). Recently, we have documented a rapid decline in language proficiency among secondary school students in Papua New Guinea (PNG) due to declining use of indigenous languages at home, increasing numbers of mixed-language families where parents do not speak the same indigenous language, increasing urbanization, and declines in traditional skills such as hunting, horticulture, house building, and use of medicinal plants (Kik et al. 2021). We have also shown that these socioeconomic and cultural factors are likely to lead to further deterioration of language skills in the future, increasingly globalized, world. These trends will also lead to a loss of ethnobiological knowledge, which is closely linked to language skills (Kik et al. 2023).

Our results raise important questions about the future of languages and traditional ethnobiological knowledge in the tropics. How widespread is such accelerated decline of indigenous languages and ethnobiological knowledge? Is it caused by factors common across the tropics, or is PNG an exception, for example, because of its unique history of limited colonial influence and customary land tenure system? We explore these questions in Cameroon (274 languages, including 213 from the Niger-Congo family and 56 from the Afro-Asian family), which is the West African language hotspot, using the same methods and population segment as in PNG.

Interethnic contact, language shift, formal education, the transition to a market economy, new technologies, urbanization, religious beliefs, changing values, and modern media have been identified as global drivers of the decline in indigenous language skills and ethnobiological knowledge (Zent 2013, Hunn 2008, Si 2020). Some of these socioeconomic drivers are universal, but others may differ between West African and Melanesian societies, potentially leading to different expectations for the dynamics of language and ethnobiological knowledge between Cameroon and PNG.

PNG and Cameroon have the world's highest values of the Greenberg index of language diversity (the probability that an individual does not share the same language with another randomly selected individual): 0.988 for PNG and 0.974 for Cameroon (Eberhard et al. 2020). However, the average number of speakers per language is more than 10 times higher in Cameroon than in PNG (Table 1). Both Cameroon (in its Anglophone part, where our study was conducted) and PNG use a local English-based creole, Tok Pisin in PNG and Cameroon Pidgin English (CPE) in Cameroon. These languages were used for communication between numerous indigenous language populations that suddenly came into contact as a result of colonialism. Both countries have other lingua franca languages that are used locally, not considered here (Ayafor & Green 2017, Markussen-Daval & Bakker 2017, Romaine 1992, Wurm & Muehlhausler, 1984).

Both are lower-middle-income countries (World Bank 2020) with similar scores on the UN Human Development Index and the KOF Globalization Index (which quantifies globalization along economic, social, and political dimensions; Haelg 2019) (Fig. S2). They are historically distinct from each other, with a long history of large-scale social organization including kingdoms, advanced technology such as metalworking, long-distance trade, slave trade, and colonialism in Cameroon (Fowler & Zeitlyn, 1996).

Both Cameroon and PNG have predominantly young populations, with a median age of 19 years in Cameroon and 22 years in PNG (Ritchie & Roser 2019). The total fertility rate per woman in 2017 was 3.9 children in

Cameroon and 4.2 children in PNG. However, these high rates are predicted to fall below the population replacement level by 2100, to 1.4 in Cameroon and 1.8 in PNG (Vollset et al. 2020).

Cameroon is more urbanised than PNG, its population is more educated and less dependent on horticulture, but there are some pastoralist societies (Table 1). These differences predict a higher loss of language and ethnobiological knowledge in Cameroon than in PNG, based on the models we have developed to assess the various drivers of language and ethnobiological knowledge loss in PNG (Kik et al. 2021). Currently, 34% of indigenous languages in Cameroon and 32% in PNG are considered endangered based on the EGIDS classification of language endangerment in the *Ethnologue* (Eberhard et al. 2020), which is based on the intergenerational transfer of languages and the social domains of their use.

We argue that despite cultural, social, and historical differences among countries, quantitative analyses of language proficiency and its drivers are urgently needed to monitor and potentially counteract the rapid dynamics of language decline that are occurring among a large proportion of the world's languages. Sutherland (2003) applied the IUCN Red List criteria for endangered species to languages and concluded that a greater proportion of languages are endangered than mammal or bird species. Since then, monitoring the status of endangered vertebrates has arguably received more attention than languages. Here, we apply methodologically consistent surveys to numerous languages in global hotspots of linguistic diversity to provide an example of a quantitative approach to monitoring global linguistic and cultural diversity. This is an attempt to find commonalities in the processes of linguistic and ethnobiological knowledge loss between two historically, socially, and biologically very different regions.

Material and Methods

Language skills and ethnobiological knowledge variables

We surveyed students attending high school (the last two years of secondary school) in 11 secondary schools in the Anglophone, southwestern part of Cameroon (with 111 indigenous languages, Eberhard et al. 2020) from January 2015 to December 2017. Students in these schools were recruited from across the Anglophone region in western Cameroon, while only a few were from the eastern, Francophone part. Each student was asked to complete [i] a questionnaire on family socioeconomic background and lifestyle, [ii] a test on indigenous language skills, and [iii] a test on ethnobiological knowledge of plants and birds (Dataset S2). All surveys were voluntary, with informed consent, and anonymous. They were administered in schools and achieved >90% participation, avoiding the problem of self-selection in volunteer recruitment studies, where only more proficient speakers may be willing to participate. Our questionnaire was the same as that used by Kik et al. (2021) in PNG, except that the test of birds included locally common Cameroonian species. The main variables were as follows (see Dataset S2 for the full questionnaire):

Indigenous language skills were quantified by: [L1] the number of body parts from a list of 24 frequently and infrequently used terms named from photographs (O'Grady et al. 2009), and [L2] a student's self-assessment on the scale: 0 - no language skills; 1 - passive comprehension; 2 - speaking, but poorly; and 3 - fluent language use. We used two tests of ethnobiological knowledge: [E1] the number of bird species, from 10 widespread species ranging from easy to more difficult to recognize, that each student could name in an indigenous language using pictures, and [E2] the 10 plant species listed freely with their indigenous names and traditional uses other than staple foods. We used 19 independent variables to explain language skills (L1-L2) and ethnobiological knowledge (E1-E2), which were divided into four classes:

[A] Language traits: [A1] Language population size: the number of language users was estimated by interpolating or extrapolating the number listed in the *Ethnologue* database (Eberhard et al. 2020) to the year 2000 based on general population trends in Cameroon. [A2-A3] Language status: we used either the detailed EGIDS categories [A2] given for each language in the *Ethnologue*, or language status [A3], classified as endangered (EGIDS 6b to 10) or not endangered (EGIDS 1 – 6a). [A4] Elevation: median elevation for each language (in m a.s.l., log transformed), based on *Ethnologue* language maps. [A5] Availability of Bible translation, which is often the only written literature in indigenous languages (our research focused mainly on Christian regions).

[B] Family socioeconomic traits: [B1] Urbanization: the place of residence of the student's childhood in: 1 – village, 2 – town or city. [B2] Remoteness: the place where the student lived in childhood accessible by : 1 – road, 2 – boat (no road), 3 – airplane (no road or boat), 4 – walking only. [B3] Education of parents: the highest education attained by either parent: 1 – no school, 2 – lower primary (1st–6th grade), 3 – higher primary (7th–8th grade), 4 – lower secondary (9th-10th grade), 5 – higher secondary (11th–12th grade), 6 – any tertiary education. [B4] Parental employment: the highest employment category attained by either parent: 1 – subsistence farming, 2 – cash crop farming, 3 – salaried job or small business.

[C] Family language use: [C1] Parents' language proficiency: L2 scores were estimated by respondents for their parents; the higher parent's score was used. [C2] Language use at home: 1 – indigenous language (alone or with other languages, including Creole CPE and English/French), 2 – Creole CPE only, 3 – English/French (alone or with Creole CPE). [C3] Languages of parents: 1 – mother and father speak the same indigenous language, 0 – the family is linguistically mixed.

[D] Student traits: [D1] Gender: 1 – female, 0 – male. [D2-D3] Grade 10 test scores in English/French (D2) and math (D3), from 1 (excellent) to 4 (failed). [D4-D6] Traditional and contemporary technical skills: Students rated their skills (0 – none, 1 – poor, 2 – good) on five traditional tasks (D4): Hunting, fishing, horticulture (growing staple foods), building a house from traditional materials, and using plants to treat diseases, and on two contemporary technical tasks (D5): Using a mobile phone and a computer. The difference between traditional and contemporary technical skills was used as an additional explanatory variable (D6). Indigenous language instruction (D7): Intention to teach an indigenous language to one's children (1 – yes, 0 – no), by those who have the relevant language skills, with a predefined list of justifications for this choice: no, because (i) the indigenous language belongs to an old culture or (ii) it is not a useful skill for my children; yes, because (i) everyone in my village/town does it, (ii) it is a useful skill for my children, or (iii) it is part of my culture. This variable was not used for GLM models.

Language skills and ethnobiological knowledge analysis

We used generalised linear mixed models to assess the effects of the four classes of variables (A - D) on students' language skills (quantified as L1) as a response variable. The probability of obtaining correct answers was modelled as a binomial variable, with students and individual languages treated as random variables in all models. We used hierarchical model selection based on the Akaike Information Criterion (AIC) (Burnham & Anderson 2002) to compare the fit of each model. First, we used model selection separately for each class (A – D) of predictor variables. For the variables that had more than one level, we built models with polynomials of different order, from N – 1 levels to a linear relationship. For each class, we considered all variable combinations within that class and used different polynomial orders where appropriate. If more than one variable represented an alternative expression of the same factor (A2 vs. A3, D6 vs. D4 and D5), we excluded models that contained these variables together. We did not consider interactions between variables because we wanted to limit the degrees of freedom in the models. After obtaining the best-performing model for each class (Table S1), we combined the variables from each of these class-specific best-performing models to test whether different classes of variables jointly affected language skills. We built these models by combining all variables from the model with the best performance in each class into models with two, three, and all four classes, in all possible combinations, again without interactions (Table S2).

The relative role of each class and individual variable was examined by calculating by how much the AIC value increased after the focal variable or class was removed from the full model. Variables with a nonsignificant marginal effect were removed from the final model. We also assessed the direction and shape of the effects for individual predictor variables. We predicted the response variable by varying each of the predictor variables in the model with the best performance over its range, while holding the other predictors at their original means over the entire population of test scores.

We also applied the generalized linear mixed models to analyze students' ethnobiological knowledge (E1 and E2). We used the same variables and model-building strategy as for L1, except that we omitted the class of language traits (A) and added language skills (L1) as a new independent variable and used a Poisson distribution for knowledge about plants, since they were free-choice lists.

The relationships between students' language self-assessment (L2) and their ethnobiological knowledge of birds (E1) and plants (E2) and language proficiency test scores (L1) in the two different countries were examined by modeling L2, E1, and E2 as a function of L1 and country, combining the datasets from the present study and from Kik et. al (2021). We used a linear mixed model for L2 and generalized linear mixed models for E1 and E2. In all cases, language was added as a random factor, and we used model selection to compare models with combinations of L1 and country, including their interaction.

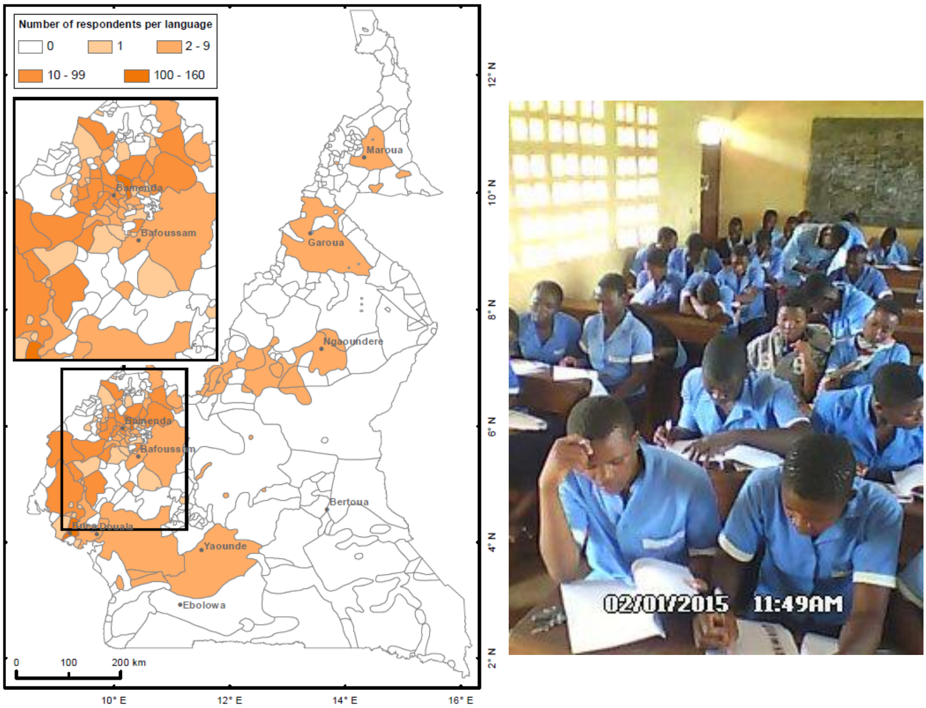


Fig. 1. Languages studied in Cameroon with the number of students surveyed (L); a survey of students in Atlantic Technical and Commercial High School in Limbe, Cameroon (R).

Results and Discussion

Language skills and ethnobiological knowledge in decline

We collected data from 831 secondary school students speaking 65 indigenous languages (24% of languages spoken in Cameroon), including 19 languages with ≥10 respondents (Fig. 1, Dataset S1). We found a marked decline in language skills within a generation, based on students' assessments of the language proficiency of their parents and of themselves. Whereas 92% of students' parents reported fluency in an indigenous language and only < 1% of them had no indigenous language skills at all, only 54% of students considered themselves fluent in an indigenous language, whereas 8% of students reported no indigenous language proficiency (Fig. 2A). The 19 languages with ≥10 respondents lost an average of 37±3.7% (±s.e.) fluent speakers between the two generations represented by parents and the students we surveyed (Fig 2B). This decline in fluency was almost identical to the situation reported from PNG using the same survey protocol (Fig. 2C, from Kik et al. 2021). However, the decline in language proficiency may be overestimated because secondary school students are most likely a biased sample of their age cohort, as discussed below.

At the same time, students in both countries were often multilingual, as 41% of students in Cameroon and 56% in PNG had at least passive knowledge of more than one indigenous language (Table 1). In Cameroon, as many as 23% of students were as proficient or better in another language than the language(s) of their parents.

Despite their similarity in L2 language skills, students from the two countries differed significantly in their L1 language test scores. In Cameroon, students named 2 (0 - 13) body parts (median, Q1-Q3), whereas in PNG they named 18 (10 – 23) body parts (Fig. 4, Table S7). The difference between the two countries was additive to the correlation between self-assessed language proficiency (L2) and language test scores (L1) (Fig. 3A, D). Whereas recognition of the median number of nine body parts was rated as “fluent” in Cameroon, the same results were rated as “passive understanding only" (median eight body parts named) or “speaking poorly” (median 12 body parts named) in PNG.

Measuring language skills based on self-assessments may suffer from several biases (Grinevald & Bert 2011). Young people might rate themselves as less fluent in indigenous languages than elders because they have less cultural knowledge. Individual respondents or entire cohorts may have different perceptions of what it means to be “fluent.” This was clearly the case with our results from Cameroon, where self-assessment criteria have shifted and are less stringent than in PNG. Self-assessment results from Cameroon overestimated actual fluency, in contrast to another study from Cameroon where self-assessment of fluency was quite accurate (Mba & Nsen Tem, 2020).

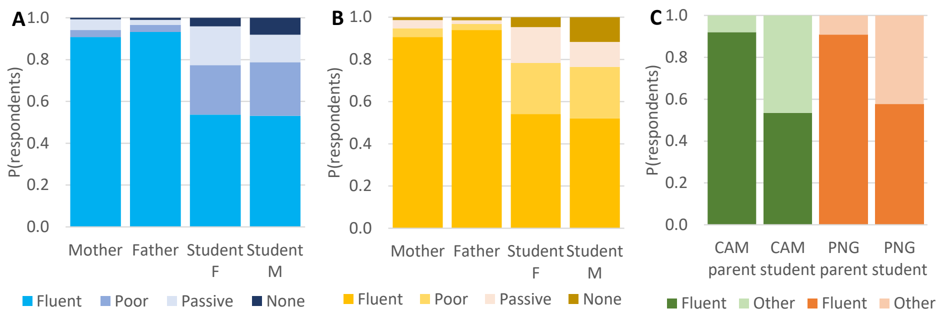


Fig. 2. Indigenous language skills in Cameroon. The proportion of respondents with four levels of language skills (L2) (A) for 831 students (female and male) and their parents, and (B) averaged for the 19 well-sampled languages (N ≥ 10 students per language); (C) the proportion of fluent speakers among parents and students in Cameroon (CAM) and Papua New Guinea (PNG, from Kik et al. 2021). Language skills were assessed by respondents for themselves and their parents on four-point scale: 0 - no language skills, 1 - passive understanding, 2 - speaking but poorly, 3 - fluency (L2).

Drivers of change

We tested the potential impact of a range of factors characterizing students' life skills, language use at home, socioeconomic conditions, and language characteristics on language skills in Cameroon (Fig. 3, Table 1, and Fig. S1) and compared the results with an analysis of similar data from PNG (Kik et al. 2021).

In both countries, language proficiency was most strongly correlated with three key variables: urbanization, students' traditional skills, and language use at home. An additional variable, the proportion of linguistically mixed families, was important only in PNG. There may be some cultural differences between countries that are not captured in this analysis. For example, in Cameroon and other West African countries (Childs 2003), in addition to competition between Creole CPE and English/French, there may be pressure to move from a smaller to a more dominant indigenous language, which is not the case in PNG, where none of the indigenous languages is spoken by more than 5% of the population and has lingua franca status (Eberhard et al. 2020).

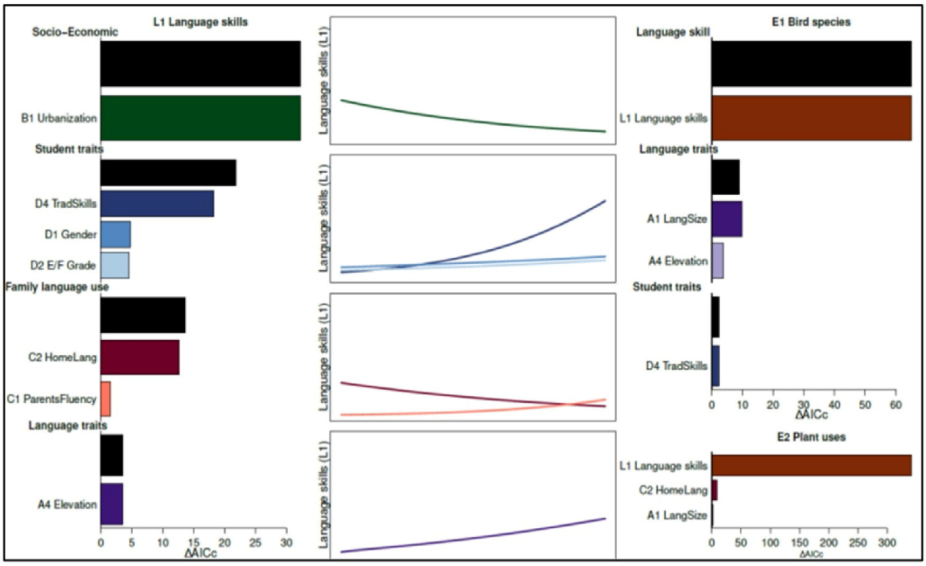


Fig. 3. Effects of language and socioeconomic factors on indigenous language skills and ethnobiological knowledge. Generalized linear mixed models (GLMM) describe variability in students' language skills (L1) and knowledge of bird species (E1) and traditional plant use (E2). The model for language language skills included 12 fixed variables divided into four classes (see Materials and Methods). Variables were selected within each class (SI Appendix, Table S1) before being included in a global model (SI Appendix, Table S2). Bars show AIC improvement by adding each group (black) and each variable within each group into a model that includes all other variables and quantifies the marginal effect of each class/variable. The line plots show the shape of the effect of each variable over its range, while holding the other variables constant. Only significant ($P < 0.05$)

variables are shown: (A) Language traits: language size (A1) and mean elevation (A4); (B) Socioeconomic traits: Birthplace urbanization (B1); (C) Family language use: parents' language skills (C1) and language use at home (C2); (D) Student characteristics: Gender (D1), school grade in English/French (E/F) (D2), and traditional skills (hunting, fishing, horticulture, traditional house building, medicinal plants) (D4). Models describing variability in student knowledge of bird species (E1) and traditional plant use (E2) used language skills (L1) and three classes of explanatory variables (family language use, socioeconomic traits, and student traits) (SI Appendix, Tables S3 - S6). L1 is defined in Fig. 2, the other variables in Materials and Methods.

A childhood in the village rather than in a town or city was the most important predictor of good language skills in Cameroon. Overall, 57% of the population in Cameroon and 61% of the students surveyed are urban, a much higher proportion than 13% of the population and 36% of the students surveyed who live in towns or cities in PNG (Table 1 and Fig. S2). Moreover, PNG students in particular are disproportionately from urban areas, so their language proficiency may be less representative of the population as a whole (Kik et al. 2021). Urbanization in Cameroon has steadily increased from 40% in 1990 to 57% in 2019, while PNG is one of the few countries in the tropics that has not urbanized in the last 30 years, with 80% of its population > living in rural areas (Fig. S2). Traditional land ownership by indigenous people, which is legally recognized in PNG, is an important socioeconomic factor that, combined with the poor accessibility of many rural areas in PNG, results in the majority of the population remaining in rural areas (Koczberski et al. 2009). While the other countries in the West African language hotspot also continue to urbanize, PNG is projected to be one of the few countries in the world where the majority of the population will remain rural by 2050 (Ritchie & Roser 2018). These divergent trends between Cameroon and PNG are clearly relevant to future trends in language skills. Urbanization is leading to the loss of intergenerational social contact, increasing the proportion of mixed-language families, and leading to the loss of traditional skills (Bromham et al. 2020).

Student characteristics, particularly traditional skills, are the second most important predictor of language skills in Cameroon and were also important in PNG (Kik et al. 2021). Students reported having better traditional skills in PNG than in Cameroon (Table 1). More than half of the students in both countries reported having good horticultural skills, whereas hunting skills interested only a minority (Table 1, see also Kik et al. 2023). At the same time, bushmeat consumption is both an important source of nutrition and a threat to many species in sub-Saharan Africa, especially as it is also marketed in urban areas (van Vliet & Mbazza, 2011). This is in contrast to PNG, where bushmeat is mainly consumed by the rural population (Kik et al. 2023).

The self-assessed language skills of males and females were similar (Fig. 2), while tests of language skills showed that male students in Cameroon had slightly better language skills than female students (Fig. 3). Students' school scores in English/French are inversely correlated with their indigenous language skills, suggesting a possible interference between traditional knowledge and formal education and indigenous knowledge. However, this effect is weak in Cameroon and absent in PNG.

Language use at home represents another important determinant of language proficiency. In both countries, indigenous language use competes with creole languages (Tok Pisin and CPE), English (or French in Cameroon), and in Cameroon, possibly with some dominant indigenous languages. Indigenous languages are spoken at home by 27% of students in Cameroon and 30% in PNG. In PNG, the influence of mixed-language families, where each parent speaks a different indigenous language, is another important factor in addition to home language use. Although both countries have exceptionally high language diversity, as quantified by the Greenberg Index, Cameroonian languages tend to have more speakers (median: 10,233) than PNG languages (median: 1,320; Table 1). This may explain the higher proportion of linguistically mixed families in PNG (37%) than in Cameroon (13%) in our data (Table 1). Our models for PNG predict a further increase in mixed-language families due to increased human mobility. A similar trend is likely for Cameroon, but it may be less important than in PNG (Kik et al. 2021). Parents' indigenous language proficiency was high in both countries and therefore had little impact on students' language proficiency.

Language traits were generally poor predictors of language skills. Language location at a particular altitude in Cameroon or in a particular geographic area in PNG had a small effect on language proficiency. In Cameroon, the trend toward high altitude may reflect the transition from the lower altitude, more urbanized southwestern region to the more traditional, high-altitude northwest. These two regions are Anglophone and were represented in our survey.

The EGIDS classification of language endangerment (Lewis & Simons 2010), based on the intergenerational transmission of languages and the social domains of their use, was a significant predictor of language proficiency only in PNG, and its effect was weak. Of note, this factor does not account for the number of speakers of a language. We tested language size separately and found that it had no significant effect on language proficiency in either country, although it did have an effect on bird knowledge in Cameroon.

While the factors for language decline documented here have been identified previously (Amano et al. 2014, Bromham et al. 2020, Austin & Sallabank 2011), our analysis quantifies and compares their relative importance in two large, linguistically very important regions that are both geographically distant and socially and historically distinct. Our results suggest a potentially pantropic importance of these factors for language loss and may allow for the development of models of future dynamics of language proficiency in response to socioeconomic change.

Ethnobiological knowledge was strongly related to language proficiency in both countries. Correlation between L1 language skills and bird knowledge (E1) was demonstrated in both countries. However, at the same language level, students from Cameroon had poorer bird knowledge than students from PNG (Fig. 4, Table S7). Such a large difference in bird knowledge between the two countries may be difficult to interpret because we had to use lists of local bird species, which may not be equally difficult to identify. However, it is likely to reflect a real cultural difference between Cameroon, where birds are rarely hunted and form a negligible part of the bushmeat consumption and trade, and PNG, where birds have much greater importance as bushmeat, while feathers of many species are traded as valuable commodities and used in traditional ceremonies. For example, birds accounted for only <0.1% of bushmeat biomass in a local study in Cameroon and Nigeria (Fa et al. 2006), while they accounted for 30% of biomass in a similar study in PNG (Mack & West 2005). Furthermore, while some bird species, such as turacos, are culturally important in Cameroon (Nkengbeza et al. 2023), none are as culturally prominent as the cassowary in PNG (Bulmer, 1967), which was also the most recognized species in our PNG tests (Kik et al. 2021).

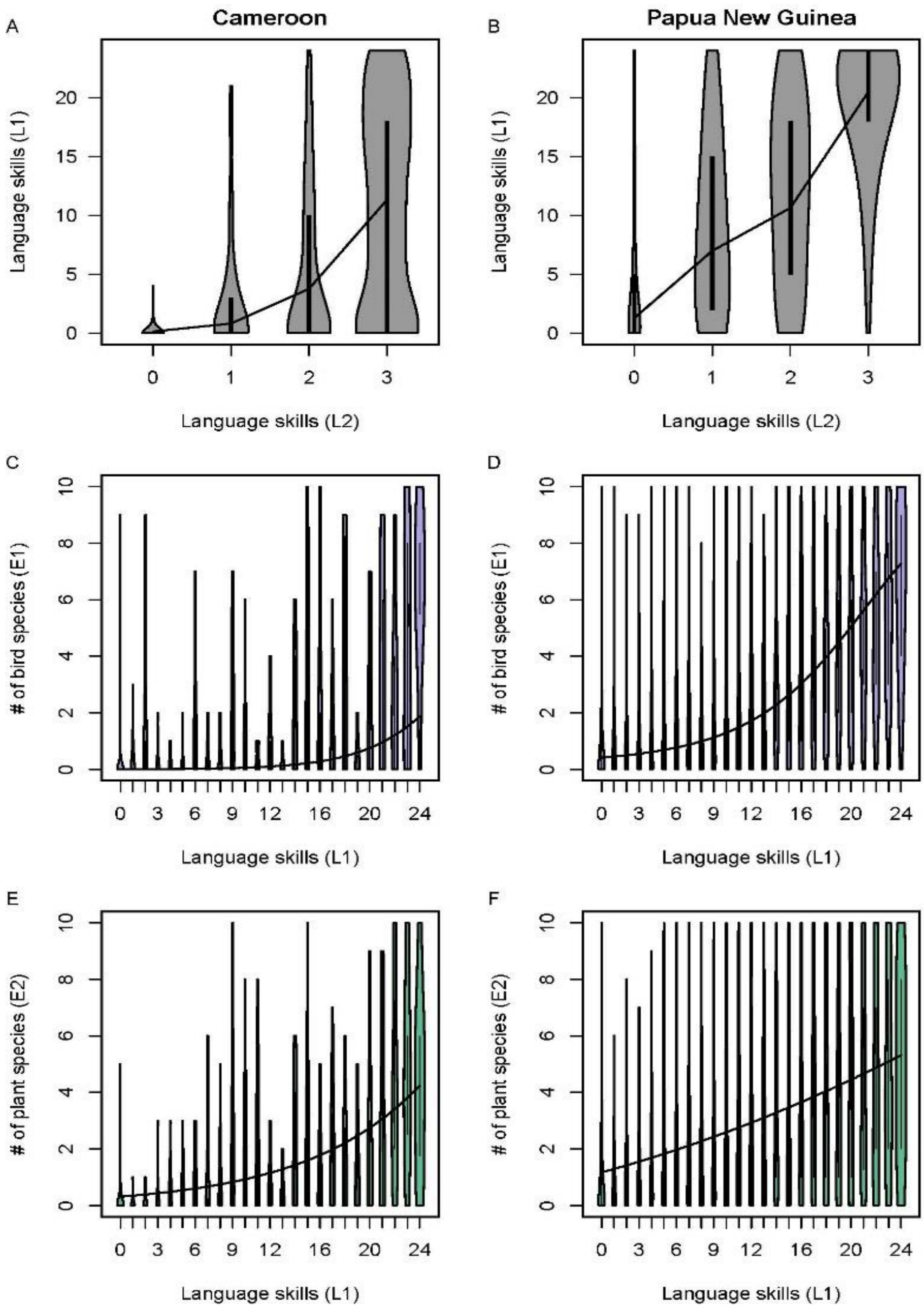


Fig. 4. Correlation between self-assessed language skills (L1) and performance on language tests (L2) for students from Cameroon (A) and PNG (B), and correlation between L2 language skills and ethnobiological

knowledge of birds (E1) and plants (E2) for students from Cameroon (B, E) and PNG (D, F). Variables L2 and E1 showed an additive effect between country and L1, while E2 showed an interaction between country and L1 (Table S7). Language skills L1: number of body parts named (0-24); L2: 0 – none, 1 – passive, 2 – poor, 3 – fluent.

Knowledge of traditional uses of plants (E2) was correlated with language skills (L1) and differed between Cameroon and PNG, but the two factors, country identity and L1 scores, showed a significant interaction, indicating a different L1 x E2 relationship in each country (Fig. 4, Table S7). Plant species were selected and listed by respondents, allowing direct comparison of E2 values between Cameroon and PNG.

The rapid parallel decline in language proficiency and ethnobiological knowledge documented for Cameroon and PNG applies to secondary school students, who comprise only a portion of young people. In Cameroon, 46% of 18- to 19-year-olds (51% of the urban population and 35% of the rural population) attended secondary school in 2018, compared with 27% in PNG in 2016 (40% of the urban population and 25% of the rural population) (World Bank 2023). Secondary school students represent a skewed sample of the total cohort of young people in these countries, as they are disproportionately from urban, educated families with formal employment and are therefore likely to have poorer indigenous language skills (Table 1, Kik et al. 2021). However, the proportion of secondary school students in the population of Cameroon, PNG, and other tropical countries will continue to increase in the future, making our estimates, and thus concerns about the future of linguistic and cultural diversity in the tropics, more relevant over time.

Table 1. Language, socioeconomic and lifestyle variables characterizing the surveyed students in Cameroon in comparison with PNG (from Kik et al. 2021). The A-D variables are further described in the Methods.

Var#	Variable	Cameroon	PNG
A1	Language population size, sampled languages, median[Q1-Q3]	34093 [14282, 78497]	3093 [1350, 8500]
A3	Students speaking endangered languages, %	22.5	13.9
A6	Students speaking languages with a Bible translation, %	30.2	84.0
B1	Students who spent childhood in a village, %	38.7	64.7
B2	Student's childhood residence accessible by road %	93.3	80.4
B3	Families having ≥1 parent with secondary of higher education, %	69.6	63.2
B4	Families with subsistence agriculture income only, %	7.0	30.9
C2	Families using indigenous language at home, %	27.0	30.0
C3	Families with parents speaking the same indigenous language, %	86.7	63.1
D1	Female students, %	57.1	41.0
D4	Students with good hunting skills, %	9.0	22.4
D4	Students with good fishing skills, %	9.7	39.3
D4	Students with good horticultural skills, %	51.9	67.8
D4	Students with good house building skills, %	9.9	28.1
D4	Students with good plant medicinal use skills, %	23.3	31.0
D5	Students with good mobile phone use skills, %	79.4	67.9
D5	Students with good computer use skills, %	40.5	28.3
D8	Students able and wishing to teach indigenous language to their children %	95.7	87.7
	Student's age, median [Q1-Q3)	18 [17, 20]	19 [18, 20]
	Student's no. of siblings, median [Q1-Q3]	4 [3, 6]	4 [3, 6]
	Families owning land, %	88.9	91.7
	Families owning cash crop plantation, %	84.5	52.0
	Families with access to electricity, %	79.5	53.8
	Language population size, all languages, median[Q1-Q3]	10233 [2858, 34916]	1320 [523, 3703]

Future of language and cultural diversity

We have quantified the importance of key determinants of language proficiency loss for the world's two most linguistically diverse hotspots and shown that both countries are experiencing rapid declines in language proficiency among young, educated cohorts, driven by a number of common factors. Given the expected trends in the main drivers of language loss, this trend is likely to intensify in the future in both hotspots. Ethnobiological knowledge is correlated with indigenous language skills and therefore equally at risk (Aswani et al. 2018).

The loss of language and biocultural knowledge is related to trends considered desirable in contemporary societies, such as education, travel, and the cash economy, or it is a consequence of economic development, such as urbanization, which also leads to mixed-language marriages. These forces will make it more difficult to preserve cultural diversity. Ongoing urbanization is likely a strong driver of language decline, especially in West African hotspots. Our results show a shift from 71% fluent rural dwellers to 42% fluent urban dwellers, illustrating the magnitude of change expected in the transition from rural to urban populations in Cameroon. At the same time, urbanization in Cameroon is projected to increase from 58% in 2021 to 73% in 2050 (Fig. S2).

Language diversity has resulted from the social and geographic isolation of human populations (Hua et al. 2019). In today's increasingly globalized world, it is becoming increasingly impractical. The KOF globalization index of the world has risen steadily over the past 40 years (Fig. S2, Haelg 2019). KOF scores for both Cameroon and PNG are below the global average, but they have also increased, with Cameroon keeping pace with the world's increasing globalization (Fig. S2). Moreover, the effects of globalization appear to be more damaging in Cameroon. Young Cameroonians' attitudes toward cultural indigenous knowledge are often negative, as it is seen as a backward activity reserved for the poor. This attitude has led, for example, to the decline of traditional pottery, which was common in western Cameroon until about 1950 (Forni 2007).

The emerging challenges for indigenous languages were recognized by our respondents in both Cameroon and PNG. Most students would like to teach their children an indigenous language: 96% in Cameroon and 88% in PNG (Table 1). Similar attitudes have also been documented in the Francophone part of Cameroon (Hodieb 2020). Indigenous languages are mostly seen as an important part of cultural identity, while their practical use for communication serves as motivation for a smaller proportion of students: 39% in Cameroon and only 9% in PNG. The difference between Cameroon and PNG in perceptions of the practicality of indigenous languages likely reflects the smaller size of PNG languages (Table 1).

The survival of indigenous languages and traditional knowledge will be probably determined by factors other than their practicality. Cultural characteristics, particularly the balance between receptivity to innovation and preservation of traditions, may be critical in mediating the impact of external factors of language loss on individual languages (Aikhenvald 2004). While Creole languages (Tok Pisin, CPE) and English/French can be viewed as languages of economic opportunity and prestige, their use can either lead to a balanced, stable di/tri-glossia with an indigenous language or to a dynamics in which these languages penetrate all areas of life at the expense of the vernacular. The use of Creole languages and/or English/French differs from historically widespread multilingualism, which can still be seen in the high proportion of students who speak more than one indigenous language and which does not lead to language attrition (Aikhenvald 2004).

Balanced di- and tri-glossia, where indigenous languages continue to be used for ritual purposes and for communication outside of government, school, and other institutions, depends on the importance of pride in one's language and identity and pressure on newcomers to conform to village norms of language and culture. The future of indigenous languages also depends on how urbanization plays out and whether urbanized people maintain ties with their rural relatives. Urbanization means a steady outflow of skilled workers from rural communities, while at least some of the outgoing urban elites returning to the village may bring another influx of interest in reviving the native language and culture (Aikhenvald 2004). This may be particularly important in PNG where most urban residents maintain their links to their rural areas of origin where they can claim traditional land ownership.

Ethnobiological knowledge can be preserved by finding new uses for it, for example, as a basis for training paraecologists and parataxonomists for modern research (Novotny et al. 2012). Biocultural knowledge is more at risk than languages because it can disappear even when a language continues to be widely used (Kik et al. 2023), as shown by the different rates of loss of ethnobiological knowledge between Cameroon and PNG. It is particularly at risk because it is largely passed on orally and much ethnobiological knowledge is not recorded in scientific literature (Camara-Leret & Dennehy 2019, Ndenecho et al. 2009). There are great but largely untapped opportunities for locally driven research cataloguing ethnobiological and other cultural knowledge in tropical countries (Kik et al. 2021, Maffi & Woodley 2010).

Data availability. All data used for the analysis are included in the article, the SI Appendix and Datasets S1-S2.

Acknowledgements

We thank the students, teachers, and principals of the 11 secondary schools that participated in the study and the Applied Linguistics Programme at the University of Bamenda, Cameroon, for hosting the study. The study was supported by the Czech Science Foundation (18-23889S) and the European Research Council (669609). We thank Sean Allison for comments on the manuscript.

References

Aikhenvald, A. Y. Language endangerment in the Sepik area of Papua New Guinea. In *Lectures on endangered languages: 5. Endangered Languages of the Pacific Rim* (eds. Sakiyama, O. & Endo, F.) 97-142 (ELPR, Suita, Osaka, 2004).

Amano, T., Sandel, B., Eager, H., Bulteau, E., Svenning, J-C., Dalsgaard, B., Rahbek, C., Davies, R. G. & Sutherland, W. J. Global distribution and drivers of language extinction risk. *Proc. R. Soc. B* 281, 20141574 (2014).

Aswani, S., Lemahieu, A. & Sauer, W. H. H. Global trends of local ecological knowledge and future implications. *PLoS ONE* 13, e0195440 (2018).

Austin, P. K. & Sallabank, J. (eds.). *The Cambridge Handbook of Endangered Languages* (Cambridge University Press, Cambridge, 2011).

Ayafor, M. & Green, M. *Cameroon Pidgin English: A Comprehensive Grammar. London Oriental and African Language Library 20.* (John Benjamins Publishing Company, Amsterdam, 2017)

Bromham, L., Hua, X., Algy, C. & Meakins, F. Language endangerment: a multidimensional analysis of risk factors. *J. Lang. Evol.* 5, 75–91 (2020).

Bulmer, R. Why is the cassowary not a bird? A problem of zoological taxonomy among the Karam of the New Guinea Highlands. *Man NS* 2, 5-25 (1967).

Burnham, K. P. & Anderson, D. R. *Model Selection and Multimodel Inference. A Practical Information-Theoretic Approach* (2nd Ed., Springer, New York, 2002).

Cámara–Leret, R. & Dennehy, Z. Indigenous knowledge of New Guinea's useful plants: a review. *Econ. Bot.* 73, 405-415 (2019).

Campbell, L. & Okura, E. New knowledge produced by the Catalogue of Endangered Languages. In *Cataloguing the World's Endangered Languages* (eds. Campbel L. & Bellew, A.) 79-84 (Routledge, Oxford, 2018).

Childs, G. T. *An Introduction to African Languages* (John Benjamins Publishing Company, Amsterdam, 2003).

Eberhard, D. M., Simons, G. F. & Fennig, C. D. (eds.). *Ethnologue: Languages of the World* (23rd Ed., SIL International, Dallas, 2020).

Fa, J. E., Seymour, S., Dupain, J., Amin, R., Albrechtsen, L. & Macdonald, D. Getting to grips with the magnitude of exploitation: Bushmeat in the Cross–Sanaga rivers region, Nigeria and Cameroon. *Biol. Conserv.* 129, 497-510 (2006).

Forni, S. Containers of life. Pottery and social relations in the Grassfields (Cameroon). *Afr. Arts* 40, 42-53 (2007).

Fowler, I. & Zeitlyn, D. (eds.) *African Crossroads: Intersections between History and Anthropology in Cameroon (Cameroon Studies 2)* (Berghahn Books, New York, Oxford, 1996).

Grinevald, C. & Bert, M. Speakers and communities. In *The Cambridge Handbook of Endangered Languages* (eds. Austin, P. K. & Sallabank, J.) 45-65 (Cambridge University Press, New York, 2011).

Haelg, F. The KOF globalisation index – A multidimensional approach to globalisation. *Jahrb. fur Natl. Stat.* 240, 691-696 (2019).

Hodieb, L. Multilingualism and language attitude: the "Cameroonian paradox". *Ideação* 22, 83-96 (2020).

Hunn, E. S. *A Zapotec Natural History: Trees, Herbs, and Flowers, Birds,* *Beasts, and Bugs in the Life of San Juan Gbëë* (Arizona University Press, Tuscon, 2008).

Hua, X., Greenhill, J. S., Cardillo, M., Schneemann, H. & Bromham, L. The ecological drivers of variation in global language diversity. *Nat. Commun.* 10, 2047 (2019).

Kik, A. et al. Language and ethnobiological skills decline precipitously in Papua New Guinea, the world's most linguistically diverse nation. *Proc. Natl. Acad. Sci. U.S.A.* 118, e2100096118 (2021).

Kik, A. et al. Hunting skills and ethnobiological knowledge among the young, educated Papua New Guineans: Implications for conservation. *Glob. Ecol. Conserv.* 43, e02435 (2023).

Koczberski, G., Curry, G. N. & Imbun, B. Property rights for social inclusion: Migrant strategies for securing land and livelihoods in Papua New Guinea. *Asia Pac. Viewp.* 50, 29-42 (2009).

Lewis, M. P. & Simons, G. F. Assessing endangerment: expanding Fishman's GIDS. *Rev. Roum. Linguist.* 55, 103-120 (2010).

Mack, A. L. & West, P. *Ten Thousand Tonnes of Small Animals: Wildlife Consumption in Papua New Guinea, a Vital Resource in Need of Management*. *Resource Management in Asia-Pacific Working Paper No. 61*. (The Australian National University, Canberra, 2005).

Markussen-Daval, A., & Bakker, P. (2017). Typology of Creole languages. In *The Cambridge Handbook of Linguistic Typology* (eds. Aikhenvald, A. Y. & Dixon, R. M. W.) 254-86 (Cambridge University Press, Cambridge, 2017).

Maffi, L. & Woodley, E. *Biocultural Diversity Conservation. A Global Sourcebook* (Earthscan, London, 2010).

Mba, G. & Nsen Tem, A. Ways to assess multilingual competence in small, unwritten languages: The case of Lower Fungom. In *African Multilingualisms: Rural Linguistic and Cultural Diversity* (eds. Di Carlo, P. & Good, J.), 205-224 (Lexington Books, Lanham, MD, 2020).

Ndenecho, E. N. Herbalism and resources for the development of ethnopharmacology in Mount Cameroon region. *Afr. J. Pharm.* 3, 78-86 (2009).

Nkengbeza, S. N., Nja B. T., Younchahou, M. N. & Nana, E. D. Can cultural values associated with turacos be used to enhance biodiversity conservation in Cameroon? *Oryx* 57, 129-131 (2023).

Novotny, V., Weiblen, G. D., Miller, S. E. & Basset Y. The role of paraecologists in Twenty-first-century tropical forest research. In *Methods in Forest Canopy Research* (eds. Lowman, M. D., Schowalter, T. D. & Franklin, J. F.) 154-157 (University of California Press, Berkeley and Los Angeles, California, 2012).

O'Grady, W. O., Schafer, A. J., Perla, J., Lee, O.-S. & Wieting, J. A psycholinguistic tool for the assessment of language loss: The HALA Project. *Lang. Doc. Conserv.* 3, 100–112 (2009).

Ritchie, H. & Roser, M. Urbanization. https://ourworldindata.org/urbanisation (2018)

Ritchie, H. & Roser, M. Age Structure. https://ourworldindata.org/age-structure (2019).

Romaine, S. *Language, Education, and Development: Urban and Rural Tok Pisin in Papua New Guinea.* (Oxford University Press, Clarendon, 1992).

Si, A., Patterns in the transmission of traditional ecological knowledge: a case study from Arnhem Land, Australia. *J. Ethnobiol. Ethnomedicine* 16, 52 (2020).

Sutherland, W. J. Parallel extinction risk and global distribution of languages and species. *Nature* 423, 276-279 (2003).

United Nations. World Urbanization Prospects: The 2018 Revision. https://population.un.org/wup/ (2018).

van Vliet, N. & Mbazza, P. Recognizing the multiple reasons for bushmeat consumption in urban areas: A necessary step toward the sustainable use of wildlife for food in Central Africa. *Hum. Dimens. Wildl.* 16, 45–54 (2011).

Vollset, S. E et al. Fertility, mortality, migration, and population scenarios for 195 countries and territories from 2017 to 2100: a forecasting analysis for the Global Burden of Disease Study. *Lancet* 396, 1285-1306 (2020).

World Bank. Country Classification. https://datahelpdesk.worldbank.org/knowledgebase/topics/19280-country-classification (2020).

World Bank. Education attainment and enrollment around the world. https://www.worldbank.org/en/research/brief/edattain (2023).

Wurm, S. A. & Muehlhausler, P. (eds.) *Handbook of Tok Pisin (New Guinea Pidgin)*. (Pacific Linguistics, The Australian National University, 1984).

Zent, S. Processual perspectives on traditional environmental knowledge. Continuity, erosion, transformation, innovation. In *Understanding Cultural Transmission in Anthropology: A Critical Synthesis* (eds. Ellen, R., Lycett, S. J. & Johns, S. E.) 213-265 (Berghahn Books, New York, Oxford, 2013).

Supporting information

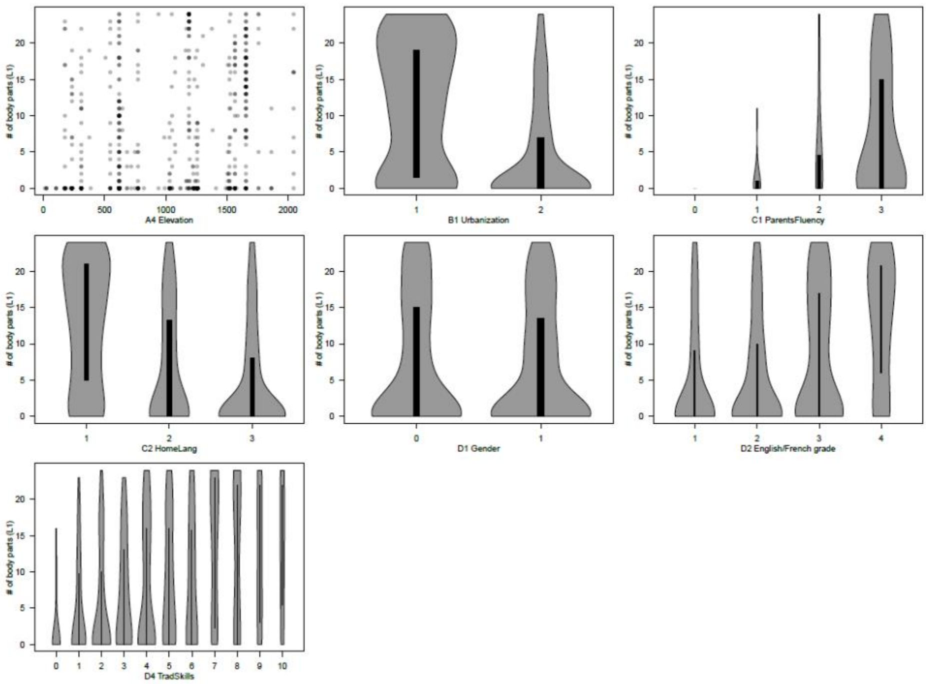


Fig. S1. Effect of independent variables explaining indigenous language skills (L1) of students from Cameroon. The bars (and data points for elevation) show the density distribution of the L1 response variable for a given level of the predictor variable, with the width of the bar proportional to the number of students belonging to that class. Urbanization: village (1), town or city (2); parents' fluency: from no language skills (0) to fluency (3); Home language use: indigenous (1), Creole Kamtok (2), or English/French (3); Gender: male (0), female (1); English/French grade: from excellent (1) to failing (4); Traditional skills: from low (0) to high (10); see Materials and Methods for details on variables.

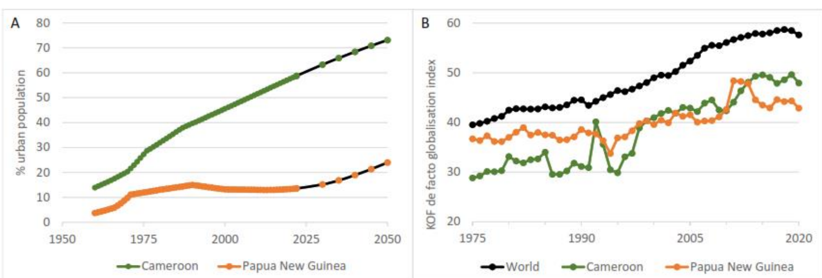


Fig. S2. Urbanization (A) and globalization (B) trends in Cameroon and Papua New Guinea. Population data from Ritchie & Roser (2018) and World Bank (2023), population predictions from United Nations (2018), globalization data from Haelg (2019).

Table S1. Model selection results for the candidate models assessing the role of language-related variables A1 – A6, socio-economic variables B1 – B4, family language use variables C1 – C3, and student-related variables D1 – D6 on the language fluency of students. dAICc = delta corrected Akaike Information Criterion, df = degrees of freedom. All models include Student and Language as random factors on the intercept. Note that D7 was not used in model building.

Variable class	Models	dAICc	df
Language traits	A4_elevation	0	4
Language traits	A4_elevation^ 2	0.6	5
Language traits	A1_LogN.2000^2 + A4_elevation	1.7	6
Language traits	A1_LogN.2000 + A4_elevation	1.9	5
Language traits	A1_LogN.2000^2 + A4_elevation^2	2.3	7
Language traits	A1_LogN.2000 + A4_elevation^2	2.6	6
Language traits	A1_LogN.2000^2 + A3_Endangered + A4_elevation^2	3	8
Language traits	A1_LogN.2000^2 + A4_elevation^2 + A6_Bible	4.1	8
Language traits	A1_LogN.2000^2 + A3_Endangered + A4_elevation^2 + A6_Bible	4.9	9
Language traits	A1_LogN.2000^2 + A2_Status^3 + A4_elevation^2 + A6_Bible	5.3	11
Language traits	Null (random factors + intercept)	5.8	3
Language traits	A1_LogN.2000	7.8	4
Socio-Economic	B1_Urbanization + B2_Isolation^2 + B3_ParentEdu	0	7
Socio-Economic	B1_Urbanization	0.3	4
Socio-Economic	B1_Urbanization + B3_ParentEdu	0.4	5
Socio-Economic	B1_Urbanization + B2_Isolation^2 + B3_ParentEdu + B4_ParentJob^2	2.5	9
Socio-Economic	B1_Urbanization + B2_Isolation^2 + B3_ParentEdu^2 + B4_ParentJob	2.7	9
Socio-Economic	B1_Urbanization + B3_ParentEdu + B4_ParentJob^2	2.8	7
Socio-Economic	B1_Urbanization + B2_Isolation^2 + B4_ParentJob^2	3	8
Socio-Economic	B1_Urbanization + B2_Isolation + B3_ParentEdu + B4_ParentJob^2	3.2	8
Socio-Economic	B1_Urbanization + B2_Isolation^2 + B3_ParentEdu^2 + B4_ParentJob^2	4.4	10
Socio-Economic	B3_ParentEdu	58.3	4
Socio-Economic	B2_Isolation^2 + B3_ParentEdu + B4_ParentJob^2	64.6	8
Socio-Economic	Null (random factors + intercept)	65.1	3
Language use	C2_HomeLang^2 + C1_ParentMaxFluency^2	0	7
Language use	C2_HomeLang^2 + C1_ParentMaxFluency	0.6	6
Language use	C2_HomeLang + C1_ParentMaxFluency^2	0.9	6
Language use	C2_HomeLang + C1_ParentMaxFluency	1.1	5
Language use	C2_HomeLang	4.9	4
Language use	C1_ParentMaxFluency	45.6	4
Language use	Null (random factors + intercept)	48.7	3
Student traits	D1_Gender + D2_GradeEng + D4_TradSkills	0	6
Student traits	D1_Gender + D2_GradeEng + D4_TradSkills + D5_ModSkills	1.9	7
Student traits	D1_Gender + D2_GradeEng^3 + D4_TradSkills	3.7	8
Student traits	D2_GradeEng^3 + D3_GradeMath^3 + D4_TradSkills + D5_ModSkills	3.8	8
Student traits	D1_Gender + D2_GradeEng^3) + D4_TradSkills + D5_ModSkills	5.6	9
Student traits	D2_GradeLang + D4_TradSkills + D5_ModSkills	7.6	6
Student traits	D2_GradeEng^2) + D4_TradSkills + D5_ModSkills	9.4	7
Student traits	D2_GradeLang^3 + D4_TradSkills + D5_ModSkills	11.1	8
Student traits	D2_GradeLang^3 + D4_TradSkills + D5_ModSkills	11.1	8
Student traits	D1_Gender + D4_TradSkills + D5_ModSkills	14.7	6
Student traits	D4_TradSkills + D5_ModSkills	17.3	5
Student traits	D1_Gender + D2_GradeLang ^ 3 + D5_ModSkills	48.6	8
Student traits	Null (random factors + intercept)	54.2	3

Table S2. Model selection results for the candidate models assessing the combined role of the four variable classes A – D included in this study on the language fluency of students. dAICc = delta corrected Akaike Information Criterion, df = degrees of freedom. All models include Student and Language as random factors on the intercept.

Combined Model classes	Combined model variables	dAICc	df
All four classes	B1_Urbanization + D1_Gender + D2_GradeEng + D4_TradSkills + C2_HomeLang + C1_ParentMaxFluency + A4_elevation	0	10
Socio-Economic + Student traits + Family language use	B1_Urbanization + D1_Gender + D2_GradeEng + D4_TradSkills + C2_HomeLang + C1_ParentMaxFluency	3.6	9
Socio-Economic + Student traits + Language traits	B1_Urbanization + D1_Gender + D2_GradeEng + D4_TradSkills + A4_elevation	13.6	8
Socio-Economic + Student traits	B1_Urbanization + D1_Gender + D2_GradeEng + D4_TradSkills	18.7	7
Socio-Economic + Family language use	B1_Urbanization + C2_HomeLang + C1_ParentMaxFluency	26	6
Student traits + Family language use	D1_Gender + D2_GradeEng + D4_TradSkills + C2_HomeLang + C1_ParentMaxFluency	40.1	8
Socio-Economic + Language traits	B1_Urbanization + A4_elevation	45.2	5
Socio-Economic	B1_Urbanization	51.5	4
Student traits + Language traits	D1_Gender + D2_GradeEng + D4_TradSkills + A4_elevation	57.5	7
Student traits	D1_Gender + D2_GradeEng + D4_TradSkills	62	6
Family language use + Language traits	C2_HomeLang + C1_ParentMaxFluency + A4_elevation	65.2	6
Family language use	C2_HomeLang + C1_ParentMaxFluency	68.7	5
Language traits	A4_elevation	110.5	4
Null	Null (random factors + intercept)	116.3	3

Table S3. Model selection results for the candidate models assessing the role of socioeconomic variables B1 – B4, family language use variables C1 – C3, and student-related variables D1 – D6 on the knowledge of bird species (E1) by students. dAICc = delta corrected Akaike Information Criterion, df = degrees of freedom. All models include Student and Language as random factors on the intercept.

Variable class	Models	dAICc	df
Language traits	L1_BodyParts + A1_LogN.2000 + A4_elevation^2	0	6
Language traits	L1_BodyParts + A1_LogN.2000^2 + A2_Status^3 + A4_elevation^2 + A6_Bible	0.4	11
Language traits	L1_BodyParts + A1_LogN.2000^2 + A4_elevation^2	1.9	7
Language traits	L1_BodyParts + A1_LogN.2000 + A4_elevation	2.6	5
Language traits	L1_BodyParts + A1_LogN.2000	2.8	4
Language traits	L1_BodyParts + A1_LogN.2000^2 + A4_elevation^2 + A6_Bible	3.6	8
Language traits	L1_BodyParts + A1_LogN.2000^2 + A3_Endangered + A4_elevation^2	4	8
Language traits	L1_BodyParts + A1_LogN.2000^2 + A4_elevation	4.6	6
Language traits	L1_BodyParts + A1_LogN.2000^2 + A3_Endangered + A4_elevation^2 + A6_Bible	5.5	9
Language traits	L1_BodyParts + A4_elevation	8.9	4
Language traits	L1_BodyParts + A4_elevation^2	9.6	5
Language traits	Null (random factors + intercept)	65.4	2
Socio-Economic	L1_BodyParts + B1_Urbanization	0	4
Socio-Economic	L1_BodyParts + B3_ParentEdu	1.5	4
Socio-Economic	L1_BodyParts + B1_Urbanization + B3_ParentEdu	1.7	5
Socio-Economic	L1_BodyParts + B1_Urbanization + B3_ParentEdu + B4_ParentJob^2	4.5	7
Socio-Economic	L1_BodyParts + B1_Urbanization + B2_Isolation^2 + B3_ParentEdu	5	7
Socio-Economic	L1_BodyParts + B1_Urbanization + B2_Isolation^2 + B4_ParentJob^2	6.1	8
Socio-Economic	L1_BodyParts + B1_Urbanization + B2_Isolation + B3_ParentEdu + B4_ParentJob^2	6.5	8
Socio-Economic	L1_BodyParts + B1_Urbanization + B2_Isolation^2 + B3_ParentEdu^2 + B4_ParentJob	7.1	9
Socio-Economic	L1_BodyParts + B2_Isolation^2 + B3_ParentEdu + B4_ParentJob^2	7.5	8
Socio-Economic	L1_BodyParts + B1_Urbanization + B2_Isolation^2 + B3_ParentEdu + B4_ParentJob^2	7.9	9
Socio-Economic	L1_BodyParts + B1_Urbanization + B2_Isolation^2 + B3_ParentEdu^2 + B4_ParentJob^2	8	10
Socio-Economic	Null (random factors + intercept)	57.8	2
Language use	L1_BodyParts + C1_ParentMaxFluency	0	4
Language use	L1_BodyParts + C2_HomeLang	1.2	4
Language use	L1_BodyParts + C2_HomeLang + C1_ParentMaxFluency	1.6	5
Language use	L1_BodyParts + C2_HomeLang + C1_ParentMaxFluency^2	3.5	6
Language use	L1_BodyParts + C2_HomeLang^2 + C1_ParentMaxFluency	3.6	6
Language use	L1_BodyParts + C2_HomeLang^2 + C1_ParentMaxFluency^2	5.5	7
Language use	Null (random factors + intercept)	56.9	2
Student traits	L1_BodyParts + D1_Gender + D2_GradeLang + D4_TradSkills	0	6
Student traits	L1_BodyParts + D4_TradSkills	0.2	4
Student traits	L1_BodyParts + D2_GradeLang + D4_TradSkills + D5_ModSkills	1.1	6
Student traits	L1_BodyParts + D1_Gender + D4_TradSkills + D5_ModSkills	1.2	6
Student traits	L1_BodyParts + D1_Gender + D2_GradeLang + D4_TradSkills + D5_ModSkills	1.2	7
Student traits	L1_BodyParts, 1 + D4_TradSkills + D5_ModSkills	1.7	5
Student traits	L1_BodyParts + D2_GradeLang^2 + D4_TradSkills + D5_ModSkills	2.7	7
Student traits	L1_BodyParts + D1_Gender + D2_GradeLang^2 + D4_TradSkills + D5_ModSkills	2.9	8
Student traits	L1_BodyParts + D1_Gender + D2_GradeLang^3 + D4_TradSkills	3.8	8
Student traits	L1_BodyParts + D2_GradeLang^3 + D4_TradSkills + D5_ModSkills	4.8	8
Student traits	L1_BodyParts + D1_Gender + D2_GradeLang^3 + D4_TradSkills + D5_ModSkills	4.9	9
Student traits	L1_BodyParts + D1_Gender + D2_GradeLang^3) + D5_ModSkills	5.1	8
Student traits	Null (random factors + intercept)	59.1	2

Table S4. Model selection results for the candidate models assessing the combined role of the four variable classes A – D on the knowledge of bird species (E1) by students. dAICc = delta corrected Akaike Information Criterion, df = degrees of freedom. All models include Student and Language as random factors on the intercept.

Combined Model classes	Combined model variables	dAICc	df
Student traits + Language traits	L1_BodyParts + D4_TradSkills + A1_LogN.2000 + A4_elevation^2	0	7
Socio-Economic + Student traits + Language traits	L1_BodyParts + B1_Urbanization + B3_ParentEdu + D4_TradSkills + A1_LogN.2000 + A4_elevation^2	2	9
Language traits	L1_BodyParts + A1_LogN.2000 + A4_elevation^2	2.4	6
Family language use + Language traits	L1_BodyParts + C2_HomeLang + C1_ParentMaxFluency + A1_LogN.2000 + A4_elevation^2	3.4	8
All four classes	L1_BodyParts + B1_Urbanization + B3_ParentEdu + D4_TradSkills + A1_LogN.2000 + A4_elevation^2 + C2_HomeLang + C1_ParentMaxFluency	3.6	11
Socio-Economic + Language traits	L1_BodyParts + B1_Urbanization + B3_ParentEdu + A1_LogN.2000 + A4_elevation^2	3.8	8
Student traits	L1_BodyParts + D4_TradSkills	8.9	4
Socio-Economic + Student traits	L1_BodyParts + B1_Urbanization + B3_ParentEdu + D4_TradSkills	10.6	6
Family language use + Student traits		11.4	6
Socio-Economic	L1_BodyParts + B1_Urbanization + B3_ParentEdu	11.6	5
Family language use	L1_BodyParts + C2_HomeLang + C1_ParentMaxFluency	12.4	5
Socio-Economic + Family language use + Student traits	L1_BodyParts + B1_Urbanization + B3_ParentEdu + D4_TradSkills + C2_HomeLang + C1_ParentMaxFluency	13.3	8
Socio-Economic + Family language use	L1_BodyParts + B1_Urbanization + B3_ParentEdu + C2_HomeLang + C1_ParentMaxFluency	14.2	7
Null	Null (random factors + intercept)	67.8	2

Table S5. Model selection results for the candidate models assessing the role of socioeconomic variables B1 – B4, family language use variables C1 – C3, and student-related variables D1 – D6 on the knowledge of traditional plant use (E2) by students. dAICc = delta corrected Akaike Information Criterion, df = degrees of freedom. All models include Student and Language as random factors on the intercept.

Variable class	Models	dAICc	df
Language traits	L1_BodyParts + A1_LogN.2000 + A4_elevation^2	0	6
Language traits	L1_BodyParts + A1_LogN.2000^2 + A2_Status^3 + A4_elevation^2 + A6_Bible	0.4	11
Language traits	L1_BodyParts + A1_LogN.2000^2 + A4_elevation^2	1.9	7
Language traits	L1_BodyParts + A1_LogN.2000 + A4_elevation	2.6	5
Language traits	L1_BodyParts + A1_LogN.2000	2.8	4
Language traits	L1_BodyParts + A1_LogN.2000^2 + A4_elevation^2 + A6_Bible	3.6	8
Language traits	L1_BodyParts + A1_LogN.2000^2 + A3_Endangered + A4_elevation^2	4	8
Language traits	L1_BodyParts + A1_LogN.2000^2 + A4_elevation	4.6	6
Language traits	L1_BodyParts + A1_LogN.2000^2 + A3_Endangered + A4_elevation^2 + A6_Bible	5.5	9
Language traits	L1_BodyParts + A4_elevation	8.9	4
Language traits	L1_BodyParts + A4_elevation^2	9.6	5
Language traits	Null (random factors + intercept)	65.4	2
Socio-Economic	L1_BodyParts + B3_ParentEdu	0	4
Socio-Economic	L1_BodyParts + B1_Urbanization + B2_Isolation^2 + B3_ParentEdu^2 + B4_ParentJob	1.7	9
Socio-Economic	L1_BodyParts + B1_Urbanization + B3_ParentEdu	2	5
Socio-Economic	L1_BodyParts + B1_Urbanization	3.1	4
Socio-Economic	L1_BodyParts + B1_Urbanization + B2_Isolation^2 + B3_ParentEdu	3.3	7
Socio-Economic	L1_BodyParts + B1_Urbanization + B2_Isolation^2 + B3_ParentEdu^2 + B4_ParentJob^2	3.4	10
Socio-Economic	L1_BodyParts + B2_Isolation^2 + B3_ParentEdu + B4_ParentJob^2	4.6	8
Socio-Economic	L1_BodyParts + B1_Urbanization + B3_ParentEdu + B4_ParentJob^2	5.2	7
Socio-Economic	L1_BodyParts + B1_Urbanization + B2_Isolation^2 + B4_ParentJob^2	6.5	8
Socio-Economic	L1_BodyParts + B1_Urbanization + B2_Isolation^2 + B3_ParentEdu + B4_ParentJob^2	6.6	9
Socio-Economic	L1_BodyParts + B1_Urbanization + B2_Isolation + B3_ParentEdu + B4_ParentJob^2	7.3	8
Socio-Economic	Null (random factors + intercept)	1403.6	3
Language use	L1_BodyParts + C2_HomeLang	0	4
Language use	L1_BodyParts + C2_HomeLang + C1_ParentMaxFluency	0.5	5
Language use	L1_BodyParts + C2_HomeLang + C1_ParentMaxFluency^2	1.9	6
Language use	L1_BodyParts + C2_HomeLang^2 + C1_ParentMaxFluency	2	6
Language use	L1_BodyParts + C2_HomeLang^2 + C1_ParentMaxFluency^2	3.5	7
Language use	L1_BodyParts + C1_ParentMaxFluency	10	4
Language use	Null (random factors + intercept)	919.3	3
Student traits	L1_BodyParts + D1_Gender + D2_GradeLang + D4_TradSkills	0	6
Student traits	L1_BodyParts	1.6	3
Student traits	L1_BodyParts + D1_Gender + D2_GradeLang + D4_TradSkills + D5_ModSkills	1.9	7
Student traits	L1_BodyParts + D1_Gender + D2_GradeLang^3 + D5_ModSkills	2.4	8
Student traits	L1_BodyParts + D1_Gender + D2_GradeLang^3 + D4_TradSkills	2.7	8
Student traits	L1_BodyParts + D1_Gender + D4_TradSkills + D5_ModSkills	2.7	6
Student traits	L1_BodyParts + D1_Gender + D2_GradeLang^2 + D4_TradSkills + D5_ModSkills	2.9	8
Student traits	L1_BodyParts + D4_TradSkills	3.2	4
Student traits	L1_BodyParts + D4_TradSkills + D5_ModSkills	4	5
Student traits	L1_BodyParts + D1_Gender + D2_GradeLang^3 + D4_TradSkills + D5_ModSkills	4.5	9
Student traits	L1_BodyParts + D2_GradeLang + D4_TradSkills + D5_ModSkills	4.8	6
Student traits	L1_BodyParts + D2_GradeLang^2 + D4_TradSkills + D5_ModSkills	5.5	7
Student traits	L1_BodyParts + D2_GradeLang^3 + D4_TradSkills + D5_ModSkills	6.8	8
Student traits	Null (random factors + intercept)	911.6	3

Table S6. Model selection results for the candidate models assessing the combined role of the four variable classes A – D on the knowledge of traditional plant use (E2) by students. dAICc = delta corrected Akaike Information Criterion, df = degrees of freedom. All models include Student and Language as random factors on the intercept.

Combined Model classes	Combined model variables	dAICc	df
Socio-Economic + Family language use + Language traits	L1_BodyParts + B3_ParentEdu + C2_HomeLang + A1_LogN.2000 + A4_elevation^2	0	6
Family language use + Language traits	L1_BodyParts + C2_HomeLang + A1_LogN.2000 + A4_elevation^2	1	5
Socio-Economic + Family language use	L1_BodyParts + B3_ParentEdu + C2_HomeLang	2.7	5
Family language use	L1_BodyParts + C2_HomeLang	3.6	4
Socio-Economic + Language traits	L1_BodyParts + B3_ParentEdu + A1_LogN.2000 + A4_elevation^2	8.3	5
Language traits	L1_BodyParts + A1_LogN.2000 + A4_elevation^2	9.6	4
Socio-Economic	L1_BodyParts + B3_ParentEdu	11.6	4
Language knowledge	L1_BodyParts	12.8	3
Null	Null (random factors + intercept)	922.9	3

Table S7. Model selection results for L1 and the country as predictors for respectively L2, E1 and E2 variables, using linear mixed model for L2 and generalized linear mixed models (binomial for E1 and Poisson for E2), with language as a random factor. The only variable that showed some interaction was E2, with the others showing an additive effect between country and L1.

Self-Assessment L2	dAICc	df	Birds E1	dAICc	df	Plants E2	dAICc	df
L1 * Country	0	6	L1 * Country	0	6	L1 * Country	0	5
L1 + Country	1.9	5	L1 + Country	0.9	5	L1 + Country	68	4
L1	71.5	4	L1	76.4	4	L1	144.7	3
Null	1737.9	3	Country	2387.8	4	Country	2546	3
Country	1739.6	4	Null	2534	3	Null	2671	2

Dataset S1 Legend

Data for the independent and dependent variables for individual respondents, used for the GLMM analyses.

Dataset S2 Legend

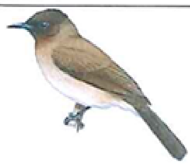
Questionnaire used for data collection.

Only the bird test section of Cameroon questionnaire is included here (since the bird species are different from those in PNG)

Birds test

We will show you 10 species of common Cameroonian birds. Write the name of each bird species in your native language (or circle [I do not know] option). Use the same native language as you used for the language test. If you do not know the name in native language , try at least pidgin or English.

	Birds species	Name in my language	Name in pidgin	Name in English	I do not know
1	 Scientific name: **Milvus migrans**				
2	 Scientific name: **Turtur tympanistria**				
3	 Scientific name: **Colius striatus**				
4	 Scientific name: **Halcyon leucocephala**				
5	 Scientific name:**Strix woodfordii**				

6	 Scientific name: **Pycnonotus barbatus**				
7	 Scientific name: **Elminia longicauda**				
8	 Scientific name: **Corvus albus**				
9	 Scientific name: **Passer griseus**				
10	 Scientific name: **Ploceus cucullatus**				

APPENDICES

Appendix I: The importance of Indigenous and local people for cataloging Biodiversity. [Trends in Ecology & Evolution: in press: https://doi.org/10.1016/j.tree.2023.08.017] (IF= 20.589).

Trends in
Ecology & Evolution

CellPress

Series: Local and Indigenous ecological knowledge

Science & Society

The importance of Indigenous and local people for cataloging biodiversity

Juan C. Copete [1,*]
Alfred Kik [2,3,4]
Vojtech Novotny [2,3,4] and
Rodrigo Cámara-Leret [1,5,*,@]

Indigenous and local peoples' (ILPs) role in cataloging life on Earth has been significant but underappreciated. ILPs knowledge faces growing cultural and biological threats. Greater participation by ILPs in research would make science more efficient, conservation more sustainable, and traditional knowledge stronger, but formidable obstacles remain.

Traditional knowledge at the service of science

Only a fraction of the millions of species on Earth have been cataloged. How much of species discovery and knowledge of their ecology have their origins in Indigenous and local knowledge (ILK)? All cultures that have interacted for long periods of time with their natural environment have developed rich biological classification systems [1]. The taxonomies of plants and vertebrates used by ILPs often exhibit high correspondence with species recognized by scientific taxonomy. For example, one Papua New Guinean system has 137 names for 138 bird species [2]. Another system in China has a correspondence of 82%, demonstrating a high similarity between traditional and scientific knowledge in botanical nomenclature [3]. It is, therefore, unsurprising that historians are increasingly showing that European explorers did not work alone when cataloging the Earth's biodiversity. European explorers in the tropics relied heavily on local assistants to find, collect, and classify the rich and varied fauna and flora. Alexander von Humboldt [4] recognized the value of Indigenous peoples' knowledge over 200 years ago: 'The master of one of the canoes offered to remain on board the Pizarro as coasting pilot. He was a Guayqueria of an excellent disposition, sagacious in his observations, and he had been led by intelligent curiosity to notice the productions of the seas as well as the plants of the country. By a fortunate chance, the first Indian we met on our arrival was the man whose acquaintance became the most useful to us in the course of our researches. I feel a pleasure in recording in this itinerary the name of Carlos del Pino, who, during the space of sixteen months, attended us in our course along the coasts, and in the inland country.' Alfred Russell Wallace hired at least 1200 local collectors in the Malay Archipelago between 1854 and 1862 and benefited from their knowledge to make some of his famous 'discoveries' – for example, Wallace's flying frog (*Rhacophorus nigropalmatus* Boulenger) [5]. He also relied on the local knowledge of Indigenous peoples in the Amazon to develop his hypothesis that the great rivers of the Amazon function as geographical barriers for primates and birds [6].

Ever since the times of von Humboldt and Wallace, scholars have continued to draw on ILK to explore biodiversity (Figure 1). In Malaysia, ILPs identified 2063 fruit consumption and 1360 seed dispersal interactions involving 164 plant species and 34 animal taxa [7]. That study showed that ILPs gathered better data than professional scientists alone. In the Brazilian Amazon, ILPs have demonstrated their sophisticated knowledge and recorded 92 plant species consumed by six fish species in the rivers Negro, Tapajós, and Tocantins [8]. Finally, in India, Gupta *et al.* showed that ILK was of utmost importance for assessing endangered species in places with little or no published information [9] (Figure 1).

Indigenous and local knowledge informs conservation

ILK has also brought important insights of practical value for conservation. Indigenous rangers in Australia were better at surveying lizard communities than non-Indigenous researchers as they recorded also more static and cryptic individuals [10]. The scientific and applied conservation benefits of promoting culturally diverse research teams were recently evidenced in a study by foreign and Iban and Dusun researchers in Borneo [11]. By linking Iban and Dusun ILPs biological classification systems with population genetics, Gardner *et al.* recognized two distinct wild-related species (*Artocarpus odoratissimus* Blanco and *Artocarpus mutabilis* Becc.) to breadfruit that were previously considered as a single species in Linnean taxonomy.

Participatory work and recognition in research

To accelerate our understanding of the natural world, we need to draw on the entire pool of human thoughts and experience and give credit where it is due. General principles of collaboration (including respect, legality, and safety) have been proposed to promote inclusive and equitable fieldwork with local communities [12]. The participation of ILPs should be recognized by co-authorship where appropriate – despite their lack of official academic affiliation – for example, by 'group co-authorship' [13]. Further, the names of new species should reflect local geography and/or Indigenous languages and cultures where appropriate. Biodiversity research of many tropical countries is driven by foreign researchers. This poses a serious problem for the development of local research capacity as well as for biodiversity conservation which must be locally driven to be sustainable.

Figure 1. Examples of Indigenous and local people (ILPs) and the biodiversity they helped catalog. (A) Collecting and discussing the Chocó flora at Tado, Colombia. (B) A researcher from the Chocó (Colombia), identifying Amazonian palms during a study visit at the Aarhus University Herbarium, Denmark. (C) In Africa, the Biota Project worked with ILPs to document the flora of Namibia (e.g., the quiver tree, *Aloidendron dichotomum*). (D) In India, ILPs provide abundance data important for the monitoring and conservation of species (e.g., rhino rays, *Rhina ancylostoma*). (E) In Malaysia, ILPs were key in documenting ecological networks for frugivores (e.g., grey langur, *Semnopithecus entellus*). (F) In Borneo, ILPs contributed to unravel species of breadfruit, *Artocarpus*. (G) In Australia, ILPs monitored populations of the yellow-spotted monitor lizard, *Varanus panoptes*. (H) In Papua New Guinea, ILPs set up experimental plots for a rainforest regeneration experiment in the Saruwaged Mountains. [Photo credits: (A,B) Juan C. Copete; (C) Manfred Knabe; (D–G) Wikimedia; (H) Vojtech Novotny].

Research careers for Indigenous peoples

Paraecologist and parataxonomist are vocations that represent the next step for ILPs from being informants or field assistants [14]. These distinct careers, analogous to paramedics in health professions, combine ILK and familiarity with local ecosystems with formal training in research methods and taxonomy. Paraecologists and parataxonomists have been shown to increase the efficiency and scope of ecological research, as well as ensure long term on site monitoring impossible to sustain by visiting researchers and students (Figure 1). Despite their proven merits, these careers remain rare in contemporary ecological research. The concept was originally developed for the study of rich biodiversity in tropical countries by foreign scientists [14]. However, it has not been accepted by the institutionalized science in tropical countries that generally remains reluctant to incorporate paraecologists and parataxonomists from ILPs into its career structure. Further, research projects and institutions should facilitate progression from paraecologists to university students where appropriate.

Increasing endangerment of Indigenous and local knowledge

Despite the potential for ILPs biological classification systems and ecological knowledge to accelerate biological research, their contribution is highly contingent on the conservation of Indigenous languages, which are globally declining at alarming rates, even faster than biological species. A study on language and ethnobiological skills in Papua New Guinea showed that only 58% of 6190 surveyed students, compared with 91% of their parents, were fluent in Indigenous languages. Moreover, the medicinal uses known to the students fluent in Indigenous languages were replaced by a few, mostly non-native species for students speaking English or Tok Pisin, the lingua franca. The rapid cultural and economic globalization of ILPs also shifts interests of young people away from traditional livelihoods, such as hunting, that would help them to understand and appreciate the value of biodiversity [15].

Although the past role of ILPs in biological discovery is difficult to quantify, the previous examples highlight how current biodiversity research and conservation can be more efficient and yield better results when ILPs are involved and when local and scientific knowledge integrated, particularly when conducting research on Indigenous lands. And yet, current research practice is poorly suited to take the advantage of the research potential represented by ILPs. A wider involvement of ILPs in research and conservation would benefit both Indigenous communities and academia.

Acknowledgments

We thank the editor and two reviewers for their insightful feedback. J.C.C. and R.C-L. were supported by a SNSF Starting Grant (TMSGI3_211659: 'INDIGENOMICS', to R.C-L.). V.N. and A.K. were supported by a Czech Expro 19-28126X grant.

Declaration of interests

No interests are declared.

[1]Department of Systematic and Evolutionary Botany, Zollikerstrasse 107, 8008 Zurich, Switzerland
[2]University of South Bohemia, Branisovska 31a, Ceske Budejovice, Czech Republic
[3]Biology Centre, Institute of Entomology, Czech Academy of Sciences, Branisovska 31, Ceske Budejovice, Czech Republic
[4]New Guinea Binatang Research Center, Madang, Papua New Guinea
[5]www.rcamaraleret.com

*Correspondence:
juancarlos.copetematurana@uzh.ch (J.C. Copete) and Rodrigo.camaraleret@uzh.ch (R. Cámara-Leret).
Twitter: @R_CamaraLeret

https://doi.org/10.1016/j.tree.2023.08.017

References

1. Berlin, B. (1973) Folk systematics in relation to biological classification and nomenclature. *Annu. Rev. Ecol. Evol. Syst.* 4, 259–271
2. Mayr, E. *et al.* (1969) *Methods and Principles of Systematic Zoology*, McGraw-Hill Book Company, New York
3. Soyolt *et al.* (2013) Wild plant folk nomenclature of the Mongol herdsmen in the Arhorchin national nature reserve, Inner Mongolia, PR China. *J. Ethnobiol. Ethnomed.* 9, 30
4. Humboldt, A.v. (1852) *Personal Narrative of Travels to the Equinoctial Regions of America, During the Year 1799-1804.* London, Bohn
5. van Wyhe, J. (2018) Wallace's help: the many people who aided AR Wallace in the Malay Archipelago. *J. Malays Branch R. Asiat. Soc.* 91, 41–68
6. Ribas, C.C. (2023) Wallace knew Indigenous knowledge was key. *Nature* 613, 24–26
7. Ong, L. *et al.* (2021) Building ecological networks with local ecological knowledge in hyper-diverse and logistically challenging ecosystems. *Methods Ecol. Evol.* 12, 2042–2053
8. Pereyra, P.E.R. *et al.* (2023) Fishers' knowledge reveals ecological interactions between fish and plants in high diverse tropical rivers. *Ecosystems* 26, 1095–1107
9. Gupta, T. *et al.* (2023) Drawing on local knowledge and attitudes for the conservation of critically endangered rhino rays in Goa, India. *People Nat.* 5, 645–659
10. Ward-Fear, G. *et al.* (2019) Sharper eyes see shyer lizards: collaboration with indigenous peoples can alter the outcomes of conservation research. *Conserv. Lett.* 12, e12643
11. Gardner, E.M. *et al.* (2022) Engagement with indigenous people preserves local knowledge and biodiversity alike. *Curr. Biol.* 32, 495–512
12. Ramirez-Castañeda, V. *et al.* (2022) A set of principles and practical suggestions for equitable fieldwork in biology. *Proc. Natl. Acad. Sci. U. S. A.* 119, e2122667119
13. Ward-Fear, G. *et al.* (2020) Authorship protocols must change to credit citizen scientists. *Trends Ecol. Evol.* 35, 187–190
14. Schmiedel, U. *et al.* (2016) The role of paraecologists and parataxonomists in leading citizen science into the biodiversity-rich world. *Conserv. Biol.* 30, 506–519
15. Kik, A. *et al.* (2021) Language and ethnobiological skills decline precipitously in Papua New Guinea, the world's most linguistically diverse nation. *Proc. Natl. Acad. Sci. U. S. A.* 118, e2100096118

Appendix II: Survey activities on language skills and ethnobiological knowledge in PNG between 2015 and 2018.

A) transportation of survey materials to Karkar Secondary School in Madang Province, B) one of the surveyed schools in Western Highlands Province, C) ~ 9000 questionnaires used for the survey, and D) hired students from Divine Word University involved in data entry.

SUMMARY

Thesis summary

The thesis examines the state of language skills and ethnobiological knowledge, as well as the socioeconomic and cultural drivers of their loss, among secondary school students in two global language diversity hotspots, Papua New Guinea (PNG) and Cameroon. I used questionnaires as well as language skills and knowledge tests for 7,021 respondents representing 392 languages in PNG and 65 languages in Cameroon. The results show a rapid decline in language skills and ethnobiological knowledge among young people in both countries and describe the key factors contributing to this decline. The thesis also examines and discuss possible future scenarios that may lead to further loss or maintenance of high linguistic and cultural diversity in the face of rapid technological lifestyle changes in these regions.

Chapter I examines language skills and ethnobiological knowledge of young people in PNG based on a large, nationwide survey. Based on comprehensive data, the model, which evaluates several drivers of language attrition and ethnobiological knowledge loss, reveals a rapid parallel decline in language proficiency and traditional knowledge within a span of a single generation. The results show that a student's upbringing has a substantial impact on how well-versed they are in native language and ethnobiological knowledge and that rural areas are more conducive to their acquisition and maintenance than urban areas. Language proficiency, knowledge of plants, birds, and traditional skills (e.g., hunting, fishing) were all better among students who spent their childhood in rural settings than among those who grew up in urban areas. I have shown that the language spoken at home can have a significant impact on language acquisition. The use of language at home was in turn partly determined by the share of linguistically mixed families, which increased with urbanization. These drivers provided support for our model which predicted that the present generation's proficiency in indigenous languages will continue in decline in the future. The decline in language skills was, as expected, accompanied by severely decreased ethnobiological

knowledge in the present student generation as their knowledge of medicinal plant use, for instance, tend to be limited to a few, often introduced, plant species. These empirical results are in contrast to the sentiment of a majority of students who stated the intention to teach their indigenous language to their children in the future. However, the pressure of modernization and rapidly changing lifestyle may prevail over this determination to keep one's language and culture alive.

Chapter II explored the hunting skills of secondary students representing the young, educated population segment in PNG. I observed a shift of interest in students from subsistence hunting, traditionally regarded as a prestigious activity, to other activities regarded as more interesting and bringing higher status in the community, including attaining formal education. The results show that there is a tradeoff between investing in traditional subsistence skills, such as hunting, and formal education and academic achievement, corroborating the results of similar studies conducted elsewhere (Luz et al. 2017; 2015). As expected, students from rural areas possessed better hunting skills, as well as other traditional skills, than students from urban areas, and generally, in the remote areas with poor infrastructure. Male students possess much better hunting skills than female students. Good hunters displayed better knowledge of birds compared to those not interested in hunting. The contemporary lifestyle changes lead to a gradual loss of interest in hunting, potentially alleviating some pressure on endangered species. However, they also lead to the loss of ethnobiological knowledge and in some cases the motivation for forest conservation, as sustainable hunting was amongst the benefits mentioned by indigenous landowners for pursuing rainforest conservation.

Chapter III focuses on the Melpa language, one of the largest languages in PNG, and applies the analytical approach used in Chapter I to assess socioeconomic drivers of the language skills and ethnobiological knowledge decline within a single language. Melpa is the largest language in our data, represented by 1,313 respondents. The analysis also benefitted from the fact that I am a native Melpa speaker. The results show that Melpa speakers remain fluent in their native language, but they are nevertheless losing their ethnobiological knowledge of plants and birds. With the exception of cassowary, a culturally important bird species, birds were little known by secondary school students, indicating their disconnection from nature and a decline in traditional cultural knowledge. The students' knowledge of traditionally used plants was also limited, and a majority of the plants listed were nonnative species. The decline in language and ethnobiological knowledge in Melpa speakers was driven by the same factors documented in Chapter I for all PNG languages, particularly urbanization, language use at home, mixed language marriages, and decline in traditional skills.

Finally, **Chapter IV** on the survey of language skills and ethnobiological knowledge in Cameroon, which used the same method as the one undertaken in PNG. Cameroon represents the second largest language diversity hotspot – the West African one. This chapter explores individual-level parameters of family language use, socio-economic status, life skills, and language traits as drivers of language skills and ethnobiological knowledge among secondary students in the anglophone part of Cameroon and compared the results with those from PNG. I show a parallel set of drivers of language skills and ethnobiological knowledge decline between Cameroon and PNG, particularly urbanization and language use at home. However, the impact of growing up in linguistically mixed families was lower in Cameroon than in PNG, likely because the languages in Cameroon have larger number of speakers on average, compared to PNG. The students in PNG have better ethnobiological knowledge of birds and plants than those in Cameroon, across all levels of language proficiency. The current impact of modernization and lifestyle changes on traditional knowledge is higher in Cameroon than in PNG.

The thesis also includes a paper I coauthored (included in the **Appendices**). This paper was inspired by the present research as well as other research projects working with indigenous communities and highlights the importance of the involvement of local communities and indigenous peoples in both anthropological and biological research and conservation since combining their traditional knowledge with scientific knowledge can improve both research and conservation efforts.

In conclusion, the studies included in this Thesis show clearly that language proficiency and ethnobiological knowledge are rapidly declining among the contemporary young, educated segments of population in both PNG and Cameroon, representing a wider trend in the language diversity hotspots of New Guinea and West Africa, and possibly in other linguistically diverse regions in the tropics. There is a clear connection between lifestyle changes due to rising economic development and increasing threats to indigenous languages and traditional knowledge in indigenous ethnolinguistic groups. Our research provides support for previous studies that described the main causes of language endangerment (Amano et al. 2014; Bromham et al. 2022). Further economic development, including the increasing importance of formal education and increase in urbanization will lead to language mixing with subsequent language shift and language extinction, and it will also attract young people to new lifestyles that cause them to lose their connection with nature. This will lead to a decline in their interest in traditional activities like hunting and a decrease in their knowledge of plants and animals. On a positive note, the same changes may have a positive impact on conservation attitudes driven by modern concerns of biodiversity decline and climate change, not recognized in traditional societies.

Traditional knowledge may be endangered even more than indigenous languages, as even a language being healthy does not guarantee the survival of the knowledge it carries, as shown in Chapter III. The pressure of socioeconomic factors on the use of their language and ethnobiological knowledge may be very strong in many indigenous communities that aspire to join the modern world and globalized economy and see using more widely spoken languages as a gateway to this goal. A way to save indigenous languages and the biocultural knowledge they carry may be to promote the cultural awareness of indigenous groups and, where feasible, to encourage the practical use of the traditional knowledge and skills, such as their incorporation in research and development agendas.

References

Amano, T., Sandel, B., Eager, H., Bulteau, E., Svenning, J. C., Dalsgaard, B., ... & Sutherland, W. J. (2014). Global distribution and drivers of language extinction risk. *Proceedings of the Royal Society B: Biological Sciences*, *281*(1793), 20141574.

Bromham, L., Hua, X., Algy, C., & Meakins, F. (2020). Language endangerment: A multidimensional analysis of risk factors. *Journal of Language Evolution*, *5*(1), 75-91.

Bromham, L., Dinnage, R., Skirgård, H., Ritchie, A., Cardillo, M., Meakins, F., ... & Hua, X. (2022). Global predictors of language endangerment and the future of linguistic diversity. *Nature ecology & evolution*, *6*(2), 163-173.

Luz, A. C., Guèze, M., Paneque-Gálvez, J., Pino, J., Macia, M. J., Orta-Martinez, M., & Reyes-Garcia, V. (2015). How does cultural change affect indigenous peoples' hunting activity? An empirical study among the Tsimane'in the Bolivian Amazon. *Conservation and Society*, *13*(4), 382-394.

Luz, A. C., Paneque-Gálvez, J., Guèze, M., Pino, J., Macía, M. J., Orta-Martínez, M., & Reyes-García, V. (2017). Continuity and change in hunting behaviour among contemporary indigenous peoples. *Biological Conservation*, *209*, 17-26.

CURRICULUM VITAE

Alfred Kik

Nationality: Papua New Guinea

Languages spoken: Melpa (native), Melanesian Pidgin and English (fluent).

Sex: Male

Email: kixyalphy@gmail.com

EDUCATION

2019 – present: University of South Bohemia in České Budějovice, Czech Republic. *PhD student in Zoology*.

Supervisors: RNDr. Pavel Duda, Ph.D. and prof. RNDr. Vojtěch Novotný, CSc. *Environmental and socio-cultural determinants of language skills and ethnobiological knowledge in Papua New Guinea and Cameroon.*

2017 – 2019: University of Papua New Guinea – Port Moresby, PNG & New Guinea Binatang Research Center. *MSc. in research in Ethnobiology*.

Supervisors: prof. RNDr. Vojtěch Novotný, CSc. and prof. Simon Saulei. *Current trends in language skills and ethno-biological knowledge of upper secondary school students in Papua New Guinea.*

2012 – 2013: University of Goroka – Goroka, PNG. *BSc.H in Ethnobiology and ethnomedicine*.

Supervisors: Pooranalingam Jeyarathan, Ph.D. and Savitha Debritto (M.Sc.). *Ethnomycological Documentation of Mushroom Diversity of Wopkola in Mul District of Western Highlands Province, Papua New Guinea; and Investigation of Antimicrobial Properties of Selected Species*

2011 – 2012: University of Goroka – Goroka, PNG.

Postgraduate Diploma in Education (PGDE)

2007 – 2010: University of Goroka – Goroka, PNG.

Bsc., Biology and Chemistry

INTERNATIONAL FOREIGN LABORATORY VISIT

2022 (8 weeks): Columbia University, New York, USA

Host collaborator: prof. Paige West

WORK

2019 – present: Institute of Entomology, Biology Center, CAS

Ph.D. student

2015 – 2019: New Guinea Binatang Research Center – Madang, PNG.

- *Ethnolinguistic and ethnobiology research project leader*

Conducted large scale surveys in secondary schools in PNG to assess current state and future trends in indigenous language skills and ethnobiological knowledge.

-*Gardening and environment sustainability researcher project participant*

The research focused on how farming communities in Ohu villages in Madang, Papua New Guinea, use their land, what practices they use and how information about new farming practices can best be disseminated. Collaborative research with Oxford University (UK).

-*Participant in El Nino impact assessment*

The project explored adaptive capacity and resilience of subsistence farmer to extreme weather events), collaborative research with Oxford University (UK).

2017 – 2018: University of Goroka – Goroka, PNG.

-*Temporary tutor*

Taught General Biology, Microbiology, Environmental biology & Ethnobiology.

2013 – 2014: University of Goroka – Goroka, PNG

-*Temporary tutor*

Taught General Biology, Microbiology and HIV & AIDs education.

2010 – 2014: University of Goroka – Goroka, Eastern Higlands, PNG.

-*Research participant*

Involved in a baseline survey in Kiovi in preparation of edible and medicinal mushroom cultivation in Lufa District, EHP.

-*Project leader*

Mushroom plot studies in Western Highlands province.
Ethnomycological Documentation of Mushroom Diversity of Wopkola in Mul District of Western Highlands Province, Papua New Guinea; and Investigation of Antimicrobial Properties in Selected Species. BSc.H research project.

Ethnobotanical documentation and antimicrobial screening of *Crassocephalum crepidioides* (thick head). BSc degree project.

FELLOWSHIP/GRANT AWARDS

2017: Christensen Fund (USA) Standard Research Grant (Principal Investigator)

"Vernacular language skills and ethnobiological knowledge in the young generation of Papua New Guineans: assessing the future of biocultural diversity in the world's linguistically richest country", 2017-2018, USD 20,000.

2017: Association for Tropical Biology course in Tropical Ecology and Conservation, Danum Valley – Malaysia

Full scholarship for a month-long student course

2015: Masters Postgraduate Studentship, New Guinea Binatang

Research Center – Madang, PNG.

Full scholarship to study MSc at the University of PNG.

2014: Travel grant, University Research & Publication Committee (URPC) at University of Goroka – Goroka, PNG.

Funded to attend Research Science & Technology Conference at University of Papua New Guinea.

2013: Travel grant, Biology Department at University of Goroka – Goroka, PNG.

Funded to attend 7th Huon Seminar at University of Technology, PNG.

2012: Honours postgraduate studentship, University of Goroka – Goroka, PNG.

Received full scholarship to study honors degree.

TRAININGS AND WORKSHOPS

2017: Tropical ecology field course, study design and data analysis. Tropical Biology Association UK at Danum valley, Malaysia

2017: Introduction to R statistics, New Guinea Binatang Research Center, Madang, PNG

2015: Nature-Based Economics, an inter-disciplinary course, PNG Institute of Biological Research, PNG

2010: Resource & Resource Management, Research & Conservation Foundation, Six (6) months course, Papua New Guinea

COURSES OFFERED AT UNIVERSITY OF SOUTH BOHEMIA

-Biostatistics (Lecturer: RNDr. Petr Blažek, Ph.D.)

-Molecular Phylogenetics (Lecturer: prof. RNDr. Václav Hypša, CSc.)

-Sustainable Development (Lecturer: doc. Ing. Eva Cudlínová, CSc.)

-Advances in Behavioural Ecology Research (Lecturer: RNDr. Petr Veselý, Ph.D)

-Advances in Ecology (Lecturer: Pável Matos Maravi, Ph.D.)

-Behavioural Ecology (Lecturer: RNDr. Petr Veselý, Ph.D)

-Evolutionary Biology (Lecturer: RNDr. Pavel Duda, Ph.D.)

CONFERENCES

Kik, A. et al., A shift in interest from hunting among the young, educated Papua New Guineans: Implications for conservation. 6th European conference of Tropical Ecology. 19-23.6.2023. České Budějovice, Czech Republic (talk).

Kik, A., Duda, P. & Novotny, V. The influence of socio-demographic factors on language skills and ethnobiological knowledge of contemporary populations in Papua New Guinea. Polish Society for Human and Evolution studies 6th International Conference, 24 - 27.9. 2019, Prague, Czech Republic (Talk).

Kik, A., Duda, P. & Novotny, V. Lifestyle change and loss of native language skills and ethnobiological knowledge in contemporary populations in Papua New Guinea. Czech Society for Ecology 7th Conference, 4-7.9.2019, Olomouc, Czech Republic (poster presentation).

Kik, A., Beauchamp, E., Hazenbosch, M. & Morris, R. Promoting resilience of subsistence farming to El Nino events in Papua New Guinea. El Nino Conference, 14-16.05.2018, London, UK (Talk)

Kik, A., Baro, N. & Novotny, V. Serious decline in language skills and ethnobiology knowledge in the young generation in Papua New Guinea. Faculty of Arts and Social Sciences Research Symposium, 13.10.2016, Divine Word University – Madang, PNG (Talk).

Kik, A. & Jeyarathan, P. (2015). The Impacts of Climate Change and Anthropogenic Activities on Mushroom Diversity of Wopkola in the Mul District of Western Highlands Province, Papua New Guinea, 6th PNG Research Science & Technology Conference proceedings, University of Papua New Guinea.

Kik, A., Jeyarathan, P. & Debritto, S. Ethnomycological Documentation of Mushroom Diversity of Wopkola in Mul District of Western Highlands Province, Papua New Guinea; and Investigation of Antimicrobial Properties in Selected Species, 7th Huon Seminar, 13-14.11.2013, University of Technology, Lae, PNG (Talk).

PUBLICATIONS

As of November 2023: 33 citations on Google Scholar

Zhang, Y., West, P.,Thakoli, L., Suryawanshi, K., Supuma, M., Straub, D., Sithole, S., Sharma, R., Schleicher, J., Ruli, B., Rodríguez-Rodríguez, D., Rasmussen, B.M., Ramenzoni, V., Qin, S., Pugley, D.D., Palfrey, R., Oldekop, J., Nuesiri, O.E., Nouhou, N., Nguyen, T.H.V., Ndam, N., Mungai, C., Milne, S., Mabele, B.M., Lucitante, S., Lucitante, H., Liljeblad, J., Jones, N., Johnson, M., Jarrett, C., James, S.R., Kiwango, A.W., **Kik, A**., Holmes, G., Gibson, N.L., Ghoddousi, A., Geldmann, J., Gebara, F.M., Edwards, T., Dressler, W., Douglas, R.L., Dimitrakopoulos, G.P., Davidov,V., Compaoré-Sawadogo, W.F.M.E., Collins, A.Y., Cepek, M., Burow, P., Brockington, D., Philippe, M., Balinga, B., Austin, J.N., Astuti, R., Ampumuza, C., Agyei, K.F. (2023). Governance and Conservation Effectiveness in Protected Areas and Indigenous and Locally Managed Areas. *Annual Review of Environment and Resources 48* (1), 559-588. https://doi.org/10.1146/annurev-environ-112321-081348

Copete, J. C., **Kik, A**., Novotny, V., & Cámara-Leret, R. (2023). The importance of Indigenous and local people for cataloging biodiversity. *Trends in Ecology & Evolution*. https://doi.org/10.1016/j.tree.2023.08.017

Kik, A., Duda, P., Bajzekova, J., Baro, N., Opasa, R., Sosanika, G., Jorge, L. R., West, P., Sam, K., Zrzavy, J., & Novotny, V. (2023). Hunting skills and ethnobiological knowledge among the young, educated Papua New Guineans: Implications for conservation. *Global Ecology and Conservation, 43,* e02435. https://doi.org/10.1016/j.gecco.2023.e02435

Kik, A., Adamec, M., Aikhenvald, A. Y., Bajzekova, J., Baro, N., Bowern, C., Colwell, R. K., Drozd, P., Duda, P., Ibalim, S., Jorge, L. R., Mogina, J., Ruli, B., Sam, K., Sarvasy, H., Saulei, S., Weiblen, G. D., Zrzavy, J., & Novotny, V. (2021). Language and ethnobiological skills decline precipitously in Papua New Guinea, the world's most linguistically diverse nation. *Proceedings of the National Academy of Sciences, 118*(22), e2100096118. https://doi.org/10.1073/pnas.2100096118

Hazenbosch, M., Sui, S., Isua, B., Beauchamp, E., **Kik, A**., Luke, G., Matouš, P., Morris, R. J., Paliau, J., & Milner-Gulland, E. J. (2022). Quantifying unintended effects of an agroecological research project on farmers' practices and social network in Papua New Guinea. *People and Nature, 4*(6), 1592–1602. https://doi.org/10.1002/pan3.10404

PUBLICATIONS SUBMITTED

Kik, A., Neku N. A, Ewome, L. F., Jorge, R.L., Hodieb, L., Good, J., Bajzekova, J., Albrecht, T., Sam, K., Aikhenvald, Y. A., Pavel Drozd, P., Duda, P., Sarvasy, H., & Novotny.V. Decline in language proficiency and ethnobiological knowledge in major linguistic hotspots: West Africa and New Guinea. *Manuscript in preparation.*

Kik, A., Duda, P., Bajzekova, J., Kama, K., Jorge, L. R., & Novotny, V. Language skills and ethnobiological knowledge in the young and educated Indigenous Melpa speakers in Papua New Guinea. Pending minor revision (*Journal of Ethnobiology*)

Stockdale, A.J., Middleton, J., Aina, A., Cherake, G., Dem, F., Ferea, W., Hane-Nou, A., Huanduo, W., **Kik, A**., Novotny, V., Ruli, B., Yearwood, P., Cassell, J., Eldridge, A., Fairhead, J., Winchester, J., Stewart, J. A. Mobilising Papua New Guinea's Conservation Humanities: Research, Teaching, Capacity Building, Future Directions. Pending minor review (*Conservation and Society*).

Harley, C., **Kik, A**., & Janet, G. Ethnobiological nomenclature in Papuan languages. *Book chapter submitted September 2023 to main author of the book.*

PUBLICATIONS NOT PEER-REVIEWED

Kik, A., Jeyarathan, P., & Debritto, S. (2013). Ethnomycological documentation of mushroom diversity of Wopkola in Mul District of Western Highlands Province, Papua New Guinea and investigation of antimicrobial properties of selected species. In Proceedings of the 7th Huon Seminar. Papua New Guinea: University of Technology (pp. 111-20).

Kik, A. & Jeyarathan, P. (2015). The Impacts of Climate Change and Anthropogenic Activities on Mushroom Diversity of Wopkola in the Mul District of Western Highlands Province, Papua New Guinea, 6th PNG Research Science & Technology Conference proceedings, University of Papua New Guinea. www.pacjmedsci.com/RST%20Proceedings%20Vol%202.pdf

Kik, A. (2013). The Nonda of PNG. Paradise Magazine (October/November issue)

Kik, A. (2016, 14 March). Fungi's Potential. Post Courier, p. 5.

PROFESSIONAL TRAVEL

Czech Republic, United Kingdom, USA, Malaysia, PNG

COMPUTER SKILLS

R: *moderate,* GIS: *familiar*, SPSS: *Moderate*

Email: kixyalphy@gmail.com

Environmental and socio-cultural determinants of language skills and ethnobiological knowledge in Papua New Guinea and Cameroon

University of South Bohemia in České Budějovice

Faculty of Science

Branišovská 1760

CZ-37005 České Budějovice, Czech Republic

Phone: +420 387 776 201

www.prf.jcu.cz, e-mail: sekret-fpr@prf.jcu.cz