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SHORT COMMUNICATION

'First Known Photographs of Living Specimens': the power of iNaturalist for recording rare tropical butterflies

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Abstract

Insects are the most biodiverse multicellular organisms, with most of this diversity in the tropics. Butterflies follow the same pattern, with ~ 90% of species from the tropics. Anthropogenic stressors such as habitat loss and pollution are driving butterfly declines globally, with many rare tropical species likely extinct before discovery. Citizen science is a powerful tool for supplementing professional monitoring of tropical butterfly biodiversity and better understanding butterfly biogeography, especially in remote regions or on private land. We created a 'project' on the online biodiversity citizen science platform iNaturalist to collect the first known photographs of rare taxa. Almost 20% of the project's records are butterflies, with observations of 406 butterflies for which the uploaded images are the first known photographs of living specimens. Over 90% of these are from the tropics, with Indonesia, Brazil and Peru the most-represented countries, and Theclinae, Riodininae and Satyrinae the most observed subfamilies. The project's success has been driven by a strong synergistic community of experts and amateur naturalists from around the globe that facilitates real-time discussions and the identification of rare and undescribed taxa.

Implications for insect conservation Our project highlights the power of iNaturalist for documenting the occurrence of rare tropical butterflies in typically poorly monitored regions such as Papua and remote areas of South America. These data points provide the stepping stones for a better understanding of tropical butterfly biogeography, and have the potential to inform conservation and management of poorly known species.

Keywords Biogeography · Butterfly · Citizen science · Conservation · iNaturalist · Tropical

With one million described species, and estimates of at least four to five times this number yet to be discovered or described (Stork 2018; García-Robledo et al. 2020), insects are the most biodiverse group of multicellular organisms on the planet. Most of this biodiversity, including the undescribed fauna, is in the tropics (Godfray et al. 1999; Stork 2018). Butterfly diversity follows the same pattern, with ~ 90% of the world's estimated 18,000–20,000 species occurring in the tropics (Shields 1989; Bonebrake et al. 2010). The Neotropics are especially butterfly-rich with ~ 8000 described species (Callaghan et al. 2004), more than 3600 of which can be found in Colombia alone (Garwood et al. 2021). Indeed, some regions host extraordinary diversity; an area of just a few square kilometres in central Rondonia (west-central Brazil) is estimated to contain up to 1600 butterfly species (Emmel and Austin 1990), while ~ 2500 species, with at least a further 500 undescribed species, have been recorded from a 65 km transect in Cosñipata (south-east Peru; Lamas 2017).

Unfortunately, butterflies, and insects more broadly, are threatened by global stressors such as habitat loss, climate change, invasive species and pollution (Bonebrake et al. 2010; Forister et al. 2019; Wagner et al. 2021). Given relatively few butterfly species have been assessed from a conservation perspective (Régnier et al. 2015), it is difficult to quantify the impacts of these stressors, and it is likely that many species have gone extinct, and will continue to go extinct, before they have even been described (Dunn 2005; Costello et al. 2013). Similarly, many species experience

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regional extinctions without having been detected, even in well-studied areas. For example, > 100 butterfly species are estimated to have been extirpated from Singapore before being discovered in the region (Theng et al. 2020).

Given the scale of these knowledge shortfalls and the difficulties associated with monitoring butterflies in tropical environments (Bonebrake et al. 2010), it is clear these issues cannot be addressed by entomologists or taxonomists alone. One of the most promising strategies for better recording biodiversity across space and time to inform conservation efforts is the combination of professional data collection with citizen science—or community science—initiatives (Dennis et al. 2017; Didham et al. 2020). These citizen science initiatives allow the collection of biodiversity data at unprecedented scales (Mesaglio & Callaghan et al. 2021), and are especially valuable in undersampled tropical areas rarely visited by professional scientists (Callaghan et al. 2021). That many butterfly species are large, colourful, charismatic and well-recognised, especially compared to other insect groups, promotes greater participation by citizen scientists (Kühn et al. 2008; van Swaay et al. 2008; Wilson et al. 2015; Shirey et al. 2021). Butterfly-specific citizen science projects (e.g., Fontaine et al. 2016; Washitani et al. 2020; Comay et al. 2021) are valuable initiatives that foster greater awareness of and participation in butterfly conservation (Lewandowski & Oberhauser 2016; Lewandowski and Oberhauser 2017), with many also used to complement professionally-collected data (Dennis et al. 2017; Richter et al. 2018). Citizen science data have contributed to reconstructing the historical spread of a butterfly species (Ryan et al. 2019), and to closing distribution knowledge gaps for butterflies and other Lepidoptera (e.g., Sexton 2021). In many regions, the proportion of data contributed by citizen science compared to professionally collected data is rapidly increasing (Shirey et al. 2021). Citizen-based butterfly monitoring programs have also been recognised as of high value for tracking changes across space and time (Schmeller et al. 2009), and butterfly data collected through citizen science have been used to map changes in abundance and distribution in response to climate change across both a continental and decadal scale (Devictor et al. 2012).

Although not specific to butterflies, the online biodiversity citizen science platform iNaturalist (www.inaturalist.org) is a powerful tool for monitoring butterfly biodiversity across space and time, with 3.26 million observations of 10,696 butterfly species contributed by over 290,000 users since its inception in 2008. iNaturalist data have already been used to record the rediscovery of butterfly species considered locally extinct (Jain et al. 2019), to document butterfly range expansions (Chowdhury et al. 2020), and to track declines in butterfly numbers on a decadal scale (Forister et al. 2021).

One of iNaturalist's most important aspects is the 'Project' feature, which allows users to collate related observations and create an interested community of both amateur naturalists and professional scientists. Projects with well-defined purposes help stimulate greater participant engagement, and highlight unique data within observations that may otherwise go undocumented (Mesaglio and Callaghan et al. 2021). On 13 April 2020, the authors conceived *First Known Photographs of Living Specimens* (www.inaturalist.org/projects/first-known-photographs-of-living-specimens), a project designed to collect the first photographic records of both described and undescribed taxa. All observations are required to feature photographs of living individuals (thus excluding observations of e.g., pinned or preserved specimens), and each photograph must be the first known image of that taxon anywhere, not just the first to be uploaded to iNaturalist. Any user can manually add observations to the project (both their own observations and those belonging to others), however, given no single, easily-referenced repository of taxon photographs exists, all newly added records are also systematically vetted by at least one of the authors, all of whom have curatorial status on the project; this status allows the authors to remove any observations which do not fulfill the project criteria (note that observations are only removed from the project, and are still retained in iNaturalist broadly). This vetting process involves checking six major sources of publicly available and identified photographs: (1) iNaturalist; (2) Google Images; (3) the Global Biodiversity Information Facility; (4) broad, well-curated, and taxonomically and regionally-relevant databases such as BugGuide; (5) more specific well-curated, and taxonomically and regionally-relevant databases, such as Butterflies of America, Butterfly Catalogs, and Calydna Butterfly Database; and, (6) print material or online references to print material. Relevant taxonomic experts are also consulted (by 'tagging' them in observations, analogous to social media tagging) in cases where uncertainty still exists. Further, publicisation of the project across both iNaturalist and the iNaturalist discussion forum (forum.inaturalist.org) has helped build a network of users (including many taxonomic experts) that assist in adding appropriate observations to the project and vetting those that have already been added, reducing the probability that a photograph that does not meet the criteria will be added to or remain in the project. We admit it is likely that, for some of the observations in our project, earlier photographs of living specimens exist but were not detected due to e.g., being unidentified, or not being publicly available/easily searched. Importantly, however, projects are dynamic, and any observation can be retrospectively removed from the project if an earlier photograph is found.

An example of this vetting process in action was for a butterfly observation (www.inaturalist.org/observations/59945849) uploaded to iNaturalist on 18 September 2020. Within two days it was identified as *Troides prattorum* Joicey & Talbot 1922, a rare, vulnerable swallowtail butterfly endemic to Buru Island in Indonesia. With the information that the photo series was taken on 7 May 2014, the observation was added to our project. It was subsequently vetted, and passed the first five checks: it was the first observation of this species on iNaturalist, and all other photographs online are of pinned specimens. However, we found an illustrated checklist of papilionid butterflies from the island group to which Buru belongs (Peggie et al. 2005). Whilst this paper did not contain photographs of living specimens, it noted under the entry for *T. prattorum* that "MATSUKA provides wonderful pictures of live *T. prattorum* taken on Buru", with 'MATSUKA' referring to the print book 'Natural History of Birdwing Butterflies' (Matsuka 2001). The observation was thus removed from our project.

Although the project was designed to collect observations of any taxa, butterflies—especially tropical species—have become a focus. As of 9 July 2021, 406 of the 2131 observations added to the project are butterflies (Fig. 1), with 376 (92.6%) of these observed in the tropics. These butterfly observations have been contributed by 213 users covering 35 countries across 4 continents, although just 4 countries—Indonesia (106), Brazil (65), Peru (38) and Colombia (32)—contain 59.4% of the observations. Observations are also dominated by just 4 of the 22 observed subfamilies: Theclinae (125), Riodininae (52), Satyrinae (51), and Polyommatinae (36). Of the 61 observed tribes, Eumaeini (93), Satyrini (36) and Polyommatini (28) are the most observed. Nineteen observations in our project are of undescribed species, at least one of which is now in the process of being described (www.inaturalist.org/observations/75814195). Two hundred and fifty-two butterfly observations in our project represent species for which more than 100 years elapsed between their formal description and the first photograph of a live specimen, and indeed for seven of these observations, the period between description and photography of a live specimen was more than 200 years. For five observations, the associated photograph was taken before the species was formally described. There is also at least one species, *Splendeuptychia argyropsacas* Bryk, 1953 (www.inaturalist.org/observations/53193114), for which the photograph in our project likely represents the only known record (either photograph or specimen) of this species other than the 1953 type specimen.

It is clear that iNaturalist's value for recording rare tropical butterflies is driven by two key factors: its global, integrated community of experts and amateur naturalists, and its broad geographic coverage. The most important of these two is iNaturalist's ability to bring together a network of

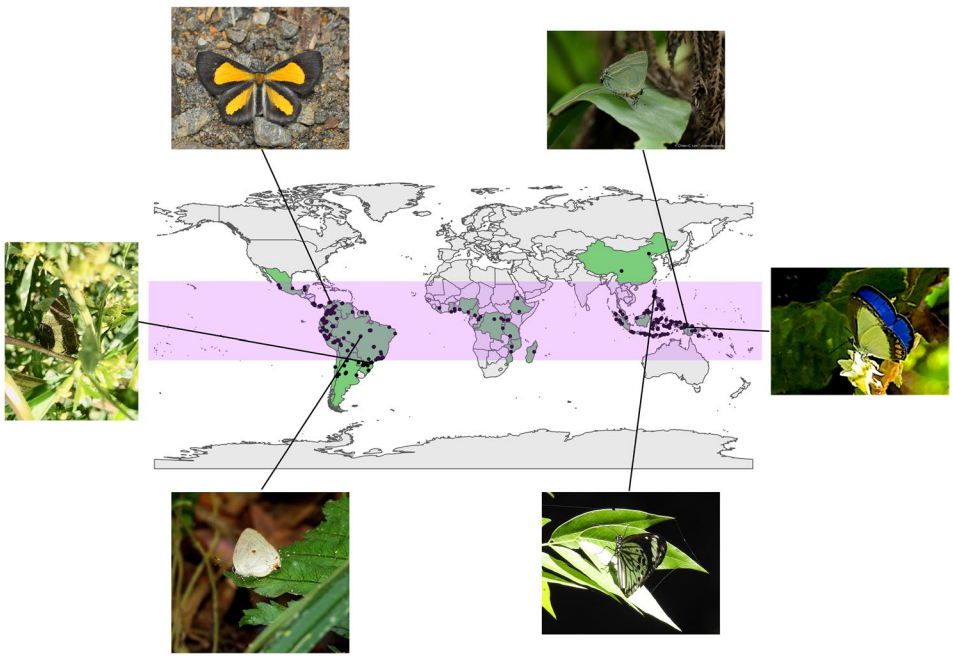

Fig. 1 Map of observations of rare butterflies uploaded to iNaturalist and added to the *First Known Photographs of Living Specimens* project (n = 406). Each black dot represents an observation of a butterfly for which the associated photograph is the first known image of a living individual of that species. The green fill indicates countries with at least one observation. The purple band represents the tropics. From top left, clockwise: undescribed *Machaya*, ©Roger Rittmaster (@rogerritt); *Artipe dohertyi*, ©Chien Lee (@cclborneo); *Epimastidia yiwikana*, ©Pamela Donaldson (@shirdipam); *Euploea tobleri*, ©Desmond Allen (@rhabdornis); *Nicolaea castinotus*, ©Sidnei Dantas (@siddantas); *Arzecla straelena*, ©Maristela Zamoner (@mzamoner)

experts—both amateur and professional—with a network of passionate amateur naturalists from around the globe to form a strong synergistic community that can discuss observations, and where the experts can identify rare taxa and teach non-expert users. This collaboration allows for more accurate identifications, and thus for a better understanding of spatial distributions, both of which inform conservation efforts (Jones et al. 2019). Crucially, this network of experts also facilitates the recognition of undescribed species. For example, this observation of an undescribed *Machaya* Hall & Willmott, 1995 (www.inaturalist.org/observations/17364065) was tentatively (given the lack of a physical specimen) recognised as such through the combined efforts of users across three continents (and indeed, the creation of our project itself was done through collaboration across multiple continents), including one of the genus' original authors, Keith Willmott, who is the director of the Florida Museum of Natural History's McGuire Center for Lepidoptera and Biodiversity, an expert in Neotropical butterflies, and a regular contributor to iNaturalist with more than 11,000 identifications of butterflies.

Importantly, as more experts continue to join iNaturalist, many old observations that have remained unidentified, sometimes for years, will be reviewed and identified. Although uploaded in 2017, this observation (www.inaturalist.org/observations/7005027) remained at 'Nymphalidae' for almost three years before Thomas Desloges, an African butterfly expert who joined iNaturalist in 2019, saw the observation and identified it as *Smerina manoro* Ward, 1871. Certainly, many more observations like this already exist on iNaturalist (i.e., identifiable once seen by the right person), highlighting the value of continued recruitment of experts, especially for taxa such as Hesperiidae which are typically more difficult to identify than families with many large and easily recognised species, such as Nymphalidae or Papilionidae. This recruitment will bolster the taxonomically and geographically broad network of expertise already present on iNaturalist, particularly those experts, both professional and amateur, who have contributed their insights to our project through either comments or identifications; these include, but are not limited to, Diego Rodrigo Dolibaina, Indiana Cristo, Luísa L. Mota, Oskar Brattström, Andrew Neild, Maristela Zamoner, Andrew Warren, Stephen Boddington and Kim Garwood.

Also important are the 'expert observers'; these are users such as professional scientists specialising in non-butterfly taxa, professional tour guides (often birding tours), or experienced photographers and naturalists who, during their work, research or travel, are able to consistently recognise and photograph rare butterfly species, and thus contribute to the project disproportionately more than the many amateur naturalists who typically contribute single observations. Within our project, these users include, but are not limited to, Ken Kertell, Sidnei Dantas, Benoit Segerer, Filho Manfredini, Pamela Donaldson, Rich Hoyer, and David Geale, and indeed these seven users alone have contributed 19.4% of all butterfly observations to our project. However, the third component of iNaturalist's integrated community, the many amateur naturalists, contribute the great majority of records to our project and iNaturalist more broadly. Although the number of butterfly observations contributed by each user in our project ranges from 1 to 21, the distribution of contributions is heavily right-skewed, with 162 (76.1%) users contributing a single observation (although many of these users are significant contributors to iNaturalist more broadly/outside our project). Most records in our project are therefore individual, opportunistic observations collected during holidays and other short-term trips to undersampled but highly diverse areas, such that the chances of photographing at least one rare species, even incidentally, are relatively high.

The second factor driving iNaturalist's value for recording rare butterflies is its facilitation of data collection from private land and remote areas. Given these poorly monitored regions and habitats are often associated with highly diverse and endemic fauna, as well as many threatened and poorly understood species, each additional data point is valuable (Tulloch et al. 2013; Callaghan et al. 2021). iNaturalist's global accessibility—the only requirement for its use is a device with Internet access, with zero costs associated with using the platform itself—is a crucial boon, particularly in regions such as Papua where data on species abundance and distribution are typically poor due to limited biodiversity monitoring and ecological studies by professional scientists (Burnett 2007). Accordingly, records of rare species such as *Epimastidia yiwikana* Schröder 2010 (www.inaturalist.org/observations/56923223) and *Artipe dohertyi* Oberthür, 1894 (www.inaturalist.org/observations/42964281) in remote, poorly-travelled regions of Papua are invaluable.

The sampling of remote regions also allows for the detection of range extensions. Indeed, many rare Neotropical Eumaeini, which appear to be narrow-range endemics based on limited sampling data, are actually more widely distributed (Bálint et al. 2016). The importance of these data for this diverse group is emphasised by a number of observations added to the 'First Photographs' project: this record of *Nicolaea castinotus* Johnson & Le Crom, 1997 (www.inaturalist.org/observations/58376433) represents a range extension of almost 2000 km southeastwards across the Amazon Basin from the type location of Guainía Department in eastern Colombia; and, this record of *Arzecla straelena* Bálint, 2019 (www.inaturalist.org/observations/21366019), a species posited to be "probably…restricted to cloud forest habitats above the lowland rainforest belt" in its original description, represents a southwards extension of ~4500 km, as well as a difference in elevation from the type location

of ~ 1370 m. Also notable are this observation of *Iolaus caesareus* Aurivillius, 1895 (www.inaturalist.org/observations/3357495), a new record for Nigeria; and, this observation of *Eunica incognita* Jenkins, 1990 (www.inaturalist.org/observations/42146412) at ~ 900 m elevation, a species previously unknown above 250 m elevation and represented by just a dozen known specimens.

iNaturalist and other biodiversity citizen science data are unlikely to be a cure-all for filling in these large spatial data gaps across the globe given the often strong biases of these data towards cities (Mesaglio and Callaghan 2021; Shirey et al. 2021), however, it is clear that even singular records collected by citizen scientists can catalyse further discoveries and important conservation efforts. In Australia, the rare, myrmecophilous lycaenid *Acrodipsas myrmecophila* Waterhouse & Lyell, 1913 was known in the Australian Capital Territory from only a single 1991 record until the 2018 discovery of a breeding site by a citizen scientist. This single observation sparked identification training for other citizen scientists, the subsequent discovery of an additional five breeding sites and one hilltopping site by more citizen scientists, the mapping of more than 350 nests of the attendant ant species, and an improved understanding of specific ecological requirements and best conservation management practices for this species (Bond 2019; Sanderson et al. 2021). The three records in our project of threatened species from poorly sampled regions, the IUCN-listed *Euploea tobleri* Semper, 1878 (near threatened; www.inaturalist.org/observations/4917747) and *Papilio jordani* Fruhstorfer, 1902 (vulnerable; www.inaturalist.org/observations/31069634), and *Panara ovifera* Seitz, 1913 (www.inaturalist.org/observations/65719954), which is listed as vulnerable in Brazil, are therefore crucial for providing the potential for similar conservation efforts, especially since the most recent assessments of *E. tobleri* and *P. jordani* were in 1996, and both species are currently annotated by the IUCN as 'needs updating'.

Clearly, iNaturalist is an important platform for recording observations of rare butterflies, especially tropical species and live individuals in the field, and our project *First Known Photographs of Living Specimens* has helped create a more focused repository for these observations. Promoting more observations in species-rich regions such as Africa and Central America, and more observations of small, less charismatic groups such as Hesperiidae will help provide the stepping stones for future conservation efforts.

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Code availability Not applicable.

Declarations

Conflict of interest The authors have no conflicts of interest to declare.

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