Received: 8 September 2022 | Accepted: 4 November 2022

DOI: 10.1002/inc3.11

INTEGRATIVE CONSERVATION XTBG WILEY

SHORT COMMUNICATION

Remote assessments of human pressure on biodiversity may miss important human threats

Christos Mammides[1] | Francesco Martini[2,3] | Constantinos Kounnamas[1]

[1]Nature Conservation Unit, Frederick University, Nicosia, Cyprus

[2]Botany Department, School of Natural Sciences, Trinity College Dublin, Dublin, Ireland

[3]Department of Forest Ecology, Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Prague, Czech Republic

Correspondence

Christos Mammides, Nature Conservation Unit, Frederick University, 7, Yianni Frederickou St, Pallouriotissa, 1036 Nicosia, Cyprus.

Email: cmammides@outlook.com

Funding information

No funding received for this study.

Abstract

Monitoring human pressure on biodiversity within protected areas (PAs) remains a challenging task due to the vast number of PAs worldwide (>250,000) and the fact that we lack basic information for most of them. Consequently, researchers are increasingly relying on remote sensing techniques to overcome this challenge. However, remote assessments of human pressure on biodiversity may miss crucial threats, such as hunting and invasive species, which are often best documented through in situ field surveys. Here, we use a unique European Union dataset documenting human threats within 8210 PAs through field surveys to assess the relationship between those threats and three commonly used indices of human pressure that are largely derived using remote-sensing methods—the Human Footprint and Human Modification indices and the LandScan Global Population Database. We find that the indices are not always related to the threats recorded within PAs through field surveys. The indices seem to best capture threats associated with urbanization, agriculture, and pollution but not necessarily others. Although remote assessments of human pressure on biodiversity are crucial for conservation, researchers and practitioners must be aware of their limitations and must complement such assessments with information collected in the field whenever possible.

KEYWORDS

area-based conservation measures, human footprint, Natura 2000 network, post-2020 global biodiversity framework, protected areas, threats to biodiversity

1 | INTRODUCTION

Humans are modifying natural systems on an unprecedented scale (Corlett, 2015). As a result, more than one million species are now threatened with extinction (Tollefson, 2019). Protected areas (PAs) represent a key strategy for halting biodiversity loss. The number of PAs has increased exponentially over the last few decades (Guan et al., 2021), now covering approximately 17% of the planet's terrestrial area (UNEP-WCMC, IUCN, 2021). In December 2022, the Parties to the Convention on Biological Diversity are expected to agree to a further increase in PAs, covering 30% of the planet by 2030. Yet, for biodiversity to be conserved, PAs must also be effective (Geldmann et al., 2019). Recent studies have shown that many of the world's PAs continue to be impacted by human activities (Anderson & Mammides, 2020; Jones et al., 2018), putting the biodiversity in those areas at risk. To further improve effectiveness, we must develop the right tools to assess human pressure within PAs in its entirety (Schulze et al., 2018). This remains a challenging task considering the vast number of PAs worldwide (>250,000; UNEP-WCMC, IUCN, 2021) and the fact that we often lack basic information regarding many of the human activities occurring in them.

To overcome this challenge, researchers are increasingly relying on remote sensing information to quantify human threats within PAs. Recent advancements in computing power and remote sensing technology have made such data exceedingly useful for assessing human pressure on biodiversity (Luque et al., 2018; Petrou et al., 2015). Remote sensing datasets are now often available on a global scale and are being updated regularly to the extent that, in some cases, we are provided with near real-time information (Radočaj et al., 2020; Ye et al., 2021). Importantly, remote sensing data are standardized and comparable across countries and regions and can capture a range of human activities impacting biodiversity (Pricope et al., 2019; Radočaj et al., 2020). Such activities include, for example, agriculture and urbanization. Combined with other pressures, they can be used to estimate the cumulative human pressure on natural systems (Kennedy et al., 2019). Consequently, it is not surprising that remote sensing information now plays a central role in our efforts to assess human threats within PAs. Results from remote assessments have proven exceedingly informative, revealing regions in which PAs have failed to mitigate human impact (Geldmann et al., 2019; Jones et al., 2018; Mammides, 2020) and drivers of human pressure within PAs (Elleason et al., 2021; Guan et al., 2021).

Two global datasets that have been used extensively to assess human pressure on natural systems—and which are largely based on remote sensing techniques (Supporting Information: Appendix A)—are the human footprint (HFP) and the human modification (HM) indices (Kennedy et al., 2019; Venter et al., 2016). Both these indices map human pressure on a global level using 8 and 13 threats, respectively; these include built-up areas, road networks, agriculture, human population densities, and others (Supporting Information: Appendix A). The majority of the threats are based on data derived using remotely sensed imagery, although a few are derived from ground-based inventories, for example, the threats based on data retrieved from the OpenStreetMap platform (Kennedy et al., 2019; Venter et al., 2016). The threats are quantified and combined to provide a cumulative human pressure score ranging from 0 to 50 in the case of HFP and 0–1 in the case of HM. The higher the score, the greater the potential impact of humans on biodiversity. Studies have successfully linked HFP to biodiversity impacts (Watson & Venter, 2019), such as increased extinction risk (Di Marco et al., 2018) and reduced animal movements (Tucker et al., 2018).

In addition to the above two indices, researchers have been also evaluating the effectiveness of PAs using other broad-scale datasets largely built using remote sensing techniques, such as human settlements (Guan et al., 2021) and human population densities (Gillespie et al., 2019) as measured, for example, by LandScan Global (Rose et al., 2021). LandScan Global disaggregates subnational population censuses into 1 km^2 grids using a multivariable dasymetric modeling approach and high-resolution satellite imagery (Rose et al., 2021).

Although such data are undeniably crucial for evaluating human pressure on biodiversity, it should be recognized that they are, for the most part, limited to human threats and activities that can be observed remotely. Consequently, they often exclude other key threats, common in PAs and known to affect biodiversity, which can only be recorded through in situ field surveys. Examples of such threats include hunting (Benítez-López et al., 2019; Schulze et al., 2018), which can result in species extirpations (Sreekar et al., 2015), and invasive species (Hulme, 2018).

An underlying assumption is that higher human pressure, as documented and quantified remotely, represents a good proxy for these other threats that are best captured through field surveys. This is a reasonable assumption, especially considering that studies have already documented such relationships. For example, researchers have long shown that road expansion facilitates the spread of invasive species (Mortensen et al., 2009) and that higher human population densities within PAs correlate with higher species richness of invasive species (Spear et al., 2013). However, the extent to which this assumption is entirely valid has not been investigated in detail. Consequently, this remains a key knowledge gap, potentially biasing our policy decisions and conservation efforts.

In this study, we address this gap using a unique European Union (EU) dataset, which documents human threats in more than 27,000 PAs (known as Natura 2000 sites) through field surveys. The threats are reported by the EU Member States responsible for surveying their Natura 2000 sites using a standardized typology (Supporting Information: Appendix B) similar to that used in other international initiatives (Salafsky et al., 2008; Stolton et al., 2019). Threats are classified into multiple broad categories (Supporting Information: Appendix B), including categories that can also be captured remotely, such as agriculture and urbanization, and categories that are better recorded using field surveys, such as the use of biological resources and invasive species.

2 | INDICES OF HUMAN PRESSURE DEVELOPED LARGELY BASED ON REMOTE SENSING TECHNIQUES

We focused our analysis on three indices used often to assess human pressure on natural systems: (a) HFP (Williams et al., 2020), (b) HM (Kennedy et al., 2019), and (c) human population densities, as measured by LandScan Global (Rose et al., 2021). We first quantified the three indices within each Natura 2000 site and then compared them to the threats in each site reported in the EU's database. Since the spatial resolution of the three indices is

1 km^2, we only included in our analysis Natura 2000 sites that are ≥5 km^2 to avoid spatial discrepancies. We also excluded sites for which information has not been updated since 2012 to reduce temporal mismatches (Supporting Information: Appendix A). In total, we analyzed 8210 PAs situated in 25 EU Member States.

First, we assessed the relationships between the various threat categories using the Phi coefficient—a statistical test suitable for measuring pairwise relationships between dichotomous variables. Phi values can range from −1 to 1, indicating a strong negative and positive relationship; values close to zero suggest no relationship. Second, we evaluated whether a larger number of threats, as reported in the EU's database, is associated with higher HFP and HM values and higher human population densities. Third, we evaluated whether the presence of each threat category is reflected by higher values of the indices examined.

3 | RELATIONSHIPS BETWEEN THE THREAT CATEGORIES AND THE THREE INDICES

We found that agriculture-related threats were the most common, occurring in 65% of the Natura 2000 sites ($n = 5299$; Supporting Information: Appendix C). Conversely, mining-related threats were the least common, occurring in 21% of the sites ($n = 1723$). Phi coefficients ranged from 0.07 to 0.31, suggesting that most of the threats did not often co-occur with each other (Figure 1). Some threats, such as those associated with urbanization and transportation (recorded in 34% and 45% of sites, respectively), were expectedly more related than others. Still, even in those cases, relationships were, at best moderate (Figure 1). Other threats, such as those related to agriculture and forestry, were only weakly associated (0.14) despite being observed in most sites (65% and 51%, respectively).

The total number of threat categories recorded in each site was only weakly related to the three indices examined (Figure 2). Although Natura 2000 sites with no threats tended to have lower HFP and HM values and human densities, the rest of the sites had, on average, similar values regardless of the total number of threats recorded in the field (Figure 2). When each category was analyzed separately, our results indicated that the indices reflected mostly the threats associated with urbanization, agriculture, and pollution but not others (Figure 3). Natura 2000 sites in which these three threat categories were recorded tended to have, on average, higher HFP and HM values and human densities compared to sites in which those threats were absent (Figure 3). In addition, sites impacted by "human intrusions and disturbances" (e.g., those resulting from recreational activities;

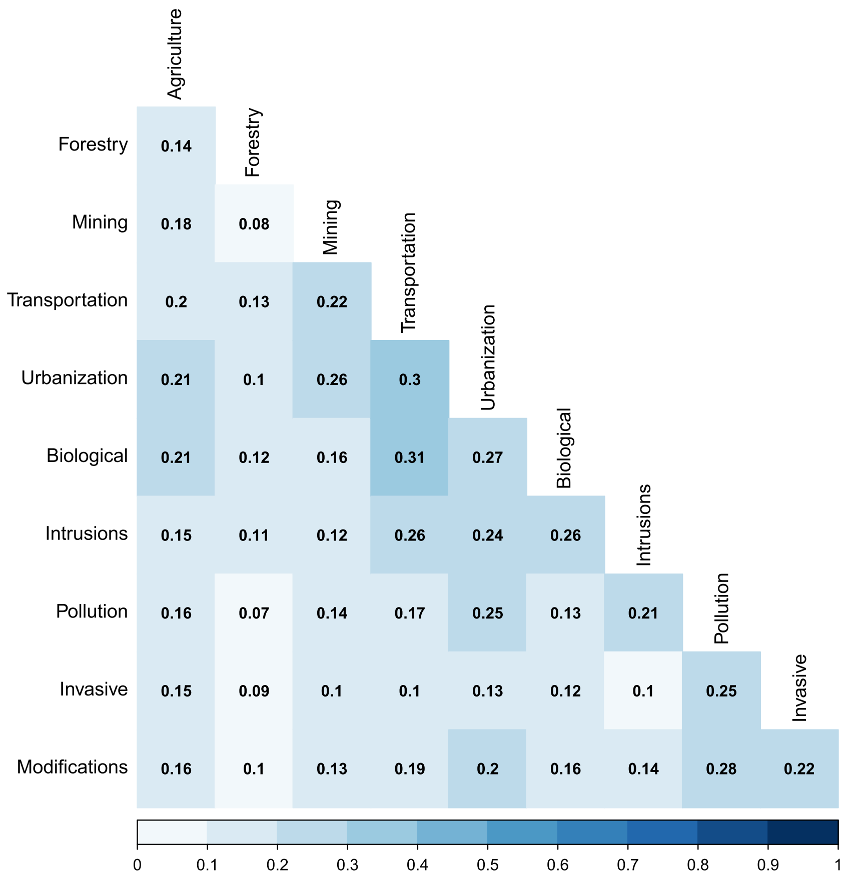

FIGURE 1 Phi coefficients between the threat categories reported in the EU's database showing that most threats are only weakly related

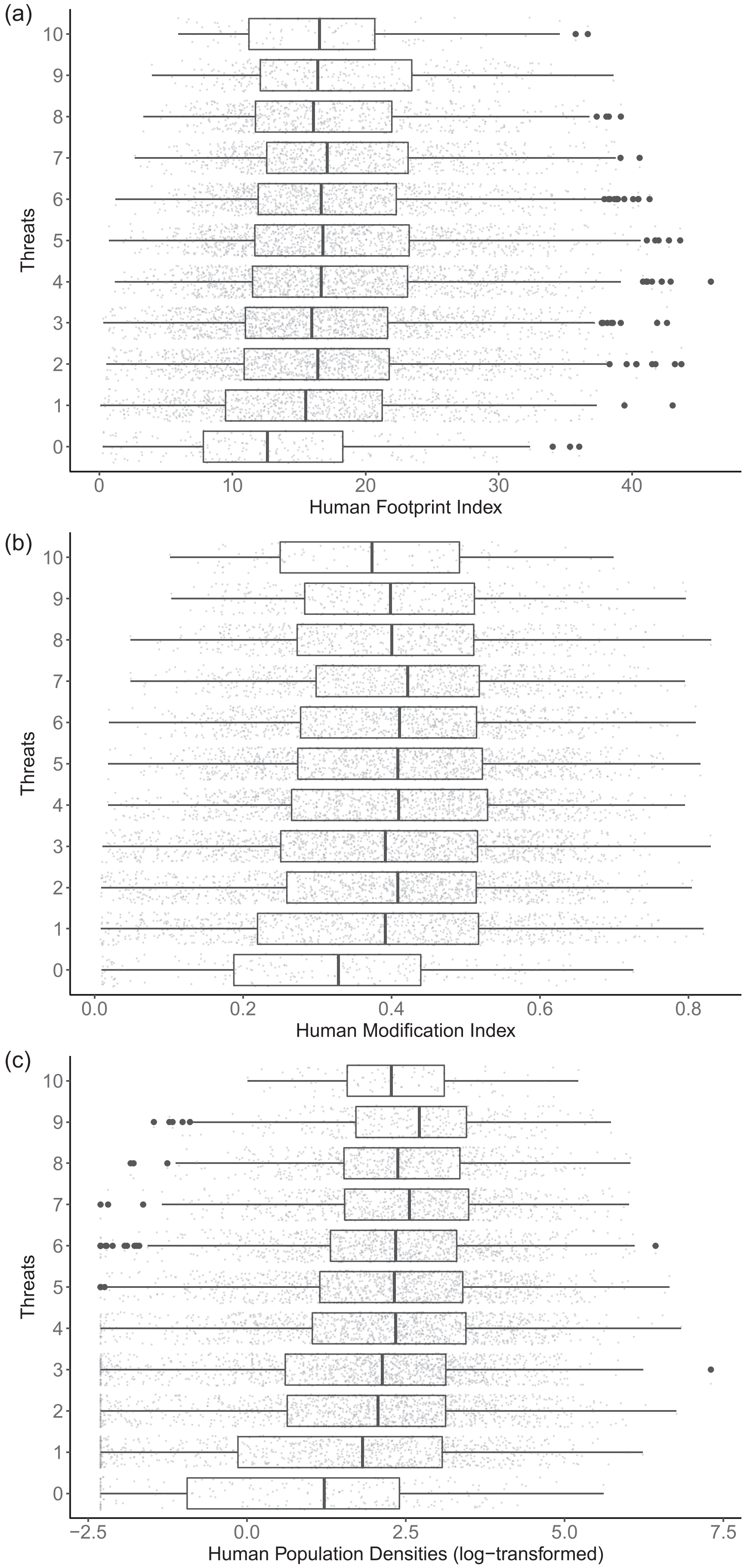

FIGURE 2 Relationships between the total number of threats recorded within each Natura 2000 site and the three indices examined: (a) human footprint, (b) human modification, (c) human population densities. Gray dots represent the individual sites.

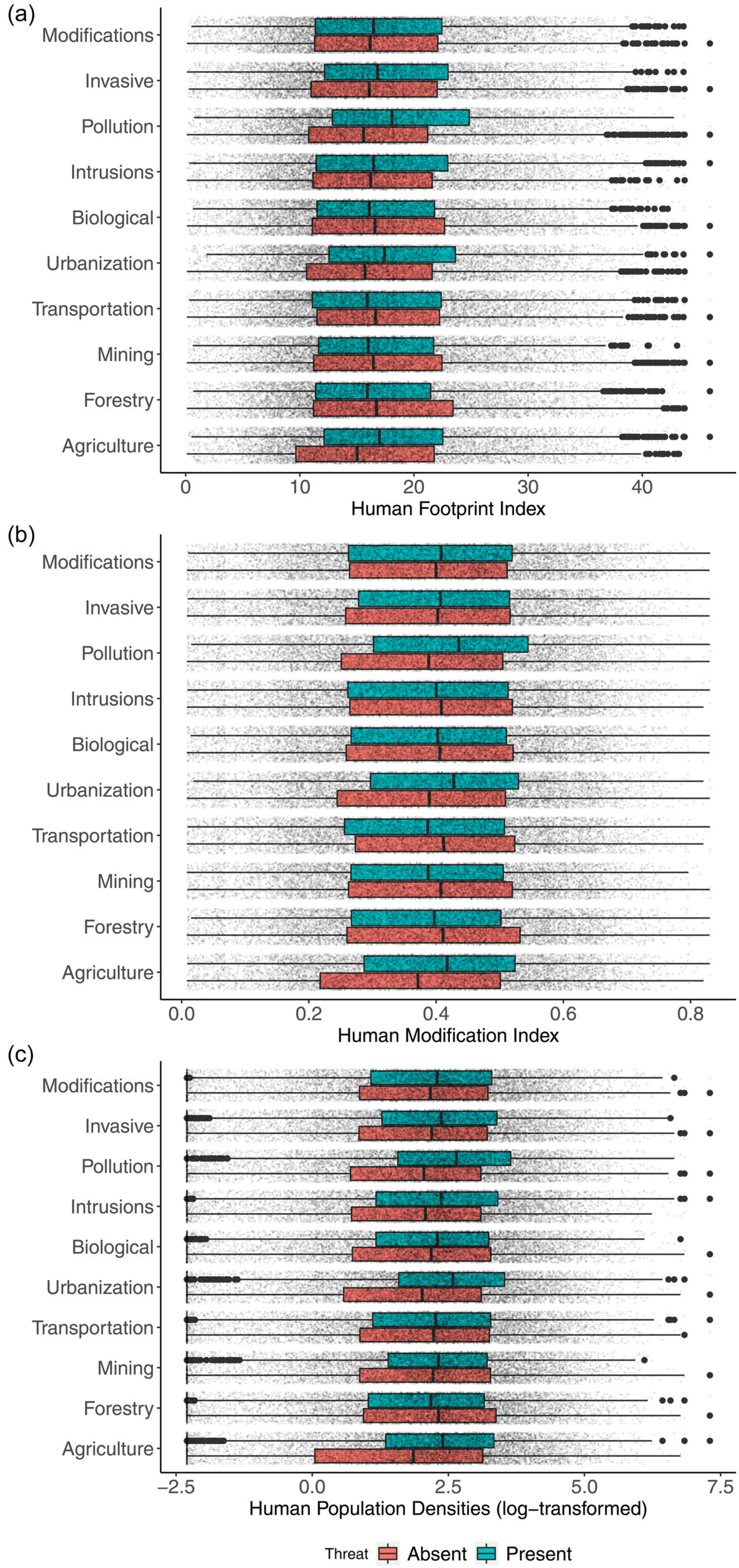

FIGURE 3 Relationships between the presence of each threat category in Natura 2000 sites and the three indices examined: (a) human footprint, (b) human modification, (c) human population densities, as opposed to sites in which the specific threat was absent. Grey dots represent the individual sites.

Supporting Information: Appendix B) tended to have higher human densities but not higher HFP or HM values (Figure 3). In the case of the other threat categories, such as those related to forestry and silvicultural activities, Natura 2000 sites tended to have lower and not higher HFP and HM values and human densities (Figure 3). This is not surprising since silvicultural activities are likely taking place in remote sites with larger forest expanses and lower human presence. Collectively, these findings suggest that remote assessments of human pressure on biodiversity may be missing important human activities and threats.

4 | ADVANTAGES AND DISADVANTAGES OF FIELD SURVEYS VERSUS REMOTE ASSESSMENTS

One could counterargue that remote assessments can be complemented with further information, potentially capturing additional threats, such as deforestation (Hansen et al., 2013). However, even in those cases, studies have shown that remotely sensed forest loss may miss smaller-scale logging, which could still significantly impact local biodiversity (Mammides, 2018; Peres et al., 2006). In general, it is not uncommon for various types of human threats to go undetected when using remote-sensing methods (Peres et al., 2006; Schulze et al., 2018). This could explain, for example, why numerous Natura 2000 sites in our dataset had relatively low HFP, HM values, and low human population densities but were still threatened by multiple types of human activities according to the field surveys (Figures 2 and 3).

Another important distinction between the two approaches is that field data tend to reflect actual biodiversity impacts, as confirmed by the experts during the surveys. For example, when it comes to agriculture-related threats, field experts can distinguish between agricultural activities that are harmful to local biodiversity versus those that are not. On the contrary, analyses based on remotely sensed information must assume that the observed agricultural category (e.g., irrigated croplands) is equally impactful across all sites. Moreover, experts in the field can record more subtle impacts that cannot be captured remotely, such as those related to the use of pesticides (Supporting Information: Appendix B). However, a major drawback of field surveys is that they are incredibly expensive and time-consuming (Rhodes et al., 2015). Moreover, they often involve multiple experts with varying expertise and experience, leading to interobserver biases and errors (Brown & Williams, 2016). Perhaps more importantly, field data are extremely difficult to update frequently. For example, in our analysis, we had to exclude hundreds of Natura 2000 sites for which information was outdated (>10 years old). Such constraints seriously limit the utility of field data for conservation purposes.

Consequently, data collected remotely will rightly remain crucial for evaluating human pressure on biodiversity. However, researchers and practitioners must be aware of their limitations, particularly concerning the fact that (a) they do not necessarily represent an actual impact on local biodiversity (since this needs to be assessed in conjunction with biodiversity observations on the ground) and (b) they often exclude key threats that cannot be observed remotely but can be equally detrimental to biodiversity (Schulze et al., 2018).

5 | CONCLUSIONS

With the above in mind, we argue that more research is needed to better understand the exact relationships between the various threats within PAs and the limitations of using mostly remote information to assess their effectiveness (Schulze et al., 2018). We focused our analysis on Natura 2000 sites for which data were available for thousands of PAs. However, the patterns we report may differ for other parts of the world with dissimilar socioeconomic conditions and in which PAs are managed differently. We hope that our preliminary findings will encourage researchers to explore these patterns further. We also hope that researchers and practitioners will recognize the need to complement information collected remotely with field surveys whenever feasible. This is particularly important for threats that are difficult to observe remotely and are unrelated to those that can be observed. Importantly, field efforts could be aided by advancing technologies, such as camera traps (Buxton et al., 2018) and acoustic sensors (Cretois et al., 2022). Moreover, international efforts such as the Protected Area Management Effectiveness Tracking Tool (MEET) could play an important role in encouraging and supporting field surveys (Stolton et al., 2019).

AUTHOR CONTRIBUTIONS

Christos Mammides: Conceptualization; data curation; formal analysis; investigation; methodology; visualization; writing – original draft; writing – review and editing. **Francesco Martini**: Investigation; visualization; writing – original draft; writing – review and editing. **Constantinos Kounnamas**: Investigation; writing – original draft; writing – review and editing.

ACKNOWLEDGMENTS

We are thankful to all the researchers and experts involved in the collection of the data used in the analysis. We also thank the editor and two reviewers for their thoughtful comments and constructive feedback. There are no funders to report for this submission.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available.

ETHICS STATEMENT

No ethics approval was required for the research reported in this article.

ORCID

Christos Mammides http://orcid.org/0000-0003-1747-175X
Francesco Martini http://orcid.org/0000-0003-0806-3930
Constantinos Kounnamas http://orcid.org/0000-0001-6797-2080

REFERENCES

Anderson, E. & Mammides, C. (2020) The role of protected areas in mitigating human impact in the world's last wilderness areas. *Ambio*, 49, 434–441. Available from: https://doi.org/10.1007/s13280-019-01213-x

Benítez-López, A., Santini, L., Schipper, A.M., Busana, M. & Huijbregts, M.A.J. (2019) Intact but empty forests? patterns of hunting-induced mammal defaunation in the tropics. *PLoS Biology*, 17, e3000247. Available from: https://dx.plos.org/10.1371/journal.pbio.3000247

Brown, E.D. & Williams, B.K. (2016) Ecological integrity assessment as a metric of biodiversity: are we measuring what we say we are? *Biodiversity and Conservation*, 25, 1011–1035.

Buxton, R.T., Lendrum, P.E., Crooks, K.R. & Wittemyer, G. (2018) Pairing camera traps and acoustic recorders to monitor the ecological impact of human disturbance. *Global Ecology and Conservation*, 16, e00493. Available from: https://www.sciencedirect.com/science/article/pii/S2351989418303573

Corlett, R.T. (2015) The anthropocene concept in ecology and conservation, *Trends in Ecology & Evolution*, 30, 36–41. Available from: https://www.cell.com/trends/ecology-evolution/abstract/S0169-5347(14)00226-2

Cretois, B., Rosten, C.M. & Sethi, S.S. (2022) Voice activity detection in eco-acoustic data enables privacy protection and is a proxy for human disturbance. *Methods in Ecology and Evolution*, 1–10. Available from: https://doi.org/10.1111/2041-210X.14005

Elleason, M., Guan, Z., Deng, Y., Jiang, A., Goodale, E. & Mammides, C. (2021) Strictly protected areas are not necessarily more effective than areas in which multiple human uses are permitted. *Ambio*, 50, 1058–1073. Available from: https://doi.org/10.1007/s13280-020-01426-5

Geldmann, J., Manica, A., Burgess, N.D., Coad, L. & Balmford, A. (2019) A global-level assessment of the effectiveness of protected areas at resisting anthropogenic pressures. *Proceedings of the National Academy of Sciences*, 116, 23209–23215. Available from: https://pnas.org/doi/full/10.1073/pnas.1908221116

Gillespie, T.W., Madson, A., Cusack, C.F. & Xue, Y. (2019) Changes in NDVI and human population in protected areas on the Tibetan plateau, *Arctic, Antarctic, and Alpine Research*, 51, 428–439. Available from: https://doi.org/10.1080/15230430.2019.1650541

Guan, Z., Elleason, M., Goodale, E. & Mammides, C. (2021) Global patterns and potential drivers of human settlements within protected areas. *Environmental Research Letters*, 16, 064085. Available from: https://iopscience.iop.org/article/10.1088/1748-9326/ac0567

Hansen, M.C., Potapov, P.V., Moore, R., Hancher, M., Turubanova, S.A., Tyukavina, A. et al. (2013) High-Resolution global maps of 21st-century forest cover change. *Science*, 342, 850–853. Available from: https://www.science.org/doi/10.1126/science.1244693

Hulme, P.E. (2018) Protected land: threat of invasive species. *Science*, 361, 561–562. Available from: https://www.science.org/doi/full/10.1126/science.aau3784

Jones, K.R., Venter, O., Fuller, R.A., Allan, J.R., Maxwell, S.L., Negret, P.J. et al. (2018) One-third of global protected land is under intense human pressure. *Science*, 360, 788–791. Available from: https://www.science.org/doi/10.1126/science.aap9565

Kennedy, C.M., Oakleaf, J.R., Theobald, D.M., Baruch-Mordo, S. & Kiesecker, J. (2019) Managing the middle: a shift in conservation priorities based on the global human modification gradient. *Global Change Biology*, 25, 811–826. Available from: https://onlinelibrary.wiley.com/doi/10.1111/gcb.14549

Luque, S., Pettorelli, N., Vihervaara, P. & Wegmann, M. (2018) Improving biodiversity monitoring using satellite remote sensing to provide solutions towards the 2020 conservation targets. *Methods in Ecology and Evolution*, 9, 1784–1786. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1111/2041-210X.13057

Mammides, C. (2018) Do satellite-derived data on forest loss correlate with indices of small-scale logging measured in the field? *African Journal of Ecology*, 56, 390–394. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1111/aje.12434

Mammides, C. (2020) A global analysis of the drivers of human pressure within protected areas at The National level. *Sustainability Science*, 15, 1223–1232. Available from: https://doi.org/10.1007/s11625-020-00809-7

Di Marco, M., Venter, O., Possingham, H.P. & Watson, J.E.M. (2018) Changes in human footprint drive changes in species extinction risk. *Nature Communications*, 9, 4621. Available from: http://www.nature.com/articles/s41467-018-07049-5

Mortensen, D.A., Rauschert, E.S.J., Nord, A.N. & Jones, B.P. (2009) Forest roads facilitate the spread of invasive plants, *Invasive Plant Science and Management*, 2, 191–199.

Peres, C.A., Barlow, J. & Laurance, W.F. (2006) Detecting anthropogenic disturbance in tropical forests. *Trends in Ecology & Evolution*, 21, 227–229. Available from: https://www.sciencedirect.com/science/article/pii/S0169534706000942

Petrou, Z.I., Manakos, I. & Stathaki, T. (2015) Remote sensing for biodiversity monitoring: a review of methods for biodiversity indicator extraction and assessment of progress towards international targets. *Biodiversity and Conservation*, 24, 2333–2363. Available from: https://doi.org/10.1007/s10531-015-0947-z

Pricope, N., Mapes, K. & Woodward, K. (2019) Remote sensing of human–environment interactions in global change research: a review of advances. *Remote Sensing*, 11, 2783. https://www.mdpi.com/2072-4292/11/23/2783

Radočaj, D., Obhođaš, J., Jurišić, M. & Gašparović, M. (2020) Global open data remote sensing satellite missions for land monitoring and conservation: a review. *Land*, 9, 402.

Rhodes, C.J., Henrys, P., Siriwardena, G.M., Whittingham, M.J. & Norton, L.R. (2015) The relative value of field survey and remote sensing for biodiversity assessment. *Methods in Ecology and Evolution*, 6, 772–781.

Rose, A., McKee, J., Sims, K., Bright, E., Reith, A. & Urban, M. (2021) *LandScan Global 2020*. Oak Ridge, TN: Oak Ridge National Laboratory.

Salafsky, N., Salzer, D., Stattersfield, A.J., Hilton-Taylor, C., Neugarten, R., Butchart, S.H.M. et al. (2008) A standard lexicon for biodiversity conservation: unified classifications of threats and actions. *Conservation Biology*, 22, 897–911.

Schulze, K., Knights, K., Coad, L., Geldmann, J., Leverington, F., Eassom, A. et al. (2018) An assessment of threats to terrestrial protected areas. *Conservation Letters*, 11, e12435. Available from: https://onlinelibrary.wiley.com/doi/10.1111/conl.12435

Spear, D., Foxcroft, L.C., Bezuidenhout, H. & McGeoch, M.A. (2013) Human population density explains alien species

richness in protected areas. *Biological Conservation*, 159, 137–147. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0006320712004909
Sreekar, R., Huang, G., Zhao, J.B., Pasion, B.O., Yasuda, M., Zhang, K. et al. (2015) The use of species–area relationships to partition the effects of hunting and deforestation on bird extirpations in a fragmented landscape. *Diversity and Distributions*, 21, 441–450. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1111/ddi.12292
Stolton, S., Dudley, N., Belokurov, A., Deguignet, M., Burgess, N.D., Hockings, M. et al. (2019) Lessons learned from 18 years of implementing the management effectiveness tracking tool (METT): a perspective from the METT developers and implementers. *Parks*, 25, 79–92.
Tollefson, J. (2019) Humans are driving one million species to extinction. *Nature*, 569, 171.
Tucker, M.A., Böhning-Gaese, K., Fagan, W.F., Fryxell, J.M., Van Moorter, B., Alberts, S.C. et al. (2018) Moving in the anthropocene: global reductions in terrestrial mammalian movements. *Science*, 359, 466–469. Available from: https://www.science.org/doi/10.1126/science.aam9712
UNEP-WCMC, IUCN. (2021) *Protected Planet Report 2020*. Cambridge UK; Gland, Switzerland: UNEP-WCMC and IUCN.
Venter, O., Sanderson, E.W., Magrach, A., Allan, J.R., Beher, J., Jones, K.R. et al. (2016) Global terrestrial human footprint maps for 1993 and 2009. *Scientific Data*, 3, 160067. Available from: http://www.nature.com/articles/sdata201667
Watson, J.E.M. & Venter, O. (2019) Mapping the continuum of humanity's footprint on land. *One Earth*, 1, 175–180. Available from: https://linkinghub.elsevier.com/retrieve/pii/S2590332219300715
Williams, B.A., Venter, O., Allan, J.R., Atkinson, S.C., Rehbein, J.A., Ward, M. et al. (2020) Change in terrestrial human footprint drives continued loss of intact ecosystems. *One Earth*, 3, 371–382. Available from: https://linkinghub.elsevier.com/retrieve/pii/S2590332220304188
Ye, S., Rogan, J., Zhu, Z. & Eastman, J.R. (2021) A near-real-time approach for monitoring forest disturbance using landsat time series: stochastic continuous change detection. *Remote Sensing of Environment*, 252, 112167.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Mammides, C., Martini, F. & Kounnamas, C. (2022) Remote assessments of human pressure on biodiversity may miss important human threats. *Integrative Conservation*, 1, 52–59. https://doi.org/10.1002/inc3.11