Guidelines and Tools for Monitoring Biodiversity

A Selection of Manuals, Guidance and Methods Reviews

Version 1.1. August 2025.

Suggested citation: IUCN SSC Species Monitoring Specialist Group, 2025. *Guidelines and Tools for Monitoring Biodiversity: A Selection of Manuals, Guidance and Methods Reviews. Version 1.1.* IUCN SSC Species Monitoring Specialist Group. Available online at: https://www.speciesmonitoring.org/guidelines-and-tools.html

Aim of this Document

The IUCN Species Survival Commission Species Monitoring Specialist Group aims to enhance biodiversity conservation by improving the availability and use of data on species populations, their habitats and threats. One of our objective sis to provide guidelines and tools for practitioners.

This document provides a bibliography of key materials of use to anyone setting up and implementing a biodiversity monitoring programme, from conservation project managers to businesses measuring their sustainability. The focus is on practical guidelines and tools around the main methods used for monitoring, and scientific reviews focused on material that provides additional case studies of the tools in use and helps understand their applications and uses, advantages and limitations. Key overviews, that may be good starting points for each topic, are highlighted in bold throughout.

Further guidelines and tools will be made available on the specialist group's website by the end of 2025.

Contents

1. Biodiversity Monitoring Design 1
2. Observer-based Monitoring - Guidelines, Manuals, Protocols and Key Papers 2
3. Monitoring Guidelines and Manuals for Different Taxa (with a focus on observer-based methods) . 3
4. Satellite-based Remote Sensing - Guidelines, Manuals, Protocols and Key Papers 7
5. Cameras (from camera traps to digital aerial surveys to underwater videos) - Guidelines, Manuals, Protocols and Key Papers 8
6. Acoustic Monitoring - Guidelines, Manuals, Protocols and Key Papers 11
7. Environmental DNA - Guidelines, Manuals, Protocols and Key Papers 13
8. Comparing Monitoring Tools 16

1. Biodiversity Monitoring Design

Guidelines and tools to help design a monitoring programme. Key overviews highlighted in bold.

Addison, P.F., Stephenson, P.J., Bull, J.W., Carbone, G., Burgman, M., Burgass, M.J., Gerber, L.R., Howard, P., McCormick, N., McRae, L. and Reuter, K.E., 2020. Bringing sustainability to life: A framework to guide biodiversity indicator development for business performance management. *Business Strategy and the Environment*, 29(8), pp.3303-3313.

Bailey, L.L., MacKenzie, D.I. and Nichols, J.D., 2014. Advances and applications of occupancy models. *Methods in Ecology and Evolution,* 5(12), pp.1269-1279.

Biodiversity Indicators Partnership, 2024. *What makes a successful indicator?* Website available at: https://www.bipindicators.net/national-indicator-development

Biodiversity Information Standards (TDWG), 2020. Standards. Website at https://www.tdwg.org/standards/

Brown, C., Reyers, B., Ingwall-King, L., Mapendembe, A., Nel, J., O'Farrell, P. et al., 2014. *Measuring Ecosystem Services: Guidance on developing ecosystem service indicators*. United Nations Environment Programme World Conservation Monitoring Centre, Cambridge, UK.

Buckingham, K., Ray, S., Granizo, C.G., Toh, L., Stolle, F., Zoveda, F., Reytar, K., Cristales, R.Z., Ndunda, P., Landsberg, F., and Matsumoto, M., 2019. *The Road to Restoration: A Guide to Identifying Priorities and Indicators for Monitoring Forest and Landscape Restoration*. FAO and WRI, Rome and London.

Buckland, S.T., , Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L. and Thomas, L., 2001. *Introduction to Distance Sampling: Estimating Abundance of Biological Populations.* Oxford University Press.

Buckland, S.T., Rexstad, E.A., Marques, T.A., and Oedekoven, C.S., 2015. *Distance Sampling: Methods and Applications.* Springer, New York, USA.

Burgess, N.D., Ali, N., Bedford, J., Bhola, N., Brooks, S., Cierna, A., Correa, R., Harris, M., Hargey, A., Hughes, J., McDermott-Long, O., et al., 2024. Global metrics for terrestrial biodiversity. *Annual Review of Environment and Resources*, *49*(1), pp.673-709.

CBD, 2022. *Decision adopted by the Conference of the Parties to the Convention on Biological Diversity at its fifteenth meeting, Part II. Kunming-Montreal Global Biodiversity Framework.* CBD/COP/DEC/15/4 19 December 2022. CBD, Montreal, Canada. https://www.cbd.int/doc/decisions/cop-15/cop-15-dec-04-en.pdf

CMP - Conservation Measures Partnership, 2025. *Open Standards for the Practice of Conservation. Version 5.* Bethesda, USA: CMP. Available at: https://www.conservationstandards.org/wp-content/uploads/2025/05/CMP-Open-Standards-Report-v5.0-FINAL-English.pdf

Danielsen, F., Jensen, P.M., Burgess, N.D., Altamirano, R., Alviola, P.A., Andrianandrasana, H., Brashares, J.S., Burton, A.C., Coronado, I., Corpuz, N., Enghoff, M. et al., 2014. A multicountry assessment of tropical resource monitoring by local communities. *BioScience*, *64*(3), pp.236-251.

del Pozo, M.S., Body, G., Rerig, G. and Basille, M., 2023. *Guide on Harmonising Biodiversity Monitoring Protocols Across Scales*. Biodiversa+ report. 60 pp. Available at https://hal.science/hal-04300324/document

Doser, J.W., Finley, A.O., Kéry, M. and Zipkin, E.F., 2022. spOccupancy: An R package for single-species, multi-species, and integrated spatial occupancy models. *Methods in Ecology and Evolution,* 13(8), pp.1670-1678.

FAO and WRI, 2024. *AURORA: Assessment, Understanding and Reporting Of Restoration Actions*. Website at: https://www.auroramonitoring.org/#/

GBIF – Global Biodiversity Information Facility, 2024. *Data standards.* Website at https://www.gbif.org/standards

Greenwood, J.J.D and Robinson, R.A., 2006. Principles of sampling. *Ecological Census Techniques, second edition*, pp. 11-86. Cambridge University Press.

Hector, A., 2021. *The New Statistics with R: An Introduction for Biologists*. Oxford University Press.

IBAT, 2021. *Species Threat Abatement and Restoration (STAR) data layer. Business User Guidance.* IBAT Alliance. https://www.ibat-alliance.org/pdf/star_business_user_guidance.pdf

IFC – International Finance Corporation, 2012. *Performance Standard 6: Biodiversity Conservation and Sustainable Management of Living Natural Resources*. IFC, Washington DC, USA.

Izquierdo-Tort, S., Alatorre, A., Arroyo-Gerala, P., Shapiro-Garza, E., Naime, J. and Dupras, J., 2024. Exploring local perceptions and drivers of engagement in biodiversity monitoring among participants in payments for ecosystem services schemes in southeastern Mexico. *Conservation Biology*, p.e14282.

Jones, J.P., Asner, G.P., Butchart, S.H. and Karanth, K.U., 2013. The 'why', 'what' and 'how' of monitoring for conservation. *Key Topics in Conservation Biology 2*, pp.329-343. J. Wiley & Sons.

Likens, G. and Lindenmayer, D., 2018. *Effective Ecological Monitoring*. CSIRO publishing, Clayton South, Australia.

Lindenmayer, D.B. and Likens, G.E., 2009. Adaptive monitoring. *Trends in Ecology and Evolution,* 24(9), pp.482-486.

Lohr, S.L., 2021. *Sampling: Design and Analysis*. Chapman and Hall/CRC.

MacKenzie, D.I. and Reardon, J.T., 2013. Occupancy methods for conservation management. *Biodiversity monitoring and conservation: Bridging the gap between global commitment and local action* (eds. B. Collen, N. Pettorelli, J.E.M. Baillie & S.M. Durant), pp.248-264. John Wiley & Sons.

MacKenzie, D.I., Nichols, J.D., Royle, J.A., Pollock, K.H., Bailey, L. and Hines, J.E., 2017. *Occupancy Estimation and Modeling: Inferring Patterns and Dynamics of Species Occurrence*. Elsevier, London, UK.

Mansourian, S. and Stephenson, P.J., 2023. Exploring challenges and lessons for monitoring forest landscape restoration. *Current Landscape Ecology Reports,* 8(4), pp.159-170.

Natural Capital Coalition, 2016. *Natural Capital Protocol*. NCC, London, UK. www.naturalcapitalcoalition.org/protocol

Reynolds, J.H., 2012. An overview of statistical considerations in long-term monitoring. *Design and Analysis of Long-term Ecological Monitoring Studies* (eds. R.A. Gitzen, J.J. Millspaugh, A.B. Cooper, D.S. Licht), pp-23-53. Cambridge University Press.

Schleicher, J., Eklund, J., D. Barnes, M., Geldmann, J., Oldekop, J.A. and Jones, J.P., 2020. Statistical matching for conservation science. *Conservation Biology*, *34*(3), pp.538-549.

Stephenson, P.J., 2019. The Holy Grail of biodiversity conservation management: monitoring impact in projects and project portfolios. *Perspectives in Ecology and Conservation,* 17(4), pp.182-192.

Stephenson, P.J. and Carbone, G., 2021. *Guidelines for Planning and Monitoring Corporate Biodiversity Performance.* IUCN, Gland, Switzerland. Available at https://portals.iucn.org/library/node/49301

TEAM Network. 2011. *Terrestrial Vertebrate Protocol Implementation Manual, v. 3.1.* Tropical Ecology, Assessment and Monitoring Network, Center for Applied Biodiversity Science, Conservation International, Arlington, VA, USA.

Thilan, A.P., Peterson, E., Menéndez, P., Caley, J., Drovandi, C., Mellin, C. and McGree, J., 2024. Bayesian design methods for improving the effectiveness of ecosystem monitoring. *Environmental and Ecological Statistics*, pp.1-27. https://doi.org/10.1007/s10651-024-00623-9

TNFD, 2023. Recommendations of the Taskforce on Nature-related Financial Disclosures. https://tnfd.global/publication/recommendations-of-the-taskforce-on-nature-related-financial-disclosures/#publication-content

Tucker, G., Fasham, M., Hill., D., Shewry, M., Shaw, P. and Wade, M., 2005. Planning a programme. *Handbook of Biodiversity Methods: Survey Evaluation and Monitoring*, pp. 6-64. Cambridge University Press.

UNDP - United Nations Development Programme, 2009. *Handbook on Planning, Monitoring and Evaluating for Development Results.* UNDP, New York, USA.

USAID - United States Agency for International Development, 2016. *Defining Outcomes and Indicators for Monitoring, Evaluation, and Learning in USAID Biodiversity Programming.* USAID, Washington DC, USA.

Wauchope, H.S., Amano, T., Geldmann, J., Johnston, A., Simmons, B.I., Sutherland, W.J. and Jones, J.P., 2021. Evaluating impact using time-series data. *Trends in Ecology & Evolution*, *36*(3), pp.196-205.

Welsh, A.H., Lindenmayer, D.B. and Donnelly, C.F., 2013. Fitting and interpreting occupancy models. *PloS One*, 8(1), p.e52015.

World Bank (2004). *Ten Steps to a Results-Based Monitoring and Evaluation System: A Handbook For Development Practitioners*. (Kusek, J.Z. & Rist, R.C.). World Bank, .Washington DC, USA.

Yoccoz, N.G., Nichols, J.D. and Boulinier, T., 2001. Monitoring of biological diversity in space and time. *Trends in Ecology & Evolution*, 16(8), pp.446-453.

2. Observer-based Monitoring - Guidelines, Manuals, Protocols and Key Papers

The references listed here cover a range of methods and taxa and ecosystems. Taxa-specific guidelines are presented in section 3. Key overviews highlighted in bold.

Borges, P.A.V., Cardoso, P., Kreft, H., Whittaker, R.J., Fattorini, S., Emerson, B.C., Gil, A., Gillespie, R.G., Matthews, T.J., Santos, A.M.C. et al., 2018. Global Island Monitoring Scheme (GIMS): a proposal for the long-term coordinated survey and monitoring of native island forest biota. *Biodiversity and Conservation,* 27(10), pp.2567-2586.

Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L. and Thomas, L. eds., 2004. *Advanced Distance Sampling: Estimating Abundance of Biological Populations.* Oxford University Press: Oxford, UK.

Buckland, S.T., Rexstad, E.A., Marques, T.A., and Oedekoven, C.S., 2015. *Distance Sampling: Methods and Applications.* Springer, New York, USA.

Costello, M.J., Basher, Z., McLeod, L., Asaad, I., Claus, S., Vandepitte, L., Yasuhara, M., Gislason, H., Edwards, M., Appeltans, W., Enevoldsen, H., et al., 2017. Methods for the study of marine biodiversity. Pp.129-163 in

Walters, M. & Scholes, R.J. (eds.), *The GEO Handbook on Biodiversity Observation Networks.* Springer, Cham, Switzerland.

Cronin, D.T., Dancer, A., Long, B., Lynam, A.J., Muntifering, J., Palmer, J., Bergl, R.A., Wich, S.A. and Piel, A.K., 2021. Application of SMART software for conservation area management. Conservation Technology, pp.203-223.

Gitzen, R.A., Millspaugh, J.J., Cooper, A.B. and Licht, D.S. eds., 2012. *Design and Analysis of Long-Term Ecological Monitoring Studies*. Cambridge University Press, Cambridge, UK.

Hammond, P.S., Francis, T.B., Heinemann, D., Long, K.J., Moore, J.E., Punt, A.E., Reeves, R.R., Sepúlveda, M., Sigurðsson, G.M., Siple, M.C. and Víkingsson, G., 2021. Estimating the abundance of marine mammal populations. *Frontiers in Marine Science*, *8*, p.735770.

Hedges, S., Maisels, F., and Blake, S., 2012. Estimating absolute densities of elephant populations using dung counts along line transects: Field methods. In S. Hedges (Ed.*), Monitoring elephants and assessing threats: A manual for researchers, managers and conservationists.* (pp. 172–213). Universities Press.

HELCOM, 2015. *Recommendations and Guidelines for Benthic Habitat Monitoring with Method Descriptions for Two Methods for Monitoring of Biotope and Habitat Extent.* Baltic Sea Pilot Project (BALSAM). HELCOM, Helsinki, Finland. https://helcom.fi/wp-content/uploads/2019/08/Recommendations-and-guidelines-for-benthic-habitat-monitoring-in-the-Baltic-Sea.pdf

Hill, D., Fasham, M., Tucker, G., Shewry, M. and Shaw, P., (eds.) 2005. *Handbook of Biodiversity Methods: Survey, Evaluation and Monitoring.* Cambridge University Press, Cambridge, UK.

Henderson, P.A. and Southwood, T.R.E., 2016. *Ecological Methods*. Fourth Edition. John Wiley & Sons, London, UK.

Karanth, K.U., Gopalaswamy, A.M., Kumar, N.S., Vaidyanathan, S., Nichols, J.D. and MacKenzie, D.I., 2011. Monitoring carnivore populations at the landscape scale: occupancy modelling of tigers from sign surveys. *Journal of Applied Ecology,* 48(4), pp.1048-1056.

Likens, G. and Lindenmayer, D., 2018. *Effective Ecological Monitoring*. CSIRO publishing, Clayton South, Australia.

Minte-Vera, C.V., De Moura, R.L. and Francini-Filho, R.B., 2008. Nested sampling: an improved visual-census technique for studying reef fish assemblages. *Marine Ecology Progress Series*, *367*, pp.283-293.

Mulvaney, J.M. and Cherry, M.I., 2020. The effectiveness of point counts and mist-netting in surveying Afrotemperate forest bird community structure in South Africa. *Emu-Austral Ornithology*, *120*(2), pp.103-113.

Peh, K.S.-H., Balmford, A.P., Bradbury, R.B., Brown, C., Butchart, S.H.M., Hughes, F.M.R., MacDonald, M.A, Stattersfield, A.J., Thomas, D.H.L., Trevelyan, R.J., Walpole, M., and Merriman, J.C., 2017. Toolkit for Ecosystem Service Site-based Assessment (TESSA). Version 2.0. Cambridge, UK. https://birdlife-hatch.org/topics/30877/page/assessing-ecosystem-services-tessa

Robinson, W.D. and Curtis, J.R., 2020. Creating benchmark measurements of tropical forest bird communities in large plots. *The Condor*, *122*(3), p.duaa015.

SMART Partnership, 2024. *SMART*. Website at https://smartconservationtools.org

Stephenson, P.J. 2021. *A Review of Biodiversity Data Needs and Monitoring Protocols for the Offshore Wind Energy Sector in the Baltic Sea and North Sea*. Renewables Grid Initiative, Berlin, Germany. https://renewables-grid.eu/publications/study-offshore-biodiversity.html

Sutherland W.J., (ed.), 2006. *Ecological Census Techniques. Second Edition.* Cambridge University Press, Cambridge, UK.

Thomas, L., Buckland, S.T., Rexstad, E.A., Laake, J.L., Strindberg, S., Hedley, S.L., Bishop, J.R., Marques, T.A. and Burnham, K.P., 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. *Journal of Applied Ecology*, *47*(1), pp.5-14.

Walters, M. and Scholes, R.J. (eds.), 2017. *The GEO Handbook on Biodiversity Observation Networks*. Springer Nature, Cham, Switzerland.

3. Monitoring Guidelines and Manuals for Different Taxa (with a focus on observer-based methods)

Key overviews highlighted in bold.

Amphibians and Reptiles

Blomberg, S. & Shine, R. 2006. Reptiles. Pp 297-307 in Sutherland W.J. (ed.), *Ecological Census Techniques. 2nd Edition.* Cambridge University Press, Cambridge, UK.

Casper, G. S., Beever, E., Gafvert, U. & Nadeau, S.M. 2018. Amphibian monitoring protocol (version 2.0): Great Lakes Inventory and Monitoring Network. Natural Resource Report NPS/GLKN/NRR—2018/1761. National Park Service, Fort Collins, Colorado, USA. https://irma.nps.gov/DataStore/DownloadFile/616753

Graeter, G.J., Buhlmann, K.A., Wilkinson, L.R. & Whitfield Gibbons, J. (eds.) 2013. *Inventory and Monitoring: Recommended Techniques for Reptiles and Amphibians: with Application to the United States and Canada*. Partners in Amphibian and Reptile Conservation.

Halliday, T.R. 2006. Amphibians. Pp 278-296 in Sutherland W.J. (ed.), *Ecological Census Techniques. 2nd Edition.* Cambridge University Press, Cambridge, UK.

Heyer, W.R., Donnelly, M.A., McDiarmid, R, Hayek, L.-A.C., Foster, M.S. (eds.) 1994. *Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians.* Smithsonian, Washington, USA.

Latham, D., Jones, E. & Fasham, M. 2005. Amphibians. Pp. 387-403 in Hill, D., Fasham, M., Tucker, G., Shewry, M. & Shaw, P. (eds.), *Handbook of Biodiversity Methods: Survey, Evaluation and Monitoring.* Cambridge University Press, Cambridge, UK.

Latham, D., Jones, E. & Fasham, M. 2005. Reptiles. Pp. 404-411 in Hill, D., Fasham, M., Tucker, G., Shewry, M. & Shaw, P. (eds.), *Handbook of Biodiversity Methods: Survey, Evaluation and Monitoring.* Cambridge University Press, Cambridge, UK.

McDiarmid, R.W., Foster, M.S., Guyer, C., Whitfield Gibbons, J. & Chernoff, N. (eds.) 2012. *Reptile Biodiversity. Standard Methods for Inventory and Monitoring*. University of California Press, Berkeley, USA.

Richardson, E., Nimmo, D.G., Avitabile, S., Tworkowski, L., Watson, S.J., Welbourne, D. & Leonard, S.W. 2018. Camera traps and pitfalls: an evaluation of two methods for surveying reptiles in a semiarid ecosystem. *Wildlife Research*, *44*(8): 637-647.

Wilkinson, J.W. 2015. *Amphibian Survey and Monitoring Handbook.* Pelagic Publishing Ltd, Exeter, UK.

Birds

Bibby C.J., Burgess N.D., Hillis, D.M., Hill, D.A. & Mustoe, S. 2000. *Bird Census Techniques. Second Edition.* Academic Press, London, UK.

BirdLife International 2006. *Monitoring Important Bird Areas: a global framework. Version 1.2.* Cambridge: BirdLife International.

Ortega-Álvarez, R., Sánchez-González, L.A., Rodríguez-Contreras, V., Vargas-Canales, V.M., Puebla-Olivares, F. and Berlanga, H., 2012. Birding for and with people: Integrating local participation in avian monitoring programs within high biodiversity areas in southern Mexico. *Sustainability*, 4(9), pp.1984-1998.

Gilbert, G., Gibbons, D. W. & Evans, J. 1998. *Bird Monitoring Methods*. RSPB, Sandy, UK.

Groom, G., Stjernholm, M., Nielsen, R.D. et al. 2013. Remote sensing image data and automated analysis to describe marine bird distributions and abundances. *Ecological Informatics,* 14: 2–8.

Hardey, J., Crick, H., Wernham, C., Riley, H., Etheridge, B., & Thompson, D. 2013. *Raptors: A Field Guide for Surveys and Monitoring. Third Edition.* Scottish Natural Heritage, Inverness, Scotland.

Komdeur, J., J. Bertelsen & G. Cracknell (eds.) 1992. *Manual for Aeroplane and Ship Surveys of Waterfowl and Seabirds.* IWRB Special Publication No.19. IWRB, Slimbridge, U.K.

Lewis, M. & Dunn, T.E. 2020. *Volunteer Seabirds at Sea Survey Methods. JNCC Report No. 63.* JNCC, Peterborough, UK

Mustoe, S., Hill, D, Frost, D. & Tucker, G., 2005. Birds. Pp 412-432 in D. Hill, M. Fasham, G. Tucker, M. Shewry and P. Shaw (eds.), *Handbook of Biodiversity Methods: Survey, Evaluation and Monitoring.* Cambridge University Press, Cambridge, UK.

Tasker, M. L., Jones, P. H., Dixon, T. I. M., & Blake, B. F. 1984. Counting seabirds at sea from ships: a review of methods employed and a suggestion for a standardized approach. *The Auk,* 101(3): 567-577.

Voříšek, P. Klvaňová, A., Wotton, S. & Gregory, R.D. 2008. *A Best Practice Guide for Wild Bird Monitoring Schemes. First edition.* CSO/RSPB, Prague, Czech Republic.

Walsh, P. M., Halley, D. J., Harris, M.P. et al. 1995. *Seabird Monitoring Handbook for Britain and Ireland.* JNCC/RSPB/ITE/Seabird Group, Peterborough, UK.

Wetlands International 2010. *Diversity and Abundance of Bird Species: Field Protocol for Waterbird Counting.* Wetlands International, The Hague, The Netherlands.

Invertebrates

Ausden, M., & Drake, M. 2006. Invertebrates. Pp 214-249 in Sutherland W.J. (ed.), *Ecological Census Techniques. 2nd Edition.* Cambridge University Press, Cambridge, UK.

Cardoso, P. 2009. Standardization and optimization of arthropod inventories – the case of Iberian spiders. *Biodiversity and Conservation,* 18: 3949-3962.

Kerrison, P., Norman, T. & Fasham, M. 2005. Aquatic invertebrates. Pp. 359-367 in Hill, D., Fasham, M., Tucker, G., Shewry, M. & Shaw, P. (eds.), *Handbook of Biodiversity Methods: Survey, Evaluation and Monitoring.* Cambridge University Press, Cambridge, UK.

New, T.R. 1998. *Invertebrate surveys for conservation.* Oxford University Press, Oxford, UK.

O'Connor, R.S., Kunin, W.E., Garratt, M.P., Potts, S.G., Roy, H.E., Andrews, C., Jones, C.M., Peyton, J.M., Savage, J., Harvey, M.C. & Morris, R.K., 2019. Monitoring insect pollinators and flower visitation: The effectiveness and feasibility of different survey methods. *Methods in Ecology and Evolution,* 10(12): 2129-2140.

Otero, M., Cebrian, E., Francour, P., Galil, B. & Savini, D. 2013. *Monitoring Marine Invasive Species in Mediterranean Marine Protected Areas (MPAs): A strategy and practical guide for managers.* IUCN, Malaga, Spain.

Peters, K., Sink, K.J., & Robinson, T.B. 2019. Sampling methods and approaches to inform standardized detection of marine alien fouling species on recreational vessels. *Journal of Environmental Management*, 230: 159-167.

Plant, C., Sands, R. & Fasham, M. 2005. Butterflies. Pp. 328-334 in Hill, D., Fasham, M., Tucker, G., Shewry, M. & Shaw, P. (eds.), *Handbook of Biodiversity Methods: Survey, Evaluation and Monitoring.* Cambridge University Press, Cambridge, UK.

Plant, C., Sands, R. & Fasham, M. 2005. Dragonflies and damselflies. Pp. 322-327 in Hill, D., Fasham, M., Tucker, G., Shewry, M. & Shaw, P. (eds.), *Handbook of Biodiversity Methods: Survey, Evaluation and Monitoring.* Cambridge University Press, Cambridge, UK.

Plant, C., Sands, R. & Fasham, M. 2005. Moths. Pp. 335-340 in Hill, D., Fasham, M., Tucker, G., Shewry, M. & Shaw, P. (eds.), *Handbook of Biodiversity Methods: Survey, Evaluation and Monitoring.* Cambridge University Press, Cambridge, UK.

Reef Life Survey, 2019. *Standardised Survey Procedures for Monitoring Rocky & Coral Reef Ecological Communities.* Reef Life Survey, Hobart, Australia.

Van Swaay, C., Regan, E., Ling, M., Bozhinovska, E., Fernandez, M., Marini-Filho, O.J., Huertas, B., Phon, C.K., Korösi, A., Meerman, J. & Pe'er, G. 2015. *Guidelines for Standardised Global Butterfly Monitoring.* GEO BON Technical Series 1. Group on Earth Observations Biodiversity Observation Network, Leipzig, Germany

Westphal, C., Bommarco, R., Carré, G., Lamborn, E., Morison, N., Petanidou, T., Potts, S.G., Roberts, S.P., Szentgyörgyi, H., Tscheulin, T. & Vaissière, B.E. 2008. Measuring bee diversity in different European habitats and biogeographical regions. *Ecological Monographs,* 78(4): 653-671.

Fish

Bouchet, P., Meeuwig, J., Huveneers, C. er al. (2018). Marine sampling field manual for pelagic BRUVS (Baited Remote Underwater Videos). Pp 105-132 in *Field Manuals for Marine Sampling to Monitor Australian Waters*, Przeslawski, R. & Foster, S. (eds). National Environmental Science Programme (NESP), Canberra, Australia.

Côté, I.M. & Perrow, M.R. 2006. Fish. Pp 250-277 in Sutherland W.J. (ed.), *Ecological Census Techniques. 2nd Edition.* Cambridge University Press, Cambridge, UK.

Edgar, G.J. & Stuart-Smith, R.D. (2014). Systematic global assessment of reef fish communities by the Reef Life Survey program. *Scientific Data,* 1(1): 1-8.

Giles, N., Sands, R. & Fasham, M. 2005. Fish. Pp. 368-386 in Hill, D., Fasham, M., Tucker, G., Shewry, M. & Shaw, P. (eds.), *Handbook of Biodiversity Methods: Survey, Evaluation and Monitoring.* Cambridge University Press, Cambridge, UK.

HELCOM 2015. *Guidelines for Coastal Fish Monitoring.* HELCOM, Helsinki, Finland. Available at https://helcom.fi/wp-content/uploads/2019/08/Guidelines-for-Coastal-fish-Monitoring-of-HELCOM.pdf

Léopold, M., Cakacaka, A., Meo, S., Sikolia, J., & Lecchini, D. 2009. Evaluation of the effectiveness of three underwater reef fish monitoring methods in Fiji. *Biodiversity and Conservation*, 18(13): 3367-3382.

Radinger, J., Britton, J. R., Carlson, S. M., Magurran, A. E., Alcaraz-Hernández, J. D., Almodóvar, A. et al. 2019. Effective monitoring of freshwater fish. *Fish and Fisheries*, 20(4): 729-747.

Reef Life Survey, 2019. *Standardised Survey Procedures for Monitoring Rocky & Coral Reef Ecological Communities.* Reef Life Survey, Hobart, Australia.

van Bleijswijk, J.D.L., Engelmann, J.C., Klunder, L. et al. (2020). Analysis of a coastal North Sea fish community: Comparison of aquatic environmental DNA concentrations to fish catches. *Environmental DNA*, 2(4): 429-445.

Mammals

Boyd, I.L., Bowen, W.D. and Iverson, S.J. (eds.), 2010. *Marine Mammal Ecology and Conservation: A Handbook of Techniques*. Oxford University Press, Oxford, UK.

Buckland, S.T., Plumptre, A.J., Thomas, L. and Rexstad, E.A., 2010. Design and analysis of line transect surveys for primates. *International Journal of Primatology,* 31, pp.833-847.

Davies, G. and Howell, K. 2002. Small mammals: bats, rodents and insectivores. Pp 45-68 in G. Davies (ed.), *African Forest Biodiversity: A Field Survey Manual for Vertebrates.* Earthwatch, Oxford, UK.

Evans, P.G.H. & Hammond, P.S. 2004. Monitoring cetaceans in European waters. *Mammal Review*, 34(1): 131-156.

Garner, G.W., Amstrup, S.C., Laake, J.L., Manly, B.F.J., McDonald, L.L., & Robertson, D.G. 1999. *Marine Mammal Survey and Assessment Methods.* CRC Press/Balkema, Rotterdam, The Netherlands.

Gurnell, J. and Flowerdew, J.R., 2019. *Live Trapping of Small Mammals: A Practical Guide. Fifth Edition.* The Mammal Society, London, UK.

Hoffmann, A., Decher, J., Rovero, F., Schaer, J., Voigt, C. and Wibbelt, G., 2010. Field methods and techniques for monitoring mammals. Pp 482-529 in *Manual on field recording techniques and protocols for all taxa biodiversity inventories and monitoring, 8.* ABC Taxa.

Krebs, C. 2006. Mammals. Pp 351-369 in Sutherland W.J. (ed.), *Ecological Census Techniques. 2nd Edition.* Cambridge University Press, Cambridge, UK.

Kühl, H., Maisels, F., Ancrenaz, M. & Williamson, E.A. 2008. *Best Practice Guidelines for Surveys and Monitoring of Great Ape Populations.* IUCN SSC Primate Specialist Group (PSG), Gland, Switzerland.

Munari, D.P., Keller, C., & Venticinque, E.M. 2011. An evaluation of field techniques for monitoring terrestrial mammal populations in Amazonia. *Mammalian Biology*, *76*(4): 401-408.

Stebbings, R., Mansfield, H. & Fasham, M. 2005. Bats. Pp. 433-449 in Hill, D., Fasham, M., Tucker, G., Shewry, M. & Shaw, P. (eds.), *Handbook of Biodiversity Methods: Survey, Evaluation and Monitoring.* Cambridge University Press, Cambridge, UK.

TEAM Network, 2011. *Terrestrial Vertebrate (Camera Trap) Monitoring Protocol Implementation Manual, Version 3.1.* Tropical Ecology, Assessment and Monitoring Network. Conservation International, Arlington, USA.
https://catalog.ipbes.net/system/assessment/136/references/files/385/original/TEAMTerrestrialVertebrate-PT-EN-3.1.pdf?1353346399

Wilson, D.E., Cole, F.R., Nichols, J.D., Rudran, R. & Foster, M.S. 1996. *Measuring and Monitoring Biological Diversity: Standard Methods for Mammals*. Smithsonian Institution Press, Washington DC, USA.

Plants and Fungi

Bullock, J.M. 2006. Plants. Pp 186-307 in Sutherland W.J. (ed.), *Ecological Census Techniques. 2nd Edition.* Cambridge University Press, Cambridge, UK.

Elzinga, C. L., & Salzer, D. W. 1998. *Measuring & Monitoring Plant Populations*. US Department of the Interior, Bureau of Land Management.

Godínez-Alvarez, H., Herrick, J. E., Mattocks, M., Toledo, D., & Van Zee, J. 2009. Comparison of three vegetation monitoring methods: Their relative utility for ecological assessment and monitoring. *Ecological Indicators*, 9(5): 1001-1008.

Halme, P., Heilmann-Clausen, J., Rämä, T., Kosonen, T., & Kunttu, P. 2012. Monitoring fungal biodiversity – towards an integrated approach. *Fungal Ecology*, *5*(6): 750-758.

Kirby, K., & Hall, J. 2019. *Woodland Survey Handbook: Collecting Data for Conservation in British Woodland*. Pelagic Publishing Ltd, Exeter, UK.

Madsen, J. D., & Wersal, R. M. 2017. A review of aquatic plant monitoring and assessment methods. *Journal of Aquatic Plant Management*, *55*(1): 1-12.

Mueller, G.M., Bills, G.F. & Foster, M.S. 2004. *Biodiversity of Fungi: Inventory and Monitoring Methods. Elsevier Academic Press,* San Diego, California, USA.

Ovaskainen, O., Abrego, N., Somervuo, P., Palorinne, I., Hardwick, B., Pitkänen, J.M., Andrew, N.R., Niklaus, P.A., Schmidt, N.M., Seibold, S. & Vogt, J. 2020. Monitoring fungal communities with the global spore sampling project. *Frontiers in Ecology and Evolution*, 7: 511.

Rich, T., Hack. V. & McMeechan, F. 2005. Vascular plants. Pp. 303-321 in Hill, D., Fasham, M., Tucker, G., Shewry, M. & Shaw, P. (eds.), *Handbook of Biodiversity Methods: Survey, Evaluation and Monitoring.* Cambridge University Press, Cambridge, UK.

Schmit, J. P., & Lodge, D. J. 2005. Classical methods and modern analysis for studying fungal diversity. *Mycology Series*, 23: 193.

Schnell, S., Kleinn, C., & Ståhl, G. 2015. Monitoring trees outside forests: a review. *Environmental Monitoring and Assessment*, 187(9): 1-17.

Stewart, S. & Wade, M. 2005. Aquatic macrophytes and algae. Pp. 295-302 in Hill, D., Fasham, M., Tucker, G., Shewry, M. & Shaw, P. (eds.), *Handbook of Biodiversity Methods: Survey, Evaluation and Monitoring.* Cambridge University Press, Cambridge, UK.

Suz, L.M., Barsoum, N., Benham, S., Cheffings, C., Cox, F., Hackett, L., Jones, A.G., Mueller, G.M., Orme, D., Seidling, W. & Van Der Linde, S. 2015. Monitoring ectomycorrhizal fungi at large scales for science, forest management, fungal conservation and environmental policy. *Annals of Forest Science*, 72(7): 877-885.

Watling, R., Fasham, M., and Dobson, D., 2005. Fungi. Pp. 271-278 in Hill, D., Fasham, M., Tucker, G., Shewry, M. & Shaw, P. (eds.), *Handbook of Biodiversity Methods: Survey, Evaluation and Monitoring.* Cambridge University Press, Cambridge, UK.

4. Satellite-based Remote Sensing - Guidelines, Manuals, Protocols and Key Papers

Using satellite-based remote sensing for biodiversity monitoring. Key overviews highlighted in bold.

Barber-Meyer, S.M., Kooyman, G.L., & Ponganis, P.J. 2007. Estimating the relative abundance of emperor penguins at inaccessible colonies using satellite imagery. *Polar Biology* 30, 1565–1570.

Beresford, A.E., Donald, P.F. and Buchanan, G.M., 2020. Repeatable and standardised monitoring of threats to Key Biodiversity Areas in Africa using Google Earth Engine. *Ecological Indicators*, *109*, p.105763.

Cavender-Bares, J., Gamon, J.A. and Townsend, P.A., 2020. *Remote Sensing of Plant Biodiversity.* Springer Nature, Cham, Switzerland.

Chabot, D., Stapleton S,. & Francis, C.M. 2022. Using Web images to train a deep neural network to detect sparsely distributed wildlife in large volumes of remotely sensed imagery: A case study of polar bears on sea ice. *Ecological Informatics* 68, 101547. doi:10.1016/j.ecoinf.2021.101547

CRSIP - Centre for Remote Imaging, Sensing and Processing, 2001. *What is remote sensing?* Tutorial developed by S.C. Liew, available online at https://crisp.nus.edu.sg/~research/tutorial/intro.htm

del Río-Mena, T., Willemen, L., Tesfamariam, G.T., Beukes, O. and Nelson, A., 2020. Remote sensing for mapping ecosystem services to support evaluation of ecological restoration interventions in an arid landscape. *Ecological indicators,* 113, p.106182.

European Space Agency, 2024. *Introducing Copernicus.* Website: https://www.esa.int/Applications/Observing_the_Earth/ Copernicus/Introducing_Copernicus

Geller, G.N., Halpin, P.N., Helmuth, B., Hestir, E.L., Skidmore, A., Abrams, M.J., Aguirre, N., Blair, M., Botha, E., Colloff, M. and Dawson, T., 2017. Remote sensing for biodiversity. *The GEO handbook on biodiversity observation networks*, pp.187-210. Springer International Publishing: Cham

GOFC-GOLD 2017. *A Sourcebook of Methods and Procedures for Monitoring Essential Biodiversity Variables in Tropical Forests with Remote Sensing*. Eds: GOFC-GOLD & GEOBON. GOFC-GOLD Land Cover Project Office, Wageningen University, The Netherlands.

Hollings, T., Burgman, M., van Andel, M., Gilbert, M., Robinson, T. and Robinson, A., 2018. How do you find the green sheep? A critical review of the use of remotely sensed imagery to detect and count animals. *Methods in Ecology and Evolution,* 9(4), pp.881-892.

Jetz, W., McGeoch, M.A., Guralnick, R., Ferrier, S., Beck, J., Costello, M.J., Fernandez, M., Geller, G.N., Keil, P., Merow, C. and Meyer, C., 2019. Essential biodiversity variables for mapping and monitoring species populations. *Nature Ecology and Evolution*, 3, 539–551.

Kuenzer, C., Ottinger, M., Wegmann, M., Guo, H., Wang, C., Zhang, J., Dech, S. and Wikelski, M., 2014. Earth observation satellite sensors for biodiversity monitoring: potentials and bottlenecks. *International Journal of Remote Sensing*, *35*(18), pp.6599-6647.

Leidner, A.K. and Buchanan, G.M. eds., 2018. *Satellite remote sensing for conservation action: Case studies from aquatic and terrestrial ecosystems*. Cambridge University Press.

Lumbierres, M., Dahal, P.R., Soria, C.D., Di Marco, M., Butchart, S.H., Donald, P.F. and Rondinini, C., 2022. Area of Habitat maps for the world's terrestrial birds and mammals. *Scientific Data*, *9*(1), p.749.

Mashiane, K., Ramoelo, A. and Adelabu, S., 2024. Prediction of species richness and diversity in sub-alpine grasslands using satellite remote sensing and random forest machine-learning algorithm. *Applied Vegetation Science,* 27(2), p.e12778.

Melin, M., Shapiro, A.C., & Glover-Kapfer, P., 2017. *LIDAR for Ecology and Conservation*. *WWF Conservation Technology Series, Number 3*. WWF-UK, Woking, UK. https://www.wwf.org.uk/sites/default/files/2019-04/Lidar-WWF-guidelines.pdf

Nagendra, H., Lucas, R., Honrado, J.P., Jongman, R.H., Tarantino, C., Adamo, M. and Mairota, P., 2013. Remote sensing for conservation monitoring: Assessing protected areas, habitat extent, habitat condition, species diversity, and threats. *Ecological Indicators*, *33*, pp.45-59.

Pettorelli, N., 2013. Satellite Data-Based Indices to Monitor Land Use and Habitat Changes. *Biodiversity Monitoring and Conservation: Bridging the Gap between Global Commitment and Local Action*, pp.95-119. Wiley, London.

Pettorelli ,N., Laurance, W.F., O'Brien, T.G., Wegmann, M., Nagendra, H., & Turner, W. 2014. Satellite remote sensing for applied ecologists: opportunities and challenges. *Journal of Applied Ecology*, 2014, 51:839-848.

Pettorelli, N., Schulte BuüHne, H., Shapiro, A.C. and Glover-Kapfer, P., 2018. *Satellite remote sensing for conservation. Conservation Technology Series, Number 4*. WWF-UK, Woking, UK.

Pettorelli, N., Williams, J., Schulte to Bühne, H. and Crowson, M., 2024. Deep learning and satellite remote sensing for biodiversity monitoring and conservation. *Remote Sensing in Ecology and Conservation*, doi: 10.1002/rse2.415.

Pintea, L., Jantz, S.M. & Wich, S.A. 2021. From the cloud to the ground: converting satellite data into conservation decisions. Pp 13-34 in S.A. Wich & A.K. Piel (eds.), *Conservation Technology.* Oxford University Press, Oxford, UK.

Reddy, C.S., Kurian, A., Srivastava, G., Singhal, J., Varghese, A.O., Padalia, H., Ayyappan, N., Rajashekar, G., Jha, C.S. and Rao, P.V.N., 2021. Remote sensing enabled essential biodiversity variables for biodiversity assessment and monitoring: technological advancement and potentials. *Biodiversity and Conservation,* 30, pp.1-14.

Secades C, O'Connor B, Brown C, Walpole M: Earth Observation for Biodiversity Monitoring: A Review of Current Approaches and Future Opportunities for Tracking Progress Towards the Aichi Biodiversity Targets. CBD Technical Series No. 72. Montreal, Canada: Secretariat of the Convention on Biological Diversity; 2014.

Wu, Z., Zhang, C., Gu, X., Duporge, I., Hughey, L.F., Stabach, J.A., Skidmore, A.K., Hopcraft, J.G.C., Lee, S.J., Atkinson, P.M. and McCauley, D.J., 2023. Deep learning enables satellite-based monitoring of large populations of terrestrial mammals across heterogeneous landscape*. Nature Communications*, 14(1), p.3072.

5. Cameras (from camera traps to digital aerial surveys to underwater videos) - Guidelines, Manuals, Protocols and Key Papers

Using different forms of cameras to monitor biodiversity. Key overviews highlighted in bold.

Camera trapping

Ahumada, J.A., Fegraus, E., Birch, T., Flores, N., Kays, R., O'Brien, T.G., Palmer, J., Schuttler, S., Zhao, J.Y., Jetz, W. and Kinnaird, M., 2020. Wildlife Insights: A platform to maximize the potential of camera trap and other passive sensor wildlife data for the planet. *Environmental Conservation,* 47(1), pp.1-6.

Ancrenaz, M., Hearn, A.J., Ross, J., Sollmann, R., and Wilting, A., 2012. *Handbook for wildlife monitoring using camera-traps*. BBEC II Secretariat Publications, Sabah.

Apps, P.J. and McNutt, J.W., 2018. How camera traps work and how to work them. *African Journal of Ecology*, 56(4), pp.702-709.

Beaudrot, L., Ahumada, J.A., O'Brien, T., Alvarez-Loayza, P., Boekee, K., Campos-Arceiz, A., Eichberg, D., Espinosa, S., Fegraus, E., Fletcher, C. and Gajapersad, K., 2016. Standardized assessment of biodiversity trends in tropical forest protected areas: the end is not in sight*. PLoS Biology*, 14(1), p.e1002357.

Buxton, R.T., Lendrum, P.E., Crooks, K.R. and Wittemyer, G., 2018. Pairing camera traps and acoustic recorders to monitor the ecological impact of human disturbance. *Global Ecology and Conservation*, *16*, p.e00493.

Collett, R.A. and Fisher, D.O., 2017. Time-lapse camera trapping as an alternative to pitfall trapping for estimating activity of leaf litter arthropods. *Ecology and evolution*, *7*(18), pp.7527-7533.

Crunchant, A.S., Egerer, M., Loos, A., Burghardt, T., Zuberbühler, K., Corogenes, K., Leinert, V., Kulik, L. and Kühl, H.S., 2017. Automated face detection for occurrence and occupancy estimation in chimpanzees. *American Journal of Primatology,* 79(3), p.e22627.

del Pozo, M.S., Body, G., Rerig, G. and Basille, M., 2023. *Guide on Harmonising Biodiversity Monitoring Protocols Across Scales*. Biodiversa+ report. 60 pp. Available at https://hal.science/hal-04300324/document

Ehlers Smith, Y.C., Ehlers Smith, D.A., Rushworth, I. and Mulqueeny, C., 2018. *Best practice guide for camera-trap survey design and implementation in KwaZulu-Natal and Ezemvelo KZN Wildlife Protected Area Networks.* Ezemvelo KZN Wildlife, Pietermaritzburg, KZN, South Africa.

eMammal, 2024, How to set up your camera trap. https://emammal.si.edu/north-carolinas-candid-critters/content/how-set-your-camera-trap-0

Falzon, G., Lawson, C., Cheung, K.W., Vernes, K., Ballard, G.A., Fleming, P.J., Glen, A.S., Milne, H., Mather-Zardain, A. and Meek, P.D., 2019. ClassifyMe: a field-scouting software for the identification of wildlife in camera trap images. *Animals*, *10*(1), p.58.

Hobbs, M. T., & Brehme, C. S. (2017). An improved camera trap for amphibians, reptiles, small mammals, and large invertebrates. PLoS One, 12(10), e0185026.

Meek, P.D., Ballard, G.A., Sparkes, J., Robinson, M., Nesbitt, B. and Fleming, P.J., 2019. Camera trap theft and vandalism: occurrence, cost, prevention and implications for wildlife research and management. *Remote Sensing in Ecology and Conservation*, 5(2), pp.160-168.

Meek, P., Fleming, P., Ballard, G., Banks, P., Claridge, A., Sanderson, J. and Swann, D. eds., 2014. *Camera Trapping: Wildlife Management and Research*. CSIRO Publishing, Collingwood, Australia.

Molloy, S.W., 2018. *A Practical Guide to Using Camera Traps for Wildlife Monitoring in Natural Resource Management Projects*. Edith Gowan University, Joondalup, Australia.

National Tiger Conservation Authority – Wildlife Institute of India, 2018. *Phase III Camera Trapping Protocol. Technical Manual Number TR 2018/01.* New Delhi & Dehradun, India

Norouzzadeh, M.S., Nguyen, A., Kosmala, M., Swanson, A., Palmer, M.S., Packer, C. and Clune, J., 2018. Automatically identifying, counting, and describing wild animals in camera-trap images with deep learning. *Proceedings of the National Academy of Sciences*, 115(25), pp.E5716-E5725.

O'Connell, A.F., Nichols, J.D. and Karanth, K.U., 2011. *Camera Traps in Animal Ecology: Methods and Analyses*. Springer, New York, USA.

Palencia, P., Rowcliffe, J.M., Vicente, J. and Acevedo, P., 2021. Assessing the camera trap methodologies used to estimate density of unmarked populations. *Journal of Applied Ecology*, *58*(8), pp.1583-1592.

Palencia, P., Vicente, J., Soriguer, R.C. and Acevedo, P., 2022. Towards a best-practices guide for camera trapping: assessing differences among camera trap models and settings under field conditions. *Journal of Zoology,* 316(3), pp.197-208.

Questad, E.J., Antill, M., Liu, N., Stavros, E.N., Townsend, P.A., Bonfield, S. and Schimel, D., 2022. A camera-based method for collecting rapid vegetation data to support remote-sensing studies of shrubland biodiversity. *Remote Sensing*, *14*(8), p.1933.

Rovero, F. and Kays, R., 2021. Camera trapping for conservation. Pp 79-104 in S.A. Wich & A.K. Piel (eds.), *Conservation Technology.* Oxford University Press, Oxford, UK.

Rovero, F. & Zimmermann, F. (eds.), 2016. *Camera Trapping for Wildlife Research.* Pelagic Publishing, Exeter, UK.

Sittinger, M., Uhler, J., Pink, M. and Herz, A., 2024. Insect detect: An open-source DIY camera trap for automated insect monitoring. *PLoS One*, *19*(4), p.e0295474.

University of Ghana, 2022. *ABCS 330 - Zoological Field Techniques. Field Manual For Shai Hills Resource Reserve.* Department of Animal Biology & Conservation Science, University of Ghana, Digibooks Ghana Ltd., Tema, Ghana.

Wearn, O.R. & Glover-Kapfer, P., 2017. *Camera-trapping for Conservation: A Guide to Best Practices. WWF Conservation Technology Series, Number 1.* WWF-UK, Woking, UK. https://www.wwf.org.uk/sites/default/files/2019-04/CameraTraps-WWF-guidelines.pdf

Wearn, O.R. and Glover-Kapfer, P., 2019. Snap happy: camera traps are an effective sampling tool when compared with alternative methods. *Royal Society Open Science*, *6*(3), p.181748.

Wei, W., Luo, G., Ran, J. and Li, J., 2020. Zilong: A tool to identify empty images in camera-trap data. *Ecological Informatics*, 55, p.101021.

WildCAM, 2021. *WildCAM Guide to Camera Trap Set Up. Version 1.2.* Developed by Alys Granados with input from WildCo Lab, the WildCAM community and Kate McKeown (University of Victoria). https://wildcams.ca/site/assets/files/1148/wildcam_guide_to_camera_trap_set_up_feb2021.pdf

Wildlife Insights, 2024. *Wildlife Insights Learning Center.* https://www.wildlifeinsights.org/get-started

Camera-trapping protocols

For trend monitoring of communities the TEAM Network protocol has been developed for tropical forest mammals and has been widely used (e.g. Rovero et al. 2020), including in temperate forests (Salvatori et al. 2023):

TEAM Network. 2011. *Terrestrial Vertebrate Protocol Implementation Manual, v. 3.1.* Tropical Ecology, Assessment and Monitoring Network, Center for Applied Biodiversity Science, Conservation International, Arlington, VA, USA. Available at: http://www.conservation.org.co/media/TEAMTerrestrialVertebrate.pdf

More flexible protocols are gaining traction, such as those proposed by Snapshot US (https://www.snapshot-usa.org/) and Snapshot EU (https://www.ab.mpg.de/358074/snapshot-europe) where the number of sites sampled can vary depending on logistics or area to be covered, and the spacing among cameras can vary too.

Camera trap data analysis and management

Bubnicki, J.W., Norton, B., Baskauf, S.J., Bruce, T., Cagnacci, F., Casaer, J., Churski, M., Cromsigt, J.P.G.M., Farra, S.D., Fiderer, C., et al. 2024. Camtrap DP: an open standard for the FAIR exchange and archiving of camera trap data. *Remote Sensing in Ecology and Conservation*, 10(3), pp.283–295.

GBIF, 2023. *Best Practices for Managing and Publishing Camera Trap Data. Version 1.0.* L. Reyserhove, B. Norton and P. Desme. https://docs.gbif.org/camera-trap-guide/en/

Falzon, G., Lawson, C., Cheung, K.W., Vernes, K., Ballard, G.A., Fleming, P.J., Glen, A.S., Milne, H., Mather-Zardain, A. and Meek, P.D., 2019. ClassifyMe: a field-scouting software for the identification of wildlife in camera trap images. *Animals*, 10(1), p.58.

Forrester, T., O'Brien, T., Fegraus, E., Jansen, P.A., Palmer, J., Kays, R., Ahumada, J., Stern, B. and McShea, W., 2016. An open standard for camera trap data. *Biodiversity Data Journal,* 4, e10197.

Rovero, F. & Zimmermann, F. (eds.), 2016. *Camera Trapping for Wildlife Research.* Pelagic Publishing, Exeter, UK.

Vélez, J., McShea, W., Shamon, H., Castiblanco-Camacho, P.J., Tabak, M.A., Chalmers, C., Fergus, P. and Fieberg, J., 2023. An evaluation of platforms for processing camera-trap data using artificial intelligence. *Methods in Ecology and Evolution,* 14(2), pp.459-477.

ZSL, 2024. *Camera trap software.* Website at https://www.zsl.org/what-we-do/conservation/protecting-species/monitoring-and-technology/camera-trap-software

Underwater Cameras and Videos

Bayley, D.T. and Mogg, A.O., 2020. A protocol for the large-scale analysis of reefs using Structure from Motion photogrammetry. *Methods in Ecology and Evolution*, *11*(11), pp.1410-1420.

Bicknell, A.W., Godley, B.J., Sheehan, E.V., Votier, S.C. and Witt, M.J., 2016. Camera technology for monitoring marine biodiversity and human impact. *Frontiers in Ecology and the Environment,* 14(8), pp.424-432.

Boldt, J.L., Williams, K., Rooper, C.N., Towler, R.H. and Gauthier, S., 2018. Development of stereo camera methodologies to improve pelagic fish biomass estimates and inform ecosystem management in marine waters. *Fisheries Research*, *198*, pp.66-77.

Bouchet, P., Meeuwig, J., Huveneers, C., Langlois, T., Letessier, T., Lowry, M., Rees, M., Santana-Garcon, J., Scott, M., Taylor, M. et al. 2018. Marine sampling field manual for pelagic BRUVS (Baited Remote Underwater Videos). In Field Manuals for Marine Sampling to Monitor Australian Waters, Przeslawski R, Foster S (Eds). National Environmental Science Programme (NESP). pp. 105-132.

eCoast 2024. Baited Remote Underwater Video Guidelines. Prepared for The Department of Conservation Science and Technical Group, Wellington by eCoast, Raglan, New Zealand. https://www.doc.govt.nz/documents/science-and-technical/inventory-monitoring/im-toolbox-marine-baited-remote-underwater-video-guidelines.pdf

Goetze, J.S., Bond, T., McLean, D.L., Saunders, B.J., Langlois, T.J., Lindfield, S., Fullwood, L.A., Driessen, D., Shedrawi, G. and Harvey, E.S., 2019. A field and video analysis guide for diver operated stereo-video. *Methods in Ecology and Evolution,* 10(7), pp.1083-1090.

Langlois, T., Goetze, J., Bond, T., Monk, J., Abesamis, R.A., Asher, J., Barrett, N., Bernard, A.T., Bouchet, P.J., Birt, M.J. and Cappo, M., 2020. A field and video annotation guide for baited remote underwater stereo-video surveys of demersal fish assemblages. *Methods in Ecology and Evolution,* 11(11), pp.1401-1409.

Drones and Aerial Photography

Castellanos-Galindo, G.A., Casella, E., Mejía-Rentería, J.C. and Rovere, A., 2019. Habitat mapping of remote coasts: Evaluating the usefulness of lightweight unmanned aerial vehicles for conservation and monitoring. *Biological Conservation*, 239, p.108282.

Duffy, J.P., Anderson, K., Shapiro, A.C., Spina Avino, F. L. DeBell and Glover-Kapfer, P., 2020. *Drone Technologies for Conservation. WWF Conservation Technology Series Number 5.* WWF-UK, Woking, UK.

Kemper, G., Weidauer, A., and Coppack, T., 2016. Monitoring seabirds and marine mammals by georeferenced aerial photography. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 8.

Millner, N., Cunliffe, A.M., Mulero-Pázmány, M., Newport, B., Sandbrook, C. and Wich, S., 2023. Exploring the opportunities and risks of aerial monitoring for biodiversity conservation. *Global Social Challenges Journal*, *2*(1), pp.2-23.

Monk, J., Barrett, N., Bridge, T., Carroll, A., Friedman, A., Ierodiaconou, D., Jordan, A., Kendrick, G. and Lucieer, V., 2018. Marine sampling field manual for autonomous underwater vehicles (AUVs). In *Field Manuals for Marine Sampling to Monitor Australian Waters,* Version 2. Przeslawski, R. & Foster, S. (Eds). National Environmental Science Program (NESP).

Seymour, A.C., Dale, J., Hammill, M., Halpin, P.N. and Johnston, D.W., 2017. Automated detection and enumeration of marine wildlife using unmanned aircraft systems (UAS) and thermal imagery. *Scientific Reports,* 7(1), pp.1-10.

Wich, S.A., Hudson, M., Andrianandrasana, H. and Longmore, S.N., 2021. Drones for conservation. Pp 35-52 in S.A. Wich & A.K. Piel (eds.), *Conservation Technology*. Oxford University Press, Oxford, UK.

Wich, S.A. & Koh, L.P. (2018). *Conservation Drones: Mapping and Monitoring Biodiversity*. Oxford University Press, Oxford, UK and New York, USA.

Witt, R.R., Beranek, C.T., Howell, L.G., Ryan, S.A., Clulow, J., Jordan, N.R., Denholm, B. and Roff, A., 2020. Real-time drone derived thermal imagery outperforms traditional survey methods for an arboreal forest mammal. *PLoS One*, 15(11), p.e0242204.

6. Acoustic Monitoring - Guidelines, Manuals, Protocols and Key Papers

Using acoustic recording devices for biodiversity monitoring. Key overviews highlighted in bold.

Aide, T.M., Corrada-Bravo, C., Campos-Cerqueira, M., Milan, C., Vega, G. and Alvarez, R., 2013. Real-time bioacoustics monitoring and automated species identification. *PeerJ*, *1*, p.e103.

Allen-Ankins, S., McKnight, D.T., Nordberg, E.J., Hoefer, S., Roe, P., Watson, D.M., McDonald, P.G., Fuller, R.A. and Schwarzkopf, L., 2023. Effectiveness of acoustic indices as indicators of vertebrate biodiversity. *Ecological Indicators*, *147*, p.109937.

Astaras, C., Linder, J.M., Wrege, P., Orume, R., Johnson, P.J. and Macdonald, D.W., 2020. Boots on the ground: The role of passive acoustic monitoring in evaluating anti-poaching patrols. *Environmental Conservation*, *47*(3), pp.213-216.

Blumstein, D.T., Mennill, D.J., Clemins, P., Girod, L., Yao, K., Patricelli, G., Deppe, J.L., Krakauer, A.H., Clark, C., Cortopassi, K.A. and Hanser, S.F., 2011. Acoustic monitoring in terrestrial environments using microphone arrays: applications, technological considerations and prospectus. *Journal of Applied Ecology*, *48*(3), pp.758-767.

Bota, G., Traba, J., Sarda-Palomera, F., Giralt, D. and Pérez-Granados, C., 2022. Passive acoustic monitoring for estimating human-wildlife conflicts: The case of bee-eaters and apiculture. *Ecological Indicators*, *142*, p.109158.

Bradfer-Lawrence, T., Duthie, B., Abrahams, C., Adam, M., Barnett, R.J., Beeston, A., Darby, J., Dell, B., Gardner, N., Gasc, A. and Heath, B., 2024. The Acoustic Index User's Guide: A practical manual for defining, generating and understanding current and future acoustic indices. *Methods in Ecology and Evolution*. https://doi.org/10.1111/2041-210X.14357

Bradfer-Lawrence, T., Gardner, N., Bunnefeld, L., Bunnefeld, N., Willis, S.G. and Dent, D.H., 2019. Guidelines for the use of acoustic indices in environmental research. *Methods in Ecology and Evolution,* 10(10), pp.1796-1807.

Browning, E., Gibb, R., Glover-Kapfer, P. & Jones, K.E., 2017. *Passive Acoustic Monitoring in Ecology and Conservation. WWF Conservation Technology Series, Number 2*. WWF-UK, Woking, UK. https://www.wwf.org.uk/sites/default/files/2019-04/Acousticmonitoring-WWF-guidelines.pdf

Burivalova, Z., Orndorff, S., Truskinger, A., Roe, P. and Game, E.T., 2021. The sound of logging: Tropical forest soundscape before, during, and after selective timber extraction. *Biological Conservation*, *254*, p.108812.

Burivalova, Z., Towsey, M., Boucher, T., Truskinger, A., Apelis, C., Roe, P. and Game, E.T., 2018. Using soundscapes to detect variable degrees of human influence on tropical forests in Papua New Guinea. *Conservation Biology*, *32*(1), pp.205-215.

Campos-Cerqueira, M., and Aide, M.T., 2016. Improving distribution data of threatened species by combining acoustic monitoring and occupancy modeling. *Methods in Ecology and Evolution,* 7(11), pp.1340-1348.

Cauchy, P., Heywood, K.J., Merchant, N.D., Risch, D., Queste, B.Y. and Testor, P., 2023. Gliders for passive acoustic monitoring of the oceanic environment. *Frontiers in Remote Sensing*, 4, p.1106533.

Clink, D. J., Pelkie, C., Charif, R. A. and Klinck, H., 2024. A primer on terrestrial passive acoustic monitoring data management: Best practices and guidelines. *The Journal of the Acoustical Society of America,* 155(3_Supplement), pp.A94-A95.

Cox, M.J., Borchers, D.L., Demer, D.A., Cutter, G.R. and Brierley, A.S., 2011. Estimating the density of Antarctic krill (Euphausia superba) from multi-beam echo-sounder observations using distance sampling methods. *Journal of the Royal Statistical Society Series C: Applied Statistics*, 60(2), pp.301-316.

Crunchant, A.S., Nakka, C.D., Isaacs, J.T. and Piel, A.K., 2021. Acoustic sensors. *Conservation Technology,*. pp 53-78.

Darras, K., Batáry, P., Furnas, B.J., Grass, I., Mulyani, Y.A. and Tscharntke, T., 2019. Autonomous sound recording outperforms human observation for sampling birds: a systematic map and user guide. *Ecological Applications*, 29(6), p.e01954.

Desjonquères, C., Gifford, T. and Linke, S., 2020. Passive acoustic monitoring as a potential tool to survey animal and ecosystem processes in freshwater environments. *Freshwater Biology*, *65*(1), pp.7-19.

Gillespie, D., Mellinger, D.K., Gordon, J.., Mclaren, D., Redmond, P., McHugh, R., Trinder, P.W., Deng, X.Y. and Thode, A., 2008. PAMGUARD: Semiautomated, open source software for real-time acoustic detection and localisation of cetaceans. *Journal of the Acoustical Society of America,* 30(5), pp.54-62.

Hill, A.P., Prince, P., Piña Covarrubias, E., Doncaster, C.P., Snaddon, J.L. and Rogers, A., 2018. AudioMoth: Evaluation of a smart open acoustic device for monitoring biodiversity and the environment. *Methods in Ecology and Evolution*, 9(5), pp.1199-1211.

Hoefer, S., McKnight, D.T., Allen-Ankins, S., Nordberg, E.J. and Schwarzkopf, L., 2023. Passive acoustic monitoring in terrestrial vertebrates: a review. *Bioacoustics*, 32(5), pp.506-531.

Hutschenreiter, A., Andresen, E., Briseño-Jaramillo, M., Torres-Araneda, A., Pinel-Ramos, E., Baier, J. and Aureli, F., 2024. How to count bird calls? Vocal activity indices may provide different insights into bird abundance and behaviour depending on species traits. *Methods in Ecology and Evolution,* 15, pp.1071–1083.

Kasten, E.P., Gage, S.H., Fox, J. and Joo, W., 2012. The remote environmental assessment laboratory's acoustic library: An archive for studying soundscape ecology. *Ecological informatics*, *12*, pp.50-67.

Knight, E.C., Hannah, K.C., Foley, G.J., Scott, C.D., Brigham, R.M. and Bayne, E., 2017. Recommendations for acoustic recognizer performance assessment with application to five common automated signal recognition programs. *Avian Conservation and Ecology,* 12(2), p.14.

Kowarski, K.A., Gaudet, B.J., Cole, A.J., Maxner, E.E., Turner, S.P., Martin, S.B., Johnson, H.D. and Moloney, J.E., 2020. Near real-time marine mammal monitoring from gliders: Practical challenges, system development, and management implications. *The Journal of the Acoustical Society of America*, 148(3), pp.1215-1230.

Linke, S., Gifford, T., Desjonquères, C., Tonolla, D., Aubin, T., Barclay, L., Karaconstantis, C., Kennard, M.J., Rybak, F. and Sueur, J., 2018. Freshwater ecoacoustics as a tool for continuous ecosystem monitoring. *Frontiers in Ecology and the Environment*, *16*(4), pp.231-238.

Madhusudhana, S., Pavan, G., Miller, L.A., Gannon, W.L., Hawkins, A., Erbe, C., Hamel, J.A. and Thomas, J.A., 2022. Choosing equipment for animal bioacoustic research. *Exploring Animal Behavior Through Sound*: *Volume 1* (eds. C. Erbe & J.A. Thomas), pp.37-86. Springer, Cham, Switzerland.

Mann, D.A., Hawkins, A.D. and Jech, J.M., 2008. Active and passive acoustics to locate and study fish. *Fish Bioacoustics*, pp.279-309. Springer, New York, USA.

Marques, T.A., Thomas, L., Martin, S.W., Mellinger, D.K., Ward, J.A., Moretti, D.J., Harris, D. and Tyack, P.L., 2013. Estimating animal population density using passive acoustics. *Biological Reviews*, *88*(2), pp.287-309.

Mellinger, D.K., Stafford, K.M., Moore, S.E., Dziak, R.P. and Matsumoto, H., 2007. An overview of fixed passive acoustic observation methods for cetaceans. *Oceanography*, *20*(4), pp.36-45.

Metcalf, O., Abrahams, C., Ashington, B., Baker, E., Bradfer-Lawrence, T., Browning, E., Carruthers-Jones, J., Darby, J., Dick, J., Eldridge, A. and Elliott, D., 2023. *Good Practice Guidelines for Long-Term Ecoacoustic Monitoring in the UK.* The UK Acoustics Network. https://e-space.mmu.ac.uk/631466/

Open Acoustic Devices, 2024. *AudioMoth Operation Manual*. Available at: https://github.com/OpenAcousticDevices/Application-Notes/blob/master/AudioMoth_Operation_Manual.pdf

Pardo, J.M., Cruz, P., Moya, S., Pizzio, E., Foletto, F., Robino, F., Aquino, J., Costa, S., Barros, Y., Cleo, F. and Di Bitetti, M.S., 2022. Predicting poaching hotspots in the largest remnant of the Atlantic Forest by combining passive acoustic monitoring and occupancy models. *Biological Conservation*, *272*, p.109600.

Pérez-Granados, C., 2023. BirdNET: applications, performance, pitfalls and future opportunities. *Ibis*, 165(3), pp.1068-1075.

Pérez-Granados, C. and Schuchmann, K.L., 2023. The sound of the illegal: Applying bioacoustics for long-term monitoring of illegal cattle in protected areas. *Ecological Informatics,* 74, p.101981.

Pérez-Granados, C. and Traba, J., 2021. Estimating bird density using passive acoustic monitoring: a review of methods and suggestions for further research. *Ibis*, *163*(3), pp.765-783.

Pijanowski, B. C., Farina, A., Gage, S. H., Dumyahn, S. L., & Krause, B. L. (2011). What is soundscape ecology? An introduction and overview of an emerging new science. *Landscape Ecology*, 26(9), 1213–1232.

Poupard, M., Ferrari, M., Best, P. and Glotin, H., 2022. Passive acoustic monitoring of sperm whales and anthropogenic noise using stereophonic recordings in the Mediterranean Sea, North West Pelagos Sanctuary. *Scientific Reports,* 12(1), p.2007.

Priyadarshani, N., Marsland, S. and Castro, I., 2018. Automated birdsong recognition in complex acoustic environments: a review. *Journal of Avian Biology*, 49(5), pp.e01447.

Ribeiro, Jr, J.W., Harmon, K., Leite, G.A., de Melo, T.N., LeBien, J. and Campos-Cerqueira, M., 2022. Passive acoustic monitoring as a tool to investigate the spatial distribution of invasive alien species. *Remote Sensing,* 14(18), p.4565.

Rowley, J.J., Callaghan, C.T., Cutajar, T., Portway, C., Potter, K., Mahony, S., Trembath, D.F., Flemons, P. and Woods, A., 2019. FrogID: Citizen scientists provide validated biodiversity data on frogs of Australia. *Herpetological Conservation and Biology*, *14*(1), pp.155-170.

Sarnocinska, J., Tougaard, J., Johnson, M., Madsen, P.T. and Wahlberg, M., 2016. Comparing the performance of C-PODs and SoundTrap/PAMGUARD in detecting the acoustic activity of harbor porpoises (*Phocoena phocoena*). *Proceedings of Meetings on Acoustics,* 27, pp.070013.

SINAY, 2024. *What is Passive Acoustic Monitoring?* Website available at https://sinay.ai/en/what-is-passive-acoustic-monitoring/

Sugai, L.S.M., Desjonqueres, C., Silva, T.S.F. and Llusia, D., 2020. A roadmap for survey designs in terrestrial acoustic monitoring. *Remote Sensing in Ecology and Conservation*, 6(3), pp.220-235.

Sugai, L.S.M., Silva, T.S.F., Ribeiro Jr, J.W. and Llusia, D., 2019. Terrestrial passive acoustic monitoring: review and perspectives. *BioScience*, *69*(1), pp.15-25.

Teixeira, D., Roe, P., van Rensburg, B.J., Linke, S., McDonald, P.G., Tucker, D. and Fuller, S., 2024. Effective ecological monitoring using passive acoustic sensors: Recommendations for conservation practitioners. *Conservation Science and Practice,* p.e13132.

Todd, V., Todd, I., Gardiner, J. and Morrin, E., 2015. *Marine Mammal Observer and Passive Acoustic Monitoring Handbook*. Pelagic Publishing Ltd.

Ulloa, J.S., Aubin, T., Llusia, D., Bouveyron, C. and Sueur, J., 2018. Estimating animal acoustic diversity in tropical environments using unsupervised multiresolution analysis. *Ecological Indicators*, *90*, pp.346-355.

Villanueva-Rivera, L.J. and Pijanowski, B.C., 2012. Pumilio: a web-based management system for ecological recordings. *Bulletin of the Ecological Society of America,* 93(1), pp.71-81.

Wildlife Acoustics, 2024. *Seven microphone detection considerations for better bioacoustics studies.* Website at: https://www.wildlifeacoustics.com/resources/blog/7-microphone-detection-considerations-for-bioacoustics-studies

Wood, C.M., Kahl, S., Rahaman, A. and Klinck, H., 2022. The machine learning–powered BirdNET App reduces barriers to global bird research by enabling citizen science participation. *PLoS Biology*, *20*(6), p.e3001670.

Wrege, P.H., Rowland, E.D., Keen, S. and Shiu, Y., 2017. Acoustic monitoring for conservation in tropical forests: examples from forest elephants. *Methods in Ecology and Evolution*, *8*(10), pp.1292-1301.

Zhao, Z., Xu, Z.Y., Bellisario, K., Zeng, R.W., Li, N., Zhou, W.Y. and Pijanowski, B.C., 2019. How well do acoustic indices measure biodiversity? Computational experiments to determine effect of sound unit shape, vocalization intensity, and frequency of vocalization occurrence on performance of acoustic indices. *Ecological Indicators*, *107*, p.105588.

Zimmer, W.M., 2011. *Passive Acoustic Monitoring of Cetaceans*. Cambridge University Press.

7. Environmental DNA - Guidelines, Manuals, Protocols and Key Papers

Using eDNA for biodiversity monitoring. Key overviews highlighted in bold.

Abbott, C., Coulson, M., Gagné, N., Lacoursière-Roussel, A., Parent, G.J., Bajno, R., Dietrich, C., May-McNally, S. 2021. *Guidance on the Use of Targeted Environmental DNA (eDNA) Analysis for the Management of Aquatic Invasive Species and Species at Risk*. DFO Canadian Science Advisory Secretariat Research Document 2021/019. iv + 42 p.

Allen, M.C., Kwait, R., Vastano, A., Kisurin, A., Zoccolo, I., Jaffe, B.D., Angle, J.C., Maslo, B. and Lockwood, J.L., 2023. Sampling environmental DNA from trees and soil to detect cryptic arboreal mammals. *Scientific Reports*, *13*(1), p.180.

Andres, K.J., Sethi, S.A., Lodge, D.M. and Andrés, J., 2021. Nuclear eDNA estimates population allele frequencies and abundance in experimental mesocosms and field samples. *Molecular Ecology*, *30*(3), pp.685-697.

Bohmann, K., Evans, A., Gilbert, M.T.P., Carvalho, G.R., Creer, S., Knapp, M., Douglas, W.Y. and De Bruyn, M., 2014. Environmental DNA for wildlife biology and biodiversity monitoring. *Trends in Ecology & Evolution,* 29(6), pp.358-367.

Bohmann, K. and Lynggaard, C., 2023. Transforming terrestrial biodiversity surveys using airborne eDNA. *Trends in Ecology & Evolution*, *38*(2), pp.119-121.

Bruce, K., Blackman, R.C., Bourlat, S.J., Hellström, M., Bakker, J., Bista, I., Bohmann, K., Bouchez, A., Brys, R., Clark, K. and Elbrecht, V., 2021. *A Practical Guide to DNA-Based Methods for Biodiversity Assessment.* Pensoft Advanced Books. https://ab.pensoft.net/article/68634/

Buxton, A., Diana, A., Matechou, E., Griffin, J. and Griffiths, R.A., 2022. Reliability of environmental DNA surveys to detect pond occupancy by newts at a national scale. *Scientific Reports,* 12(1), p.1295.

Carim, K.J., McKelvey, K.S., Young, M.K., Wilcox, T.M., and Schwartz, M.K., 2016. *A protocol for collecting environmental DNA samples from streams. Gen. Tech. Rep. RMRS-GTR-355.* Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 18 p.

Castellanos-Galindo, G.A., Casella, E., Mejía-Rentería, J.C. and Rovere, A., 2019. Habitat mapping of remote coasts: Evaluating the usefulness of lightweight unmanned aerial vehicles for conservation and monitoring. *Biological Conservation,* 239, p.108282.

Centre for Biodiversity Genomics, University of Guelph, 2021*. The Global Taxonomy Initiative 2020: A Step-by-Step Guide for DNA Barcoding. Technical Series No. 94.* Secretariat of the Convention on Biological Diversity, Montreal, Canada. 66 pages

Claver, C., Canals, O., de Amézaga, L.G., Mendibil, I. and Rodriguez-Ezpeleta, N., 2023. An automated workflow to assess completeness and curate GenBank for environmental DNA metabarcoding: The marine fish assemblage as case study. *Environmental DNA*, *5*(4), pp.634-647.

Coutant, O., Richard-Hansen, C., de Thoisy, B., Decotte, J.B., Valentini, A., Dejean, T., Vigouroux, R., Murienne, J. and Brosse, S., 2021. Amazonian mammal monitoring using aquatic environmental DNA. *Molecular Ecology Resources*, *21*(6), pp.1875-1888.

CSA - Canadian Standards Association, 2021. *CSA W214:21 Environmental DNA (eDNA) reporting requirements and terminology.* Available for a fee at https://www.csagroup.org/store/product/CSA%20W214%3A21/

CSA - Canadian Standards Association, 2023. *CSA W219:23 Performance criteria for the analyses of environmental DNA by targeted quantitative polymerase chain reaction*. Available for a fee at https://www.csagroup.org/store/product/CSA_W219%3A23/ .

Curd, E.E., Gal, L., Gallego, R., Silliman, K., Nielsen, S. and Gold, Z., 2024. rCRUX: A rapid and versatile tool for generating metabarcoding reference libraries in R. *Environmental DNA*, *6*(1), p.e489.

De Brauwer, M., Chariton, A., Clarke, L.J., Cooper, M.K., DiBattista, J., Furlan, E., Giblot-Ducray, D., Gleeson, D., Harford, A., Herbert, S., MacDonald, A.J., Miller, A., Montgomery, K., Mooney, T., Noble, L.M., Rourke, M., Sherman, C.D.H., Stat, M., Suter, L., West, K.M., White, N., Villacorta-Rath, C., Zaiko, A. and Trujillo-Gonzalez, A., 2022a. *Environmental DNA protocol development guide for biomonitoring.* National eDNA Reference Centre, Canberra, Australia.

De Brauwer M, Chariton A, Clarke LJ, Cooper MK, DiBattista J, Furlan E, Giblot-Ducray D, Gleeson D, Harford A, Herbert S, MacDonald AJ, Miller A, Montgomery K, Mooney T, Noble LM, Rourke M, Sherman CDH, Stat M, Suter L, West KM, White N, Villacorta-Rath C, Zaiko A & Trujillo-Gonzalez A., 2022b. *Environmental DNA test validation guidelines.* National eDNA Reference Centre, Canberra, Australia.

De Brauwer, M., Clarke, L.J., Chariton, A., Cooper, M.K., De Bruyn, M., Furlan, E., MacDonald, A.J., Rourke, M.L., Sherman, C.D., Suter, L. and Villacorta-Rath, C., 2023. Best practice guidelines for environmental DNA biomonitoring in Australia and New Zealand. *Environmental DNA,* 5(3), pp.417-423.

Deiner, K., Bik, H.M., Mächler, E., Seymour, M., Lacoursière-Roussel, A., Altermatt, F., Creer, S., Bista, I., Lodge, D.M., De Vere, N. and Pfrender, M.E., 2017. Environmental DNA metabarcoding: Transforming how we survey animal and plant communities. *Molecular Ecology,* 26(21), pp.5872-5895.

Dufresnes, C., Remollino, N., Stoffel, C., Manz, R., Weber, J.M. and Fumagalli, L., 2019. Two decades of non-invasive genetic monitoring of the grey wolves recolonizing the Alps support very limited dog introgression. *Scientific Reports*, *9*(1), p.148.

Ficetola, G.F., Miaud, C., Pompanon, F. and Taberlet, P., 2008. Species detection using environmental DNA from water samples. *Biology Letters*, *4*(4), pp.423-425.

Gray, M., Roy, J., Vigilant, L., Fawcett, K., Basabose, A., Cranfield, M., Uwingeli, P., Mburanumwe, I., Kagoda, E. and Robbins, M.M., 2013. Genetic census reveals increased but uneven growth of a critically endangered mountain gorilla population. *Biological conservation*, *158*, pp.230-238.

Goldberg, C.S., Turner, C.R., Deiner, K., Klymus, K.E., Thomsen, P.F., Murphy, M.A., Spear, S.F., McKee, A., Oyler-McCance, S.J., Cornman, R.S. and Laramie, M.B., 2016. Critical considerations for the application of environmental DNA methods to detect aquatic species. *Methods in Ecology and Evolution,* 7(11), pp.1299-1307.

Guthrie, A.M., Cooper, C.E., Bateman, P.W., van der Heyde, M., Allentoft, M.E. and Nevill, P., 2024. A quantitative analysis of vertebrate environmental DNA degradation in soil in response to time, UV light, and temperature. *Environmental DNA*, *6*(4), p.e581.

Hunter, M.E., Meigs-Friend, G., Ferrante, J.A., Smith, B.J. and Hart, K.M., 2019. Efficacy of eDNA as an early detection indicator for Burmese pythons in the ARM Loxahatchee National Wildlife Refuge in the greater Everglades ecosystem. *Ecological Indicators,* 102, pp.617-622.

IUCN, 2024. *IUCN Issues Brief: Environmental DNA*. IUCN, Gland, Switzerland. Available at https://www.iucn.org/resources/issues-brief/environmental-dna

Johnson, M.D., Cox, R.D., Grisham, B.A., Lucia, D. and Barnes, M.A., 2021. Airborne eDNA reflects human activity and seasonal changes on a landscape scale. *Frontiers in Environmental Science*, 8, p.563431.

Kelly, R.P., Lodge, D.M., Lee, K.N., Theroux, S., Sepulveda, A.J., Scholin, C.A., Craine, J.M., Andruszkiewicz Allan, E., Nichols, K.M., Parsons, K.M. and Goodwin, K.D., 2024. Toward a national eDNA strategy for the United States. Environmental DNA, 6(1), p.e432.

Kirse, A., Bourlat, S.J., Langen, K. and Fonseca, V.G., 2021. Unearthing the potential of soil eDNA metabarcoding—Towards best practice advice for invertebrate biodiversity assessment. *Frontiers in Ecology and Evolution*, *9*, p.630560.

Leempoel, K., Hebert, T. and Hadly, E.A., 2020. A comparison of eDNA to camera trapping for assessment of terrestrial mammal diversity. *Proceedings of the Royal Society B,* 287(1918), p.20192353.

Lopes-Lima, M., Prié, V., Camará, M., Ceríaco, L.M., Fernandes, V., Ferreira, S., Gonçalves, D.V., Lecoq, M., Martins, F.M., Parrinha, D. and de Barros, A.R., 2024. Rapid eDNA survey reveals a unique biodiversity hotspot: The Corubal River, West Africa. *BioScience*, *74*(6), pp.405-412.

Lyet, A., Pellissier, L., Valentini, A., Dejean, T., Hehmeyer, A. and Naidoo, R., 2021. eDNA sampled from stream networks correlates with camera trap detection rates of terrestrial mammals. *Scientific Reports*, 11(1), p.11362.

Lynggaard, C., Frøslev, T.G., Johnson, M.S., Olsen, M.T. and Bohmann, K., 2024. Airborne environmental DNA captures terrestrial vertebrate diversity in nature. *Molecular Ecology Resources*, *24*(1), p.e13840.

Minamoto, T., Miya, M., Sado, T., Seino, S., Doi, H., Kondoh, M., Nakamura, K., Takahara, T., Yamamoto, S., Yamanaka, H. and Araki, H., 2021. An illustrated manual for environmental DNA research: Water sampling guidelines and experimental protocols. *Environmental DNA*, 3(1), pp.8-13.

Norros, V., Laamanen, T., Meissner, K., Iso-Touru, T., Kahilainen, A., Lehtinen, S., Lohtander-Buckbee, K., Nygård, H., Pennanen, T., Ruohonen-Lehto, M., Sirkiä, P., Suikkanen, S., Tolkkinen, M., Vainio, E., Velmala, S., Vuorio, K., and Vihervaara, P., 2022. *Roadmap for implementing environmental DNA (eDNA) and other molecular monitoring methods in Finland – Vision and action plan for 2022–2025.* Reports of the Finnish Environment Institute, 20/2022. Finnish Environment Institute. https://helda.helsinki.fi/items/b93f601c-2f93-4618-b407-326b78a09c4b

Pawlowski, J., Bonin, A., Boyer, F., Cordier, T., and Taberlet, P., 2021. Environmental DNA for biomonitoring. *Molecular Ecology,* 30(13), pp.2931-2936.

Pawlowski J., Apothéloz-Perret-Gentil L., Mächler E. and Altermatt F., 2020: *Environmental DNA applications in biomonitoring and bioassessment of aquatic ecosystems. Guidelines.* Federal Office for the Environment, Bern, Switzerland. Environmental Studies. no. 2010: 71 pp.

Piaggio, A.J., 2021. Environmental DNA for conservation. Pp 53-78 in S.A. Wich & A.K. Piel (eds.), *Conservation Technology.* Oxford University Press, Oxford, UK.

Rodríguez-Ezpeleta, N., Zinger, L., Kinziger, A., Bik, H.M., Bonin, A., Coissac, E., Emerson, B.C., Martins Lopes, C., Pelletier, T.A., Taberlet, P. and Narum, S., 2021. Biodiversity monitoring using environmental DNA. *Molecular Ecology Resources,* 21, pp.1405-1409. https://digital.csic.es/bitstream/10261/241896/1/Biodiversity-Emerson-2021-MolecularEcologyResources.pdf

Ruppert, K.M., Kline, R.J. and Rahman, M.S., 2019. Past, present, and future perspectives of environmental DNA (eDNA) metabarcoding: A systematic review in methods, monitoring, and applications of global eDNA. *Global Ecology and Conservation*, *17*, p.e00547.

Saeed, M., Rais, M., Akram, A., Williams, M.R., Kellner, K.F., Hashsham, S.A. and Davis, D.R., 2022. Development and validation of an eDNA protocol for monitoring endemic Asian spiny frogs in the Himalayan region of Pakistan. *Scientific Reports,* 12(1), p.5624.

Sanches, T.M. and Schreier, A.D., 2020. Optimizing an eDNA protocol for estuarine environments: Balancing sensitivity, cost and time. *PLoS One*, 15(5), p.e0233522.

Shelton, A.O., Ramón-Laca, A., Wells, A., Clemons, J., Chu, D., Feist, B.E., Kelly, R.P., Parker-Stetter, S.L., Thomas, R., Nichols, K.M. and Park, L., 2022. Environmental DNA provides quantitative estimates of Pacific hake abundance and distribution in the open ocean. *Proceedings of the Royal Society B*, *289*(1971), p.20212613.

Sigsgaard, E.E., Jensen, M.R., Winkelmann, I.E., Møller, P.R., Hansen, M.M. and Thomsen, P.F., 2020. Population-level inferences from environmental DNA—Current status and future perspectives. *Evolutionary Applications*, *13*(2), pp.245-262.

Suarez-Bregua, P., Alvarez-Gonzalez, M., Parsons, K.M., Rotllant, J., Pierce, G.J. and Saavedra, C., 2022. Environmental DNA (eDNA) for monitoring marine mammals: Challenges and opportunities. *Frontiers in Marine Science*, *9*, p.987774.

Sugai, L.S.M., Silva, T.S.F., Ribeiro Jr, J.W. and Llusia, D., 2019. Terrestrial passive acoustic monitoring: review and perspectives. *BioScience*, 69(1), pp.15-25.

Taberlet, P., Bonin, A., Zinger, L., and Coissac, E., 2018. *Environmental DNA*. Oxford University Press, Oxford, UK.

Tetzlaff, S.J., Katz, A.D., Wolff, P.J. and Kleitch, M.E., 2024. Comparison of soil eDNA to camera traps for assessing mammal and bird community composition and site use. *Ecology and Evolution*, *14*(7), p.e70022.

Thalinger, B., Deiner, K., Harper, L.R., Rees, H.C., Blackman, R.C., Sint, D., Traugott, M., Goldberg, C.S. and Bruce, K., 2021. A validation scale to determine the readiness of environmental DNA assays for routine species monitoring. *Environmental DNA,* 3(4), pp.823-836.

The eDNA Society, 2019. *Environmental DNA Sampling and Experiment Manual, version 2,1*. Available at: https://ednasociety.org/en/manuals/

Thomsen, P.F. and Willerslev, E., 2015. Environmental DNA - An emerging tool in conservation for monitoring past and present biodiversity. *Biological Conservation,* 183, pp.4-18.
USFWS – US Fish & Wildlife Service, 2022. *Quality Assurance Project Plan eDNA Monitoring of Bighead and Silver Carps.* Available at https://www.fws.gov/sites/default/files/documents/eDNA-QAPP-2022-Whitney-Genetics-Lab.pdf
Valentini, A., Taberlet, P., Miaud, C., Civade, R., Herder, J., Thomsen, P.F., Bellemain, E., Besnard, A., Coissac, E., Boyer, F. and Gaboriaud, C., 2016. Next-generation monitoring of aquatic biodiversity using environmental DNA metabarcoding. *Molecular ecology,* 25(4), pp.929-942.
Van Der Heyde, M., Bunce, M., Dixon, K., Wardell-Johnson, G., White, N.E. and Nevill, P., 2020. Changes in soil microbial communities in post mine ecological restoration: Implications for monitoring using high throughput DNA sequencing. *Science of the Total Environment,* 749, p.142262.
Washington State University, 2024. *eDNA Resources.* Website at https://ednaresources.science/

8. Comparing Monitoring Tools

A selection of studies that summarise or compare different monitoring tools or conservation technologies. Key overviews highlighted in bold.

Barrera-Falcon, E., Rioja-Nieto, R., Hernández-Landa, R.C. and Torres-Irineo, E., 2021. Comparison of standard Caribbean coral reef monitoring protocols and underwater digital photogrammetry to characterize hard coral species composition, abundance and cover. *Frontiers in Marine Science*, *8*, p.722569.
Barta, Z., 2023. Deep learning in terrestrial conservation biology. *Biologia Futura*, *74*(4), pp.359-367.
Beranek, C.T., Southwell, D., Jessop, T.S., Hope, B., Gama, V.F., Gallahar, N., Webb, E., Law, B., McIlwee, A., Wood, J. and Roff, A., 2024. Comparing the cost-effectiveness of drones, camera trapping and passive acoustic recorders in detecting changes in koala occupancy. *Ecology and Evolution*, *14*(7), p.e11659.
Browning, E., Gibb, R., Glover-Kapfer, P. & Jones, K.E., 2017. *Passive acoustic monitoring in ecology and conservation. WWF Conservation Technology Series, Number 2*. WWF-UK, Woking, UK. https://www.wwf.org.uk/sites/default/files/2019-04/Acousticmonitoring-WWF-guidelines.pdf
Buxton, R.T., Lendrum, P.E., Crooks, K.R. and Wittemyer, G., 2018. Pairing camera traps and acoustic recorders to monitor the ecological impact of human disturbance. *Global Ecology and conservation*, *16*, p.e00493.
Castellanos-Galindo, G.A., Casella, E., Mejía-Rentería, J.C. and Rovere, A., 2019. Habitat mapping of remote coasts: Evaluating the usefulness of lightweight unmanned aerial vehicles for conservation and monitoring. *Biological Conservation*, 239, p.108282.
Ditria, E.M., Buelow, C.A., Gonzalez-Rivero, M. and Connolly, R.M., 2022. Artificial intelligence and automated monitoring for assisting conservation of marine ecosystems: A perspective. *Frontiers in Marine Science,* 9, p.918104.
Enari, H., Enari, H.S., Okuda, K., Maruyama, T. and Okuda, K.N., 2019. An evaluation of the efficiency of passive acoustic monitoring in detecting deer and primates in comparison with camera traps. *Ecological Indicators,* 98, pp.753-762.
Ford, H.V., Schrodt, F., Zieritz, A., Exton, D.A., van der Heijden, G., Teague, J., Coles, T. and Field, R., 2024. A technological biodiversity monitoring toolkit for biocredits. *Journal of Applied Ecology,* 61(9), pp.2007-2019.
Fraschini, C., 2024. *Comparing Mammal Monitoring Methods: A Case Study In South Africa.* MSc Thesis, University of Lausanne, Lausanne, Switzerland.
Garland, L., Crosby, A., Hedley, R., Boutin, S. and Bayne, E., 2020. Acoustic vs. photographic monitoring of gray wolves (*Canis lupus*): a methodological comparison of two passive monitoring techniques. *Canadian Journal of Zoology*, *98*(3), pp.219-228.
Hahn, N.R., Bombaci, S.P. and Wittemyer, G., 2022. Identifying conservation technology needs, barriers, and opportunities. *Scientific Reports*, *12*(1), p.4802.
Hochkirch, A., Samways, M.J., Gerlach, J., Böhm, M., Williams, P., Cardoso, P., Cumberlidge, N., Stephenson, P.J., Seddon, M.B., Clausnitzer, V. and Borges, P.A., 2021. A strategy for the next decade to address data deficiency in neglected biodiversity. *Conservation Biology,* 35(2), pp.502-509.
Hoefer, S., McKnight, D.T., Allen-Ankins, S., Nordberg, E.J. and Schwarzkopf, L., 2023. Passive acoustic monitoring in terrestrial vertebrates: a review. *Bioacoustics*, 32(5), pp.506-531.
Impact Labs, 2024. *Digital4Impact Tech Radar.* Website at https://impactlabs.earth/digital4impact-tech-radar-2/
Jachmann, H., 2002. Comparison of aerial counts with ground counts for large African herbivores. *Journal of Applied Ecology*, 39(5), pp.841-852.

Jenkins, L.D., 2022. Power, politics, and culture of marine conservation technology in fisheries. *Conservation Biology,* 36(3), p.e13855.

Key, I.B., Smith, A.C., Turner, B., Chausson, A., Girardin, C.A., Macgillivray, M. and Seddon, N., 2022. Biodiversity outcomes of nature-based solutions for climate change adaptation: Characterising the evidence base. *Frontiers in Environmental Science*, 10, p.905767.

Lahoz-Monfort, J.J. and Magrath, M.J., 2021. A comprehensive overview of technologies for species and habitat monitoring and conservation. *BioScience*, *71*(10), pp.1038-1062.

Madhusudhana, S., Pavan, G., Miller, L.A., Gannon, W.L., Hawkins, A., Erbe, C., Hamel, J.A. and Thomas, J.A., 2022. Choosing equipment for animal bioacoustic research. *Exploring Animal Behavior Through Sound*: *Volume 1* (eds. C. Erbe & J.A. Thomas), pp.37-86. Springer, Cham, Switzerland.

Marvin, D.C., Koh, L.P., Lynam, A.J., Wich, S., Davies, A.B., Krishnamurthy, R., Stokes, E., Starkey, R. and Asner, G.P., 2016. Integrating technologies for scalable ecology and conservation. *Global Ecology and Conservation,* 7, pp.262-275.

O'Brien, T.G., 2016. Camera traps for conservation: monitoring protected area investments. Pp. 228-241 in *Protected Areas: Are They Safeguarding Biodiversity?* Edited by Joppa LN, Baillie JEM, Robinson JG. Chichester: John Wiley & Sons.

O'Brien, T.G. and Kinnaird, M.F., 2013. The Wildlife Picture Index: a biodiversity indicator for top trophic levels. Pp. 45-71 in *Biodiversity Monitoring and Conservation: Bridging the Gaps Between Global Commitment and Local Action.* Edited by Collen B, Pettorelli N, Baillie JEM, Durant SM. John Wiley & Sons.

Pintea, L., Jantz, S.M. & Wich, S.A. 2021. From the cloud to the ground: converting satellite data into conservation decisions. Pp 13-34 in S.A. Wich & A.K. Piel (eds.), *Conservation Technology.* Oxford University Press, Oxford, UK.

Sinha, V.R. and Bimson, K., (eds.), 2021. *Nature-Based Solutions in the Ganges Brahmaputra Meghna (GBM) River Basin: Case Studies and Lessons Learned.* IUCN ARO, Bangkok, Thailand. viii + 69pp.

Speaker, T., O'Donnell, S., Wittemyer, G., Bruyere, B., Loucks, C., Dancer, A., Carter, M., Fegraus, E., Palmer, J., Warren, E. and Solomon, J., 2022. A global community-sourced assessment of the state of conservation technology. *Conservation Biology,* 36(3), p.e13871.

Stephenson, P.J., 2019. Integrating remote sensing into wildlife monitoring for conservation. *Environmental Conservation*, *46*(3), pp.181-183.

Stephenson, P.J., 2020. Technological advances in biodiversity monitoring: Applicability, opportunities and challenges. *Current Opinion in Environmental Sustainability*, *45*, pp.36-41.

Stephenson, P.J. 2021. *A Review of Biodiversity Data Needs and Monitoring Protocols for the Offshore Wind Energy Sector in the Baltic Sea and North Sea.* Renewables Grid Initiative, Berlin, Germany. https://renewables-grid.eu/publications/study-offshore-biodiversity.html

Stephenson, P.J. and Carbone, G., 2021. *Guidelines for Planning and Monitoring Corporate Biodiversity Performance.* IUCN, Gland, Switzerland. Available at https://portals.iucn.org/library/node/49301

Stephenson, P.J., Ntiamoa-Baidu, Y. and Simaika, J.P., 2020. The use of traditional and modern tools for monitoring wetlands biodiversity in Africa: challenges and opportunities. *Frontiers in Environmental Science*, *8*, p.61.

Teague, J., Megson-Smith, D.A., Allen, M.J., Day, J.C. and Scott, T.B., 2022. A review of current and new optical techniques for coral monitoring. *Oceans,* 3(1), pp.30-45.

Toma, D., Artero Delgado, C., Carandell Widmer, M., Nogueras Cervera, M., Bghiel, I., Ramón Ripoll, Á., López Navarro, J.M., Carreras Pérez, M., Palomeras Rovira, N., Real Vial, M. and Segura Duran, R., 2024. Long-lasting ecological monitoring network of lander platforms for marine protected areas. Instrumentation viewpoint, (23), pp.76-77.

Tuia, D., Kellenberger, B., Beery, S., Costelloe, B.R., Zuffi, S., Risse, B., Mathis, A., Mathis, M.W., Van Langevelde, F., Burghardt, T. and Kays, R., 2022. Perspectives in machine learning for wildlife conservation. *Nature Communications,* 13(1), pp.1-15.

Ullo, S.L. and Sinha, G.R., 2020. Advances in smart environment monitoring systems using IoT and sensors. *Sensors*, *20*(11), p.3113.

Wich, S.A., and Piel, A.K.(eds.), 2021. *Conservation Technology.* Oxford University Press, Oxford, UK.

WILDLABS Partnership, 2024. *The Inventory.* Website at https://wildlabs.net/inventory

World Bank, 2023. Guidance Note: Lessons Learned in Conservation Technology – Data Collection, Processing and Management. International Bank for Reconstruction and Development / The World Bank, Washington DC, USA. Available at https://thedocs.worldbank.org/en/doc/66b559520056090b442cbdda427fe06c-0320072023/original/GWP-GUIDANCE-NOTE-Conservation-Technology-REPORT-Sept-18th.pdf

Zwerts, J.A., Stephenson, P.J., Maisels, F., Rowcliffe, M., Astaras, C., Jansen, P.A., van Der Waarde, J., Sterck, L.E., Verweij, P.A., Bruce, T. and Brittain, S., 2021. Methods for wildlife monitoring in tropical forests: Comparing human observations, camera traps, and passive acoustic sensors. *Conservation Science and Practice*, *3*(12), p.e568.