Threatened ecosystems of Myanmar

An IUCN Red List of Ecosystems Assessment

Nicholas J. Murray David A. Keith Robert Tizard
Adam Duncan Win Thuya Htut Nyan Hlaing
Aung Htat Oo Kyaw Zay Ya Hedley Grantham

2025-09-18

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2020 | Version 1.0

Foreword

H. E. U Ohn Winn

Myanmar has always benefitted from our ecosystems for our wellbeing, our livelihoods and our economy. The Ministry of Natural Resources and Environmental Conservation (MONREC) strives for managing the natural resources including its forests and minerals as well as natural ecosystems for the benefit of both current and future generations. To ensure this future we must embrace Nature-based solutions (NBS). These solutions are actions to protect, sustainably manage, and restore our natural and modified ecosystems. That is why it is my pleasure to welcome Myanmar's first Red List of Ecosystems. Our red list will be a valuable tool to support our decisions and investments that simultaneously provide human well-being and biodiversity benefits.

Myanmar's Red List of Ecosystems has recognized and evaluated 64 ecosystem types. We now understand that almost half of our ecosystems are not threatened, and their intactness is clearly an important asset for Myanmar's future. Unfortunately, we also recognize that three of our ecosystems have changed so drastically that they could be very close to collapse; and can understand that eight of our ecosystems are Critically Endangered, nine are Endangered and twelve are Vulnerable so we need to ensure that these ecosystems are protected, restored and never lost. In understanding these ecosystems, we have a much finer view of the incredible diversity Myanmar supports and how we can work towards reaching our Forest Policy (1995), our 30-year National Forestry Master Plan targets and the fulfilment of international commitments including Nationally Determined Contributions (NDCs), Sustainable Development Goals (SDGs), Aichi Biodiversity Targets, etc. MONREC also has a responsibility to manage our freshwater and saline wetlands and the marine realm. In protecting all of our natural resources we recognize the Sustainable Development Goals specially to conserve and sustainably use our oceans and marine resources as well as protecting, restoring and sustainably using our terrestrial ecosystems.

In Myanmar's Sustainable Development Plan (2018-2030), we clearly recognize the importance of natural resources and the environment for the posterity of the nation. Under this plan MONREC will ensure a clean environment together with healthy and functioning ecosystems as well as improving land governance and sustainable management of resource-based industries ensuring our natural resources dividend benefits all our people. Myanmar's Red List of Ecosystems, our understanding of threats and this newly developed spatial information will strengthen the implementation of our plans and strategies and ensure a sustainable future for all of Myanmar.

H. E. U Ohn Winn
Union Minister
Ministry of Natural Resources and Environmental Conservation

Preface

Myanmar's Red List of Ecosystems is a tool to understand our threats and plan for conservation and sustainable management. Forests constitute the dominant ecosystems in Myanmar, and we are blessed with high forest cover (42.92%) and diversity, with 36 of our 64 ecosystems identified as forest and mangrove. These forests and biodiversity underpin a range of ecosystem services which are central to Myanmar's sustainable development, supporting human and resource needs, and contributing to a more stable climate. The loss of forests and our biodiversity leads to degradation and deterioration of ecosystem services and threatens Myanmar's irreplaceable ecological heritage.

We often discuss ecosystem services but this study documents Myanmar's terrestrial ecosystem typology and spatial distribution for the first time. This is one of the first ecosystem red lists developed within ASEAN and this will inform our implementation for decades to come to inform legislation, land-use planning, protected area expansion, monitoring and reporting, and ecosystem management. To sustain our forests and our biodiversity we need to sustainably manage all of these incredible ecosystems.

This report has supported Myanmar to reach Aichi Biodiversity Target 14: Ecosystems and essential services safeguarded under Myanmar's National Biodiversity Strategy and Action Plan (2015-2020); especially Target 14.1: By 2020, a rapid national ecosystem assessment has been carried out, identifying the status, values and trends of key ecosystems and the services they provide; Action 14.1.1: Quantify trends and pressures in the status of ecosystems and species populations that provide key ecosystem services, including distinct ecological and hydrological units such as the Ayeyarwady River Basin; and Action 14.1.2: Identify and map (using GIS) key ecosystem services through desktop analyses and participatory consultations involving multiple stakeholder groups, including, marginalized poor and vulnerable groups. These actions will support the Forest Department to reduce loss and restore degraded natural habitats, through sustained land use management and take action against those committing unlawful environmental damage to conserve and protect terrestrial, freshwater, coastal and marine areas through integrated resources planning and effective and equitable management.

Myanmar will use the Red List of Ecosystems to mainstream the protection of our environmental and biodiversity dividend into a range of planning and decision making. Whether on land, above ground or under water, a range of policy safeguards, legal protections and enforcement mechanisms will be deployed to ensure that unsuitable and destructive practices are phased out and replaced with more environmentally conscious approaches. Myanmar will also ensure that individuals and communities, including those most vulnerable, are included in decision-making processes at all levels.

This book will build a stronger foundation for achieving our Forest Policy and Sustainable Development Plan by 2030 and inform our actions for the post-2020 Global Biodiversity Framework for the Convention on Biological Diversity.

Nyi Nyi Kyaw, PhD
Director General
Forest Department
Ministry of Natural Resources and Environmental Conservation

Acknowledgments

We gratefully acknowledge the efforts of hundreds of scientists and practitioners who have contributed to the understanding of Myanmar's terrestrial ecosystems over the past two centuries. Our work is largely a synthesis exercise that would not have been possible without the dedication and contributions of those before us.

We also acknowledge all contributors to this project, particularly those who attended workshops in Myanmar over the last three years. Without input from a large and diverse expert group, the development of the Myanmar Ecosystem Typology, the ecosystem descriptions and application of the criteria would not have been possible. We also acknowledge the crucial support of field and GIS staff at WCS Myanmar. Contributors to this assessment are listed within each ecosystem assessment and in Appendix 1.

The work to develop an IUCN Red List of Ecosystems of Myanmar was made possible through the funding and support of Global Environment Facility Strengthening Sustainability of Protected Area Management in Myanmar (GEF #5159, UNDP #5162) implemented by United Nations Development Program and executed by the Myanmar Forestry Department and Wildlife Conservation Society.

Coordinating Organizations

Wildlife Conservation Society

The Wildlife Conservation Society is a globally distributed science-based conservation organization, producing and disseminating the information and knowledge necessary to inform and improve conservation and management action in wild places. With field conservation operations in nearly 60 nations and all of the world's oceans, WCS has supported governments and communities in the creation or expansion of 245 protected areas. WCS employs more than 170 PhD and DVM scientists and have trained and funded generations of field and zoo colleagues, many of whom are now leaders in conservation science, wildlife veterinary medicine, and curatorial research around the world.

Centre for Ecosystem Science, University of New South Wales

The University of New South Wales (UNSW) is a focal point for environmental research, and has research strengths that include conservation biology, environmental risk management and coastal and estuarine ecology. Hosted at UNSW, the Centre for Ecosystem Science (CES) is a world leader in ecosystem research, its application and communication of environmental change. It has well- established research strengths in environmental risk assessment, and has deep involvement in award winning ecosystem management programs such as the IUCN Red List of Ecosystems initiative. The CES has five major programs focused on biodiversity of ecosystems: wetlands and rivers; terrestrial ecosystems; marine ecosystems; remote sensing and GIS, and conservation policy and management.

(Markdown can render the Burmese alphabet using Unicode, but I wasn't able to copy the characters from the PDF document.)

Summary

The Myanmar National Ecosystem Assessment contributes to the GEF funded Strengthening Sustainability of Protected Area Management in Myanmar project. To support the Myanmar National Ecosystem Assessment, Myanmar's terrestrial ecosystems were assessed under the International Union for the Conservation of Nature (IUCN) Red List of Ecosystems Categories and Criteria. This report summarises the methods and findings of the assessment, including detailed ecological descriptions of the 64 ecosystem types assessed.

A total of 64 ecosystem types were identified and evaluated under the IUCN Red List of Ecosystems categories and criteria. Twenty-nine (45.3%) ecosystems were assigned a threatened status, consisting of 8 (12.5%) Critically Endangered ecosystem types, 9 (14.1%) Endangered and 12 (18.8%) Vulnerable ecosystem types. One ecosystem type, Central Ayeyarwady Palm Savanna ecosystem types was confirmed as Collapsed. A further two ecosystem types, Ayeyarwady kanazo swamp forest and Southern Rakhine hills evergreen rainforest, were assessed with an upper plausible status outcome of Collapsed, although their final assessment was Critically Endangered.

Twenty-eight ecosystem types were assessed as Near Threatened or Least Concern. However, a post-assessment expert review by experts suggested that 11 of the 25 Least Concern ecosystems could qualify for a different assessment outcome if more data was available. These 11 ecosystems were reclassified to Data Deficient.

Thus, 17 of Myanmar's ecosystem types were classified as Data Deficient. Data deficient ecosystem types were primarily ecosystems for which there were historical records, but with insufficient published information to assess the criteria (e.g. Rocky Tanintharyi karst). Alternatively, there were insufficient distribution records to incorporate into our mapping workflow to allow assessments of Criterion A and B (e.g. Grassy saltmarsh). Data deficient ecosystems also tended to occur in regions that were inaccessible to field researchers due to travel restrictions (e.g. Shan limestone grasslands). Urgent further work to confirm the distribution and assess the status of these data deficient ecosystems is recommended.

This IUCN Red List of Ecosystems assessment has shown a dire situation for Myanmar's ecosystems. Of the area assessed, nearly two-thirds (64%, 426,628 km2) is mapped as a natural ecosystem type, but of this over half (57.8%, 24,750 km2) of remaining area contains a threatened ecosystem type (CR, EN or VU). This means over one third of Myanmar's land area contains threatened ecosystems. There needs to be an increase in conservation efforts to reverse this situation and slow the trajectory towards collapse for ecosystems that are not currently

threatened. Conservation planning will be key to identify what are the best conservation actions and where to apply them to reduce the risk of collapse for Myanmar's natural ecosystems.

Introduction

Background

The Myanmar National Ecosystem Assessment contributes to the GEF funded Strengthening Sustainability of Protected Area Management in Myanmar project. To support the Myanmar National Ecosystem Assessment, Myanmar's terrestrial ecosystems were assessed under the International Union for the Conservation of Nature (IUCN) Red List of Ecosystems Categories and Criteria.

This report describes the development of the IUCN Red List of Ecosystems for Myanmar, which included:

- A detailed literature review of all published and unpublished material relevant to the status of ecosystems in Myanmar;
- The development of an ecosystem typology for Myanmar suitable for conducting a national scale IUCN Red List of Ecosystems assessment;
- Production of a guide to the terrestrial ecosystems of Myanmar to describe the units assessed under the red listing criteria (see ecosystem descriptions);
- More than 4000 km of reconnaissance transects traversed across Myanmar to collect georeferenced field data relevant to the mapping and assessment of Myanmar's ecosystems;
- A country-wide satellite remote sensing analysis to develop high resolution maps of Myanmar's terrestrial ecosystems from earth observation data;
- The analysis of spatial, biotic and abiotic changes to ecosystems to identify those ecosystems at the greatest risk of ecosystem collapse;
- Application of the IUCN Red List of Ecosystems categories and criteria to each ecosystem in the national typology to develop a list of threatened terrestrial ecosystems of Myanmar; and
- An expert review process for the ecosystem typology, descriptions and assessments.

To promote ecosystem conservation in Myanmar and support national-scale conservation planning and environmental reporting, all data and analysis code have been made open access (see data availability, see Appendices).

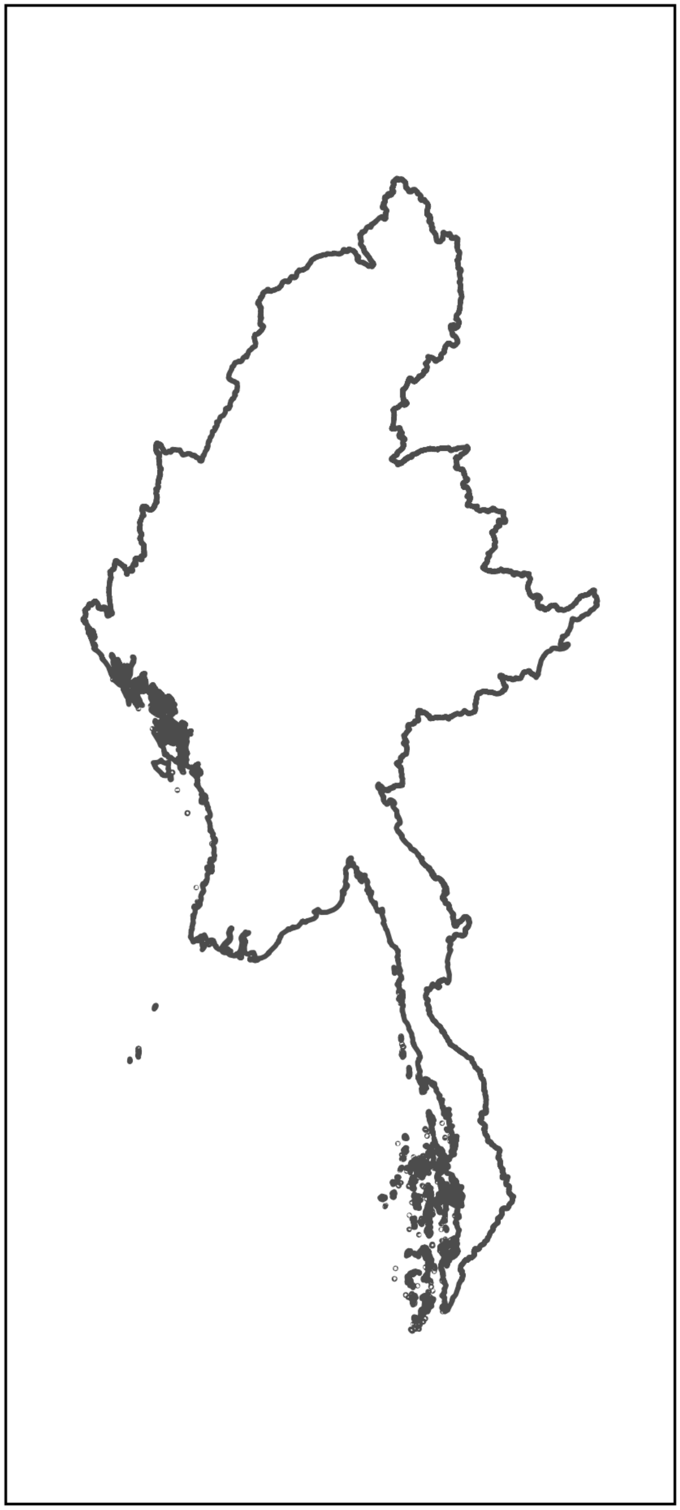

Figure 1: A map of Myanmar showing the area of assessment in grey

The ecosystems of Myanmar: an overview

Myanmar (Figure 1) has a monsoonal climate throughout its full latitudinal range (9-28°N). The rain-bearing winds come from the south-west across the Bay of Bengal, with the wettest parts of the country being the Tanintharyi coast in the south and the Rakhine Bengal coast in the north receiving in excess of 5,000 mm of rainfall annually (Figure 2). The peak rainy season lasts from June to September, with rainfall persisting into October and November. December, January and February constitute the dry 'cool' season. Precipitation averages close to zero for the months December-March and, although temperatures are marginally cooler than in the rainy season, much of the country experiences significant rates of evapotranspiration and water deficits, especially in warmer months April and May at the end of the dry season prior to arrival of the monsoon.

The strong seasonal drought, alternating with reliable and abundant rain underpins ideal conditions for development of tropical dry forests, which dominate the majority of the country throughout most of the lowlands, foothills and plateaus. The dry forests are dominated by dipterocarps and teak, and usually have a mixed evergreen-deciduous phenology, with a variable proportion of tree canopies devoid of living leaves in the latter part of the dry season when water deficit is at its maximum. A patchy distribution of dense bamboo breaks through these forests is associated with human disturbance, but may also reflect legacies of natural disturbances such as tropical storms or rare fires.

The effect of the monsoon on water balance within ecosystems is profoundly modified by topography. Coastal lowlands receiving exceptionally high rainfall or areas where evapotranspiration is reduced by topographic shelter or elevation, avoid high water deficits, and may support tropical or subtropical evergreen rainforests. An important example of these forests is found in the Tanintharyi lowlands, where the rainforests are diverse and include Sundaic elements shared with equatorial forests of Malaysia and Indonesia. Other evergreen rainforests are found in the sheltered lowland valleys of the Chindwin and upper Ayeyarwady and on the western rim of the Shan plateau.

A few of the highest tropical mountains and escarpments receiving substantial orographic condensation may support tropical montane fo rests, including mist forests with low, even tree canopies and abundant arboreal bryophytes, lichens, orchids and other epiphytes. These ecosystems are poorly documented in Myanmar, but similar forests have been recorded in other tropical parts of southeast Asia (Ashton 2014).

In other parts of the country, topography reduces moisture inputs and exacerbates loss. The monsoon winds are intercepted by the Arakan Yoma which runs parallel to the west coast and separates the central region of Myanmar from the sea. This creates a marked rain shadow in the centre of Myanmar - the "Dry Zone" were rainfall is as low as 550 mm per annum and exposed flat topography results in major evapotranspirative moisture loss in the dry season. Here, the dominant ecosystems are grassy savannas dominated by acacias and thorny shrubs amongst a continuous ground layer of C4 tussock grasses. The grass layer cures in the dry

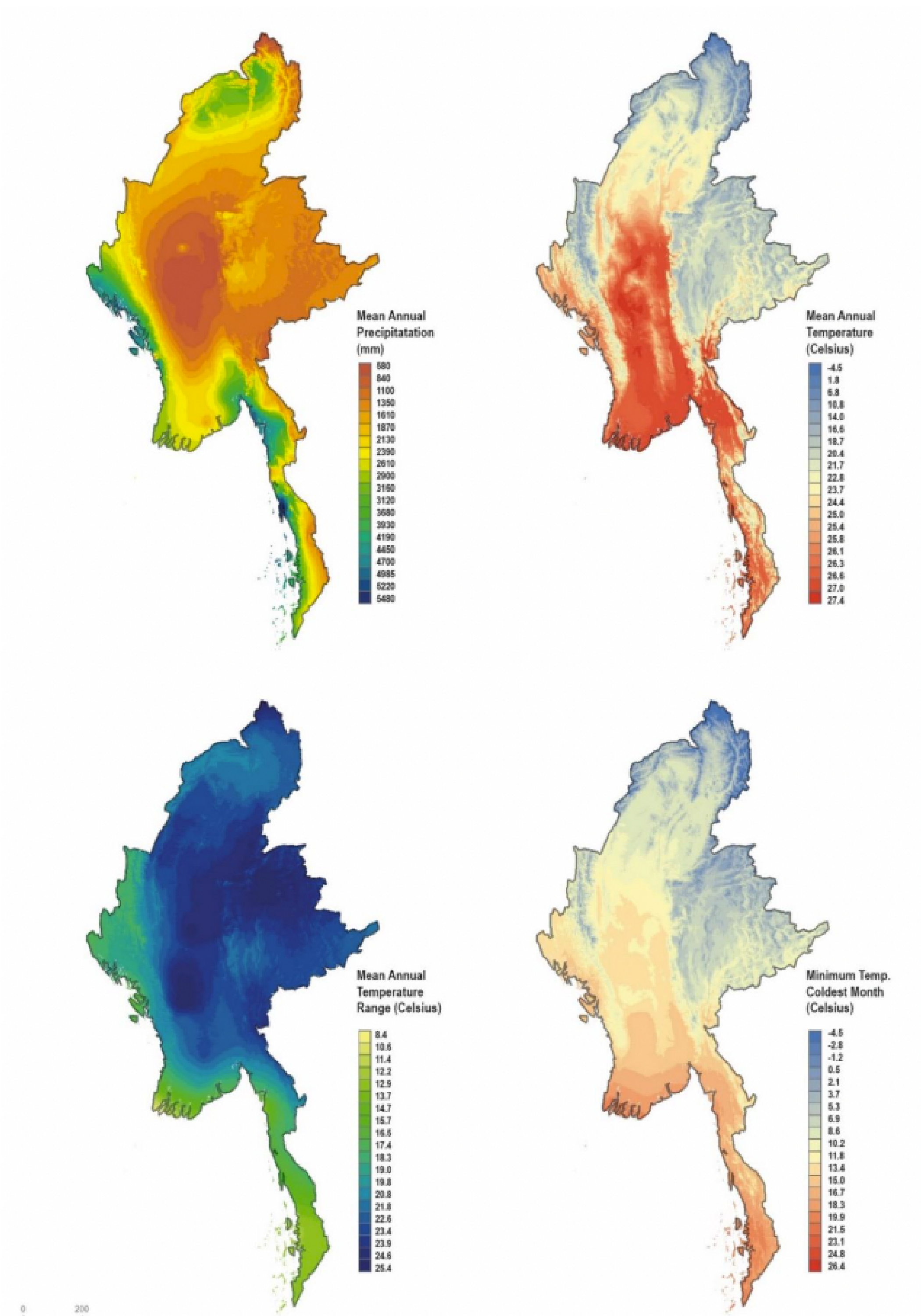

Figure 2: Major climatic gradients across Myanmar

season, allowing these ecosystems to become fire-prone when ignited by lightning (associated with dry monsoonal storms late in the dry season) or by humans. These savannas extend into the adjacent foothills surrounding the central Ayeyarwady valley, where they are dominated by dry-season deciduous broad-leaf trees. Rainfall generally increases with eleva tion, and landscapes tend to be characterised by savannas with increasingly taller and denser tree canopies on drier (south-facing) slopes, with tropical dry forests, essentially devoid of flammable grasses on more sheltered slopes. Finer textured soils that retain higher levels of moisture and nutrients also tend to favour tropical dry forests over savannas.

An interesting expression of savanna ecosystems occurs on elevated hills 1000-2000 m above sea level, where reduced evapotranspiration moderates the severity of dry season droughts. These are tall forests dominated by relatively high densities of pine trees, which nonetheless have open canopies promoting seasonal growth and curing of flammable C4 grasses. The trees have high survival rates after surface fires due to their thick insulating bark, but may be killed on rare occasions when intense fires consume their leaf canopies. Pine savannas are scattered through the Kachin, Shan and Chin hills and extend to adjacent countries. Functionally similar pine savannas occur in the Caribbean and southeastern North America. Although the pine savannas contrast markedly with the low, open acacia savannas of the dry lowlands, they are united by their flammable grassy ground layer. With increasing elevation, temperatures decline, mild frosts may occur, precipitation increases and evapotranspirative losses decline. Under these conditions, tropical forests are replaced by temperate forests with simpler structure and lower diversity. These forests are dominated by tree families with strong northern temperate affinities including oaks, chestnuts, laurels and cherries, including a number with winter-deciduous phenology, which become dominant at higher elevations. At higher elevations still, where winter snow persists for weeks or months, these temperate broad-leaf deciduous forests are replaced by temperate montane conifer forests, which become lower in stature and more open with increasing exposure to cold winds. Both types of temperate forests are largely confined to the eastern Himalayan foothills in Kachin state, but limited occurrences extend south to the highest parts of the Chin Hills. At higher elevations, with increasingly cold temperatures, shorter growing seasons and prolonged snow cover, trees give way to alpine shrublands and herbfields, and ultimately to permanent snowfields, glaciers and icy cliffs and screes at more than 5,000 m above sea level (Figure 3).

Freshwater ecosystems are partly beyond the scope of this study, but notable examples include glacial lakes restricted to the southern ridges of the Himalayas, seasonal lakes on the Ayeyarwady floodplain and rare geothermal wetlands on the Rakhine coast. Palustrine wetlands on the interface between terrestrial and freshwater realms are extensive on the Aye yarwady floodplain and riparian corridors that extend along the major rivers. These wetlands are densely vegetated with grasses, sedges and other non-woody hydrophytes, and have strongly seasonal filling and drying regimes synchronised with the monsoon. Most dry completely duringJanuary–April, but some retain permanent water. The river banks and levees support forested wetlands with tree recruitment triggered by seasonal flood recession. The lowest part of the floodplain behind the Ayeyarwady deltas includes peat forests (characterised by kanazo), which are uncommon outside equatorial regions worldwide. The interface between the terrestrial and marine realms are

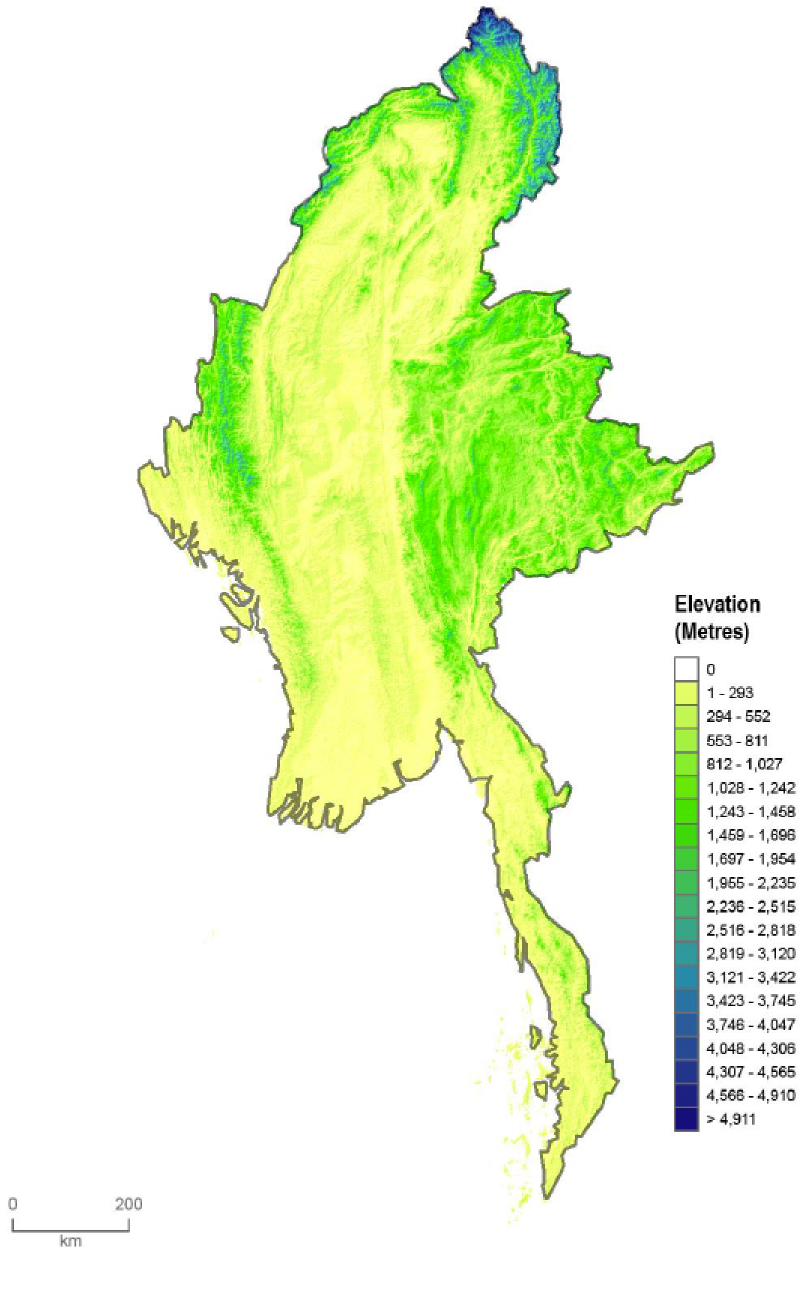

Figure 3: Elevation map of Myanmar

occupied by several coastal ecosystems, including several different compositional and structural expressions of mangrove forests, grassy saltmarshes, tidal mudflats and coastal dune vegetation. Finally, subterranean ecosystems are largely beyond the scope of this assessment, but we recognise important karst systems that include extensive dry caves and subterranean waters likely to harbour a diverse and endemic biota, and should be a focus of future assessments

Introduction to the IUCN Red List of Ecosystems

The IUCN Red List of Ecosystems (RLE) aims to support conservation in resource use and management decisions by identifying ecosystems most at risk of loss or collapse (D. A. Keith et al. 2013, 2015). Similar to the IUCN Red List of Threatened Species, the outcome of an RLE assessment is a list of ecosystems and their status for a region (Figure 1.4; (Rodríguez et al. 2011)). Because the RLE was developed to promote a consistent framework suitable for assessing and monitoring the status of ecosystems, it enables comparisons of collapse risk between countries, locations and ecosystem types (D. A. Keith et al. 2013).

For further information on the development of the RLE protocol, the theory and scientific foundations upon which they were developed, and detailed information on the purpose of each of the five criteria refer to the Guidelines for the application of IUCN Red List of Ecosystems Categories and Criteria (L. Bland et al. 2017). More information on the IUCN Red List of Ecosystems, is available in multiple languages on the IUCN Red List of Ecosystems website (www.iucnrle.org).

Assessments of ecosystem types (commonly termed 'assessment units' within Red List of Ecosystems assessments) are conducted by applying five criteria and their associated thresholds, enabling each ecosystem type to be classified according to their risk of collapse (termed 'status'). To ensure the assessment process is transparent and repeatable, each ecosystem type is clearly described according to the IUCN Red List of Ecosystems guidelines (L. Bland et al. 2017). This standard approach of applying the IUCN Red List of Ecosystems Categories and Criteria to clearly described ecosystems is critical to allow for accurate, comparable and repeatable assessments of ecosystems status and to contribute to the global IUCN Red List of Ecosystems programme.

Definitions

There are several key concepts that must be clearly defined to allow for repeatable ecosystem risk assessments:

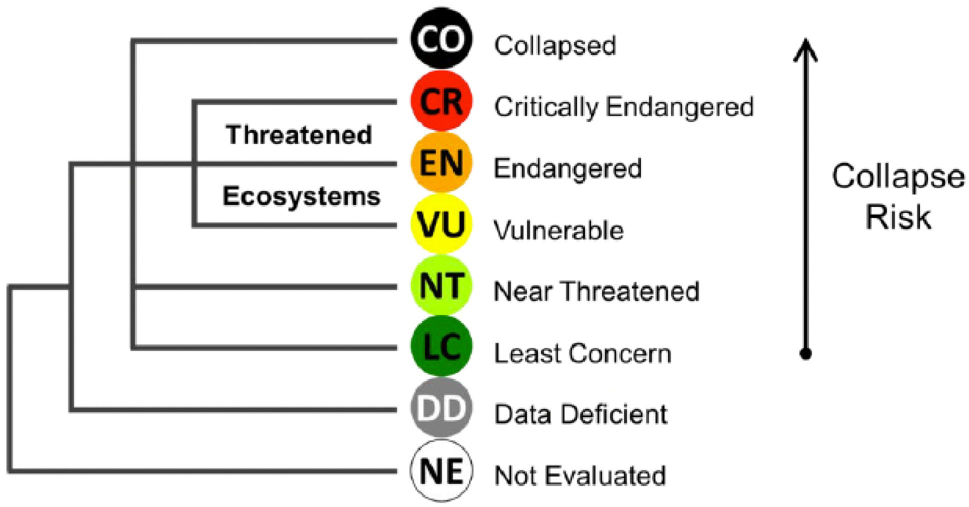

Figure 4: The IUCN Red List of Ecosystems categories, indicating the status of ecosystems. Threatened ecosystems are those assessed as Vulnerable, Endangered, or Critically Endangered. Source: (L. Bland et al. 2017)

Risk

Risk is defined as the probability of an adverse outcome over a specified time-frame. Here, the adverse outcome is the endpoint of ecosystem decline, which the RLE terms ecosystem collapse.

Ecosystem collapse

Understanding the concept of ecosystem collapse is critical for interpreting IUCN RLE assessments. For the purposes of the RLE, "an ecosystem is Collapsed when it is virtually certain that its defining biotic or abiotic features are lost from all occurrences, and the characteristic native biota are no longer sustained. Collapse may occur when most of the diagnostic components of the characteristic native biota are lost from the system, or when functional components (biota that perform key roles in ecosystem organisation) are greatly reduced in abundance and lose the ability to recruit." According to the IUCN guidelines (L. Bland et al. 2017), risks to ecosystems can be caused by a variety of threatening processes that are expressed through different symptoms of ecosystem collapse. The RLE risk model groups these symptoms into four major types, which ultimately form the RLE criteria (Figure 5).

For more information on the concept of collapse and how to identify when an ecosystem is collapsed, we recommend referring to the IUCN Red List of Ecosystems guidelines, which describes this in detail (Bland et al., 2017a; Bland et al., 2018). In this report and as

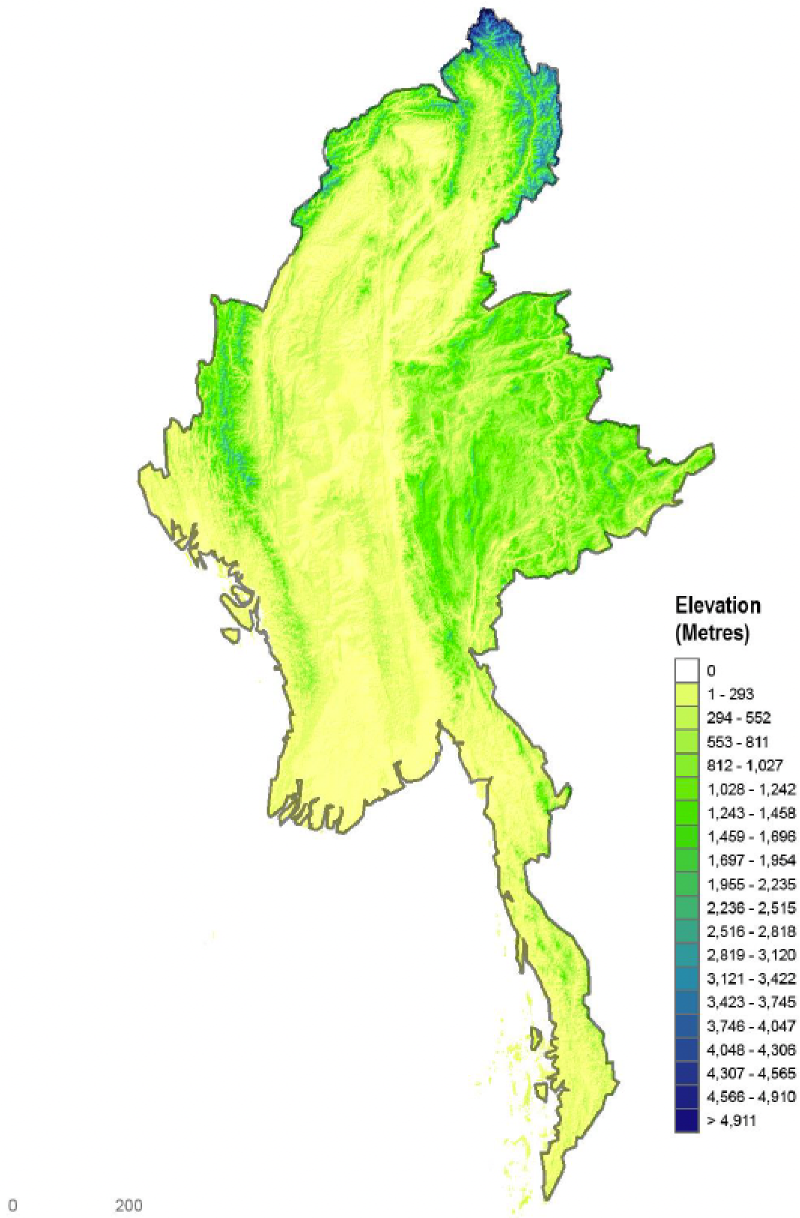

Figure 5: The IUCN Red List of Ecosystems risk assessment model. Source: (L. Bland et al. 2017).

recommended by the guidelines, we explicitly define collapse for each ecosystem type in Myanmar in their ecosystem descriptions (See section 3).

Time frames

Because risks must be assessed over specified time frames, a standard set of time frames are carefully defined in the IUCN Red List of Ecosystems Categories and Criteria. There are four specified time frames used in the RLE:

- The historical past. We notionally use the year 1750, which marks the onset of industrial-scale exploitation of ecosystems in South-East Asia;
- The recent past. This is the past 50 years (1969-2019), which is considered long enough to distinguish directional change from natural variability;
- Any 50-year period including the recent past, present and future. Predictions and inferences based on past declines, simulation models and any other model considered suitable for assessing risks into the future may be used.
- The future. Again, predictions are required to assess risks over this time frame and are usually based on models that use information about the response of ecosystems to threatening processes.

IUCN Red List of Ecosystems Categories and Criteria

IUCN Red List of Ecosystems Criteria

To assess the risk of ecosystem collapse, each ecosystem is assessed under five rule-based criteria that form the IUCN Red List of Ecosystems Criteria. These criteria were developed following nearly a decade of scientific work focused on understanding pathways of ecosystem decline, degradation, loss and collapse (Nicholson, Keith, and Wilcove 2009; Rodríguez et al. 2011, 2015; D. A. Keith et al. 2013, 2015; L. M. Bland et al. 2017; Murray et al. 2017, 2018; D. A. Keith, Akçakaya, and Murray 2018). Importantly, they relate the symptoms of ecosystem decline with the risk that an ecosystem will lose its defining features. The five criteria were designed to target different symptoms of ecosystem collapse (Figure 5). These symptoms are both distributional and functional:

- **Criterion A**: declines in distribution, which reduce carrying capacity for dependent biota;
- **Criterion B**: restricted distribution, which predisposes the system to spatially explicit threats;
- **Criterion C**: degradation of the abiotic environment, reducing habitat quality or abiotic niche diversity for component biota; and
- **Criterion D**: disruption of biotic processes and interactions

- **Criterion E**: allows for the integration of the above four symptoms into a simulation model of ecosystem dynamics to allow quantitative estimates of the risk of ecosystem collapse.

For further information on the criteria refer to the Guidelines for the application of IUCN Red List of Ecosystems Categories and Criteria (L. Bland et al. 2017).

Categories

Applying thresholds (decision rules) for each of the IUCN RLE criteria enables each ecosystem to be assigned to a category of risk ('status'). An ecosystem assessed under the RLE criteria can be placed into eight categories: Collapsed (CO), Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), Data Deficient (DD), and Not Evaluated (NE, Figure 4).

The first six categories (CO, CR, EN, VU, NT and LC) are ordered in decreasing risk of collapse. The categories Data Deficient and Not Evaluated do not indicate a level of risk. For further details of the categories refer to the Guidelines for the application of IUCN Red List of Ecosystems Categories and Criteria (L. Bland et al. 2017). We applied version 2.2 of the IUCN Red List of Ecosystems Criteria (Table 1.1).

⚠ TODO: Add Table 1.1

The IUCN Red List of Ecosystems Criteria, Version 2.2. Source: (L. Bland et al. 2017).

Assessment process

Application of the IUCN Red List of Ecosystems Categories and Criteria follows a generic sequential process that includes:

- Adapting the newly developed global ecosystem typology (D. A. Keith et al. 2020; D. Keith et al. 2022) to the area of assessment (Myanmar's terrestrial environment, Figure 1). This process is guided by experts and the result is a list of ecosystem types for the area of assessment that will be assessed under the RLE protocol;
- Describing each of the ecosystem types in ecosystem typology following the standard approach detailed in the Guidelines for the application of IUCN Red List of Ecosystems Categories and Criteria (L. Bland et al. 2017);
- If no map data is available to support the assessment, an ecosystem mapping project is required to support the ecosystem descriptions and assessment of several of the RLE criteria;

- Applying the assessment criteria to each ecosystem type, which requires extensive data searches and analyses. The outcome of each ecosystem assessment consists of a status of the ecosystem under 5 criteria and 18 subcriteria of the IUCN Red List of Ecosystems categories and criteria;
- Compiling the results into a comprehensive IUCN Red List of Ecosystems for the area of assessment (this report), which describes each ecosystem and identifies ecosystems according to their risk of collapse.

This report details each of these steps in the following sections.

Terrestrial Ecosystems of Myanmar

Terrestrial Ecosystems of Myanmar

The Myanmar ecosystem typology includes ...

Ecosystem description and assessment

Ecosystem accounts provided in this section consist of two components, an ecosystem description and a detailed summary of the application of the IUCN Red List of Ecosystem criteria. The ecosystem description follows the standard format suggested by the IUCN. Ecosystem descriptions are an essential component of IUCN Red List of Ecosystems assessments and serve the purpose of clearly defining each assessment unit. This allows repeated application of the categories and criteria to a single defined unit and supports red listing and cross-walking at the global scale. The associated assessment section provides the details the Red List assessments, including the data sources, methods of analysis, evidence statements and key references.

Table 1: Components of ecosystem description

Component	Description
Authors	Authors of the description and the assessment.
Myanmar ecosystem names	Alternative names of the ecosystem.
Biome	Biome membership according to the global ecosystem typology.
Functional group	Functional group membership according to the global ecosystem typology.
Global classification	Classification code according to the global ecosystem typology.
Description	General overview of the principal components and dynamics of the ecosystem. Includes a photograph of the ecosystem.
Distribution	Short written description and range map of the spatial distribution of the ecosystem.
Characteristic native biota	Identifies the defining biotic features of the ecosystem, including diagnostic native taxa, functional components of the characteristic biota.
Abiotic environment	Identifies the defining abiotic features of the ecosystem, including descriptions of the characteristic states or summary of values of the key abiotic variables.
Key processes and interactions	Describes the key ecosystem drivers and interactions among biota and the abiotic environment.
Major threats	Short summary of the major threats and impacts to the ecosystem.
Ecosystem collapse definition	Short description of the collapsed state of the ecosystem and any associated thresholds.
Assessment summary	Short summary of the red list of ecosystems assessment.
Assessment outcome	Short format assessed status of the ecosystem.

Component	Description
IUCN Red List of Ecosystems Categories and Criteria	Version of the IUCN Red List of Ecosystems criteria used in the assessment.
Year published	Publication year.
Date assessed	The date the ecosystem assessment was completed.
Assessment credits	Names the authors, reviewers and contributors to the assessment.
Assessment summary	Short summary of the red list of ecosystems assessment.
Criterion A	Description of data, analysis and methods used to assess the criterion and the status outcome.
Criterion B	Description of data, analysis and methods used to assess the criterion and the status outcome.
Criterion C	Description of data, analysis and methods used to assess the criterion and the status outcome.
Criterion D	Description of data, analysis and methods used to assess the criterion and the status outcome.
Criterion E	Description of data, analysis and methods used to assess the criterion and the status outcome.

Tanintharyi island rainforest

Authors: N.J. Murray, R. Tizard, D.A. Keith

Ecosystem names: Tropical rainforest (Kress et al. 2003), Lowland evergreen rainforest (G. Connette et al. 2016)

Biome: Tropical-subtropical forests biome (T1)

Functional Group: Tropical/Subtropical lowland rainforests (T1.1)

Global classification: MMR-T1.1.1

IUCN Status: Vulnerable (Least Concern – Vulnerable)

Ecosystem Photo:

Ecosystem Map:

Description: Tanintharyi island rainforest occurs on offshore islands across Tanintharyi, including the Myeik archipelago. It is a lowland, primarily evergreen, forest ecosystem that has some maritime influence. It shows a tolerance of salty ocean seaspray and historically received much of its nutrient input from nesting seabird populations that have subsequently collapsed. It occurs across a wide range of island types including limestone, rubble and sand islands. The canopy is primarily evergreen Dipterocarpaceae (Tagane et al. 2019). Stamp (1925) reported forests of "tall varied trees who dense canopy, cutting off nearly all light from the ground, is made more intense by the wealth of woody climbers which have struggled upwards to reach the light".

Distribution: Occurs on offshore islands in Tanintharyi state.

Characteristic Native Biota: Largely unknown but probably moderately diverse. A recent survey of the Myiek archipelago reported a total of 305 species belonging to 241 genera and 91 families (Tagane et al. 2019). Surveys of Lampi Island marine park indicated 20 species of Dipterocarpaceae. The islands support several localized species along the coastal edges including Great-billed Heron Ardea sumatrana, Beach Thick-knee Esacus magnirostris (NT) and Black-naped Tern Sterna sumatrana, and Collared Kingfisher Todiramphus chloris. The islands also support a range of nomadic frugivores including Nicobar Pigeon Caloenas nicobarica (NT), Large Green-pigeon Treron capellei (VU), Pied Imperialpigeon Ducula bicolor, and Plain-pouched Hornbill Rhyticeros subruficollis (VU). The islands also support a population of tool using Long-tailed Macaque Macaca fascicularis (VU).

Abiotic environment: This ecosystem occurs on offshore islands exposed to the influence of maritime salt. Largely monsoonal, with a minimum temperature of 21 degrees in December to a maximum of 28.8 in August. Precipitation is highly seasonal, with a dry season occurring from November to March followed by a strong wet season from May to October (Oo et al., 2019).

Key processes and interactions: This ecosystem received much of its nutrients from nesting seabird populations that are mostly no longer present. Dispersal is similarly mediated by mobile fauna, and endemism due to isolation is likely to be high.

Major threats: Unregulated tourism development is the principal threat to this ecosystem (UNESCO n.d.).

Ecosystem collapse definition: This ecosystem is regarded as collapsed when its area has declined to zero, when the proportion of the ecosystem considered primary forest declines to 0.

Assessment summary: **This ecosystem is broadly distributed across many isolated islands in southern Myanmar, but there is an expected reduction in climate suitability over the next three decades. Threats from humans and biotic degradation are expected to be low, as confirmed by an analysis of the Forest Landscape Integrity Index. The ecosystem qualified for listing as Vulnerable under Criterion C, with**

a plausible range of Least Concern – Vulnerable. Vulnerable (Least Concern – Vulnerable).

Assessment information:

Criteria

Status

Criterion A

A1

DD

A2a

DD

A2b

DD

A3

DD

Criterion B

B1

LC

B2

LC

subcriteria

NA

B3

LC

Criterion C

C1

DD

C2a

VU(LC-VU)

C2b

DD

C3

DD

Criterion D

D1

DD

D2a

DD

D2b

LC

D3

LC

Criterion E

E

NE

Assessment outcome: **Vulnerable (Least Concern – Vulnerable)**

Year published: 2020

Date assessed: 20th January 2020

Assessment credits:

Assessed by: Nicholas Murray

Reviewed by: David Keith

Contributions by: Lee Grismer

Criterion A: No time-series map data was available for assessing reduction in distribution of this ecosystem over any of the assessment time frames. **Data Deficient.**

Criterion B: {embed}`mmr-t1.1.1-crit-b-summary`

There is no evidence that suggests this ecosystem should meet the criteria to be listed as Near Threatened. The ecosystem is assessed as Least Concern under Criterion B1 and B2. **Least Concern.**

Criterion C: An environmental suitability model (Ferrer-Paris et al. 2019 see methods) suggests that reductions in climate suitability will occur with an extent and severity to meet the category thresholds for Vulnerable under Criterion C2a. Variation in the outcomes of the modelled scenarios suggested that the ecosystem could potentially meet thresholds for Least Concern to Vulnerable, and therefore the ecosystem is assessed as Vulnerable (the most commonly returned result from all scenarios), with plausible bounds of Least Concern – Vulnerable. **Vulnerable (Least Concern – Vulnerable).**

Criterion D: Analyses of a dataset that depicts the distribution of primary forests in South-East Asia (Potapov et al. 2019) suggest that 74.9% of the remaining extent of this ecosystem is primary forest. If 100% of the ecosystem is assumed to be primary forest in 1750, we estimate a 25.1% loss in primary forest extent since 1750. Here we assume that loss of primary forest extent has a relative severity of >90%, and the ecosystem is assessed as Least Concern under Criterion D3. Analyses of the full time-series of primary forest data (n = 18) suggests an 8.1% reduction of primary forest in this ecosystem over the period 2000-2017. A linear model fit to this dataset suggests that primary forest cover in this ecosystem will not decline sufficiently to meet any category thresholds over a 50 year period (1984-2034). The ecosystem is assessed as Least Concern under Criterion D2b. **Least Concern.**

(Note, the HTML image gets resized unless there is content following it.)

Criterion E: No models were used to assess Criterion E. **Not Evaluated.**

Criterion B Details

This notebook provides step-by-step details on {term}`Criterion B` calculations.

Setup

Import Python modules

```
import os

import ee
import geopandas as gpd
from lonboard import Map, PolygonLayer, BitmapTileLayer

from gee_redlist.ee_auth import initialize_ee
from gee_redlist.ee_rle import load_yaml, make_eoo, area_km2, get_aoo_grid_projection
```

Initialize Earth Engine

```
initialize_ee(project=os.environ['GOOGLE_CLOUD_PROJECT'])
```

Analysis

```
# Define the ecosystem that this notebook is analyzing
ecosystem_code = 'MMR-T1.1.1'
```

```
# Load the country config
country_config_path = os.environ['PIXI_PROJECT_ROOT'] + '/config/country_config.yaml'
country_config = load_yaml(country_config_path)

# Extract the GEE project path from the country config
gee_project_path = country_config['gee_project_path']

# Extract the class info for the ecosystem
class_info = [x for x in country_config['classified_image']['classes'] if x['code'] == ecosys
print(f'{class_info = }')

ecosystem_image = {
    'asset_id': f"{gee_project_path}/{ecosystem_code}/{class_info['id']}",
    'pixel_value': class_info['id']
}
print(f'{ecosystem_image = }')
```

```
class_info = {'id': 52, 'name': 'Tanintharyi island rainforest', 'code': 'MMR-
T1.1.1'}
ecosystem_image = {'asset_id': 'projects/goog-rle-assessments/assets/MMR-
T1.1.1/52', 'pixel_value': 52}
```

```
classified_image_asset_id = f"{country_config['gee_project_path']}/{country_config['classifie
print(f'{classified_image_asset_id = }')

class_img = (
    ee.Image(classified_image_asset_id)
      .eq(ecosystem_image['pixel_value'])
      .selfMask()
```

```
)
print(f'class_img: {class_img.getInfo()}')
```

```
classified_image_asset_id = 'projects/goog-rle-assessments/assets/mm_ecosys_v7b'
class_img: {'type': 'Image', 'bands': [{'id': 'b1', 'data_type': {'type': 'PixelType', 'prec
0.0008084837557075694, 28.548369897789982]}], 'properties': {'system:footprint': {'type': 'Li
```

```
# Commented out until bug is fixed: https://github.com/developmentseed/lonboard/issues/1064
# # Determine the coordinates for viewing the image
# longitude, latitude = class_img.geometry().centroid().getInfo()['coordinates']
# longitude, latitude
```

Extent of occurrence (EOO) (subcriterion B1)

Set the scale (in meters) for reducing the image pixels to polygons. Use the image's nominal scale unless is is less than 50 meters per pixel.

```
reduction_scale = max(class_img.projection().nominalScale().getInfo(), 50)
reduction_scale
```

```
90
```

Convert the classified image to vectors.

```
ecosystem_polygons = class_img.updateMask(1).reduceToVectors(
    scale=reduction_scale,
    geometry=class_img.geometry(),
    geometryType='polygon',
    maxPixels=1e12,
    bestEffort=False
)
```

Create a convex hull that encompasses the ecosystem polygons.

```
# convexHull() is called twice as a workaround for a bug
# (https://issuetracker.google.com/issues/465490917)
hull = ecosystem_polygons.geometry().convexHull(maxError=1).convexHull(maxError=1)
```

```
# Note:
#   - area() without the projection argument calculates the geodesic area.
#   - area(proj=) calculates the planar area. the area is calculated in projected units (10 I
# This is different than the javascript version, which calculates the area without reprojecti
aoo_area_km2 = hull.area(1, proj=get_aoo_grid_projection()).getInfo() * 1e2
print(f'The area of the hull is {aoo_area_km2:.2f} km²')
```

```
The area of the hull is 50141.45 km²
```

```python
aoo_area_km2_geodesic = hull.area().getInfo() * 1e-6
print(f'The geodesic area of the hull is {aoo_area_km2_geodesic:.2f} km²')
```

```
The geodesic area of the hull is 50336.64 km²
```

```python
(aoo_area_km2_geodesic - aoo_area_km2) / aoo_area_km2
```

```
0.003892813201885356
```

TRY calculating area in projected coords

```
# hull_projected = hull.transform(get_aoo_grid_projection(), maxError=1)
# hull_projected.getInfo()
```

```
# hull_projected.projection().getInfo()
```

```
# hull_projected.area(1, get_aoo_grid_projection()).getInfo() * 1e2
```

DEBUG using shapely for convex hull

```
ecosystem_polygons_gdf = gpd.GeoDataFrame.from_features(
    ecosystem_polygons.getInfo()['features'],
    crs='EPSG:4326'
)

# Save to file
ecosystem_polygons_gdf.to_parquet('test_ecosystem_polygons.parquet')
```

```
ecosystem_polygons_gdf
```

	geometry	count	label
0	POLYGON ((97.70122 10.6348, 97.70203 10.6348, ...	2	1
1	POLYGON ((97.7182 12.10704, 97.71981 12.10704,...	25	1
2	POLYGON ((97.72305 12.11755, 97.72386 12.11755...	3	1
3	POLYGON ((97.72467 12.11917, 97.72547 12.11917...	275	1
4	POLYGON ((97.72952 12.13372, 97.73194 12.13372...	140	1
...	...	...	...
600	POLYGON ((97.67131 12.04722, 97.67211 12.04722...	2	1
601	POLYGON ((97.67131 12.03671, 97.67211 12.03671...	1	1
602	POLYGON ((97.67211 12.04883, 97.67373 12.04883...	3	1
603	POLYGON ((97.67373 12.03509, 97.67616 12.03509...	146	1
604	POLYGON ((97.68101 10.46259, 97.68262 10.46259...	26	1

```
from shapely.ops import unary_union
hull_geom = unary_union(ecosystem_polygons_gdf.geometry).convex_hull
```

```
# Reproject the geometry to ESRI:54034 (World Cylindrical Equal Area) and compute area in pro
from pyproj import CRS, Transformer
import shapely

# Define projections
```

```python
wgs84 = CRS("EPSG:4326")
cea = CRS("ESRI:54034")
project_to_cea = Transformer.from_crs(wgs84, cea, always_xy=True).transform

# Project hull geometry
hull_geom_projected = shapely.ops.transform(project_to_cea, hull_geom)
```

```python
# Area is calculated in square meters (ESRI:54034's units)
hull_geom_projected.area * 1e-6
```

```
50057.86991307719
```

```python
# Try to project first, then calculate hull
ecosystem_polygons_gdf_projected = ecosystem_polygons_gdf.set_crs(wgs84).to_crs(cea)
hull_geom_projected = ecosystem_polygons_gdf_projected.geometry.union_all().convex_hull
hull_geom_projected.area * 1e-6
```

```
50057.86991307719
```

```python
diff = (hull_geom_projected.area  * 1e-6 - aoo_area_km2 ) / aoo_area_km2
diff
```

```
-0.0016668938119499528
```

END TEST

Display EOO Layers

Ecosystem Tiles

```
tile_url = class_img.getMapId(
    vis_params={
        'palette': ['blue'],
        'opacity': 0.5
    }
)['tile_fetcher'].url_format

tile_layer = BitmapTileLayer(
    data=tile_url,
    tile_size=256,
    max_requests=-1,
    min_zoom=0,
    max_zoom=19,
)
```

Ecosystem Polygons Layer

```
ecosystem_polygons_layer = PolygonLayer.from_geopandas(
    ecosystem_polygons_gdf,
    get_fill_color=[255, 0, 0, 127],
    stroked=True,
    get_line_width=2,
    get_line_color=[0, 0, 0, 150],
)
```

Ecosystem Hull Layer

```
type(hull_geom_projected)
```

```
shapely.geometry.polygon.Polygon
```

```
hull_gdf = gpd.GeoDataFrame.from_features(
    ee.FeatureCollection(hull).getInfo(),
    crs='EPSG:4326'
)

hull_layer = PolygonLayer.from_geopandas(
    hull_gdf,
    get_fill_color=[0, 0, 255, 63],
    stroked=True,
    get_line_width=200,
    get_line_color=[0, 0, 0, 150],
)
```

Display the map.

```
m = Map(
    layers=[
        ecosystem_polygons_layer,
        tile_layer,
        hull_layer,
    ],
)

m
```

```
<lonboard._map.Map object at 0x30abec310>
```

Verify that the step-by-step results are consistent

```
# Direct call to `make_eoo()`
aoo_area_km2_direct_call = area_km2(make_eoo(class_img)).getInfo()
print(f'EOO area: {aoo_area_km2_direct_call:.0f} km²')
```

```
EOO area: 50337 km²
```

```
# Assert the two values are close to each other.
# assert math.isclose(aoo_area_km2, aoo_area_km2_direct_call, abs_tol=1e-4)
```

Area of Occupancy (AOO) (subcriterion B2)

The protocol for this adjustment includes the following steps:

- Intersect AOO grid with the ecosystem's distribution map.
- Calculate extent of the ecosystem type in each grid cell ('area') and sum these areas to obtain the total ecosystem area ('total area').
- Arrange grid cells in ascending order based on their area (smaller first).
- Calculate accumulated sum of area per cell ('cumulative area').
- Calculate 'cumulative proportion' by dividing 'cumulative area' by 'total area' (cumulative proportion takes values between 0 and 1).
- Calculate AOO by counting the number of cells with a 'cumulative proportion' greater than 0.01 (i.e. exclude cells that in combination account for up to 1% of the total mapped extent of the ecosystem type).

Intersect AOO grid with the ecosystem's distribution map

Load the AOO grid projection

```
aoo_grid_proj = get_aoo_grid_projection()

aoo_grid_proj.getInfo()
```

```
{'type': 'Projection',
 'wkt': 'PROJCS["World_Cylindrical_Equal_Area", \n  GEOGCS["WGS 84", \n    DATUM["WGS_1984",
 'transform': [10000, 0, 0, 0, 10000, 0]}
```

Extract the grid scale parameters

```
aoo_x_scale, _, _, _, aoo_y_scale, _ = aoo_grid_proj.getInfo()['transform']
print(f'{aoo_x_scale = } meters')
print(f'{aoo_y_scale = } meters')
```

```
aoo_x_scale = 10000 meters
aoo_y_scale = 10000 meters
```

- Create an Earth Engine feature collection of AOO grid cells that intersect with the ecosystem, and calculate the fractional coverage of the ecosystem within the grid cell.

```
fractional_coverage_fc = class_img.unmask().reduceRegions(
  collection=class_img.geometry().coveringGrid(aoo_grid_proj),
  reducer=ee.Reducer.mean(),
).filter(ee.Filter.gt('mean', 0))

# Convert the Earth Engine feature collection to a GeoPandas GeoDataFrame.
fractional_coverage_gdf = ee.data.computeFeatures({
    "expression": fractional_coverage_fc,
    "fileFormat": "GEOPANDAS_GEODATAFRAME",
})
fractional_coverage_gdf.rename(columns={"mean": "coverage"}, inplace=True)

# Set the CRS (Earth Engine data is in EPSG:4326)
fractional_coverage_gdf = fractional_coverage_gdf.set_crs('EPSG:4326')
```

```
aoo_grid_cell_count = len(fractional_coverage_gdf)
aoo_grid_cell_count
```

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Calculate grid cell area and the total ecosystem area

- Calculate extent of the ecosystem type in each grid cell ('area') and sum these areas to obtain the total ecosystem area ('total area').

```
fractional_coverage_gdf['area'] = fractional_coverage_gdf['coverage'] * aoo_x_scale * aoo_y_s

fractional_coverage_gdf.sort_values(by="area")[0:4]
```

	geometry	coverage	area
175	POLYGON ((98.09603 12.57845, 98.18586 12.57845...	0.000035	3481.367444
125	POLYGON ((98.09603 11.93102, 98.18586 11.93102...	0.000079	7875.324046
111	POLYGON ((98.09603 11.74632, 98.18586 11.74632...	0.000079	7880.464175
74	POLYGON ((98.54519 11.1008, 98.63502 11.1008, ...	0.000079	7898.091697

```
total_area_km2 = fractional_coverage_gdf['area'].sum() / 1e6
print(f'Total ecosystem area: {total_area_km2:.0f} km²')
```

```
Total ecosystem area: 1937 km²
```

Calculate cumulative area in ordered cells

- Arrange grid cells in ascending order based on their area (smaller first).
- Calculate accumulated sum of area per cell ('cumulative area').

```
fractional_coverage_gdf = fractional_coverage_gdf.sort_values(by="area")
fractional_coverage_gdf["cumulative_area"] = fractional_coverage_gdf["area"].cumsum()

fractional_coverage_gdf.sort_values(by="area").head()
```

	geometry	coverage	area	cumulative_area
175	POLYGON ((98.09603 12.57845, 98.18586 12.57845...	0.000035	3481.367444	3481.367444
125	POLYGON ((98.09603 11.93102, 98.18586 11.93102...	0.000079	7875.324046	11356.691491
111	POLYGON ((98.09603 11.74632, 98.18586 11.74632...	0.000079	7880.464175	19237.155665
74	POLYGON ((98.54519 11.1008, 98.63502 11.1008, ...	0.000079	7898.091697	27135.247363
160	POLYGON ((97.91637 12.39331, 98.0062 12.39331,...	0.000123	12301.457861	39436.705224

Calculate the cumulative proportion

- Calculate 'cumulative proportion' by dividing 'cumulative area' by 'total area' (cumulative proportion takes values between 0 and 1).

```
fractional_coverage_gdf["cumulative_proportion"] = fractional_coverage_gdf["cumulative_area"]

fractional_coverage_gdf
```

	geometry	coverage	area	cumulative_area	cu
175	POLYGON ((98.09603 12.57845, 98.18586 12.57845...	0.000035	3.481367e+03	3.481367e+03	0.0
125	POLYGON ((98.09603 11.93102, 98.18586 11.93102...	0.000079	7.875324e+03	1.135669e+04	0.0
111	POLYGON ((98.09603 11.74632, 98.18586 11.74632...	0.000079	7.880464e+03	1.923716e+04	0.0
74	POLYGON ((98.54519 11.1008, 98.63502 11.1008, ...	0.000079	7.898092e+03	2.713525e+04	0.0

	geometry	coverage	area	cumulative_area	cu
160	POLYGON ((97.91637 12.39331, 98.0062 12.39331,...	0.000123	1.230146e+04	3.943671e+04	0.0
...	...	...	...	...	...
108	POLYGON ((98.45536 11.65401, 98.54519 11.65401...	0.549146	5.491457e+07	1.689946e+09	0.8
102	POLYGON ((98.45536 11.56174, 98.54519 11.56174...	0.561263	5.612625e+07	1.746072e+09	0.9
164	POLYGON ((98.36552 12.39331, 98.45536 12.39331...	0.586257	5.862569e+07	1.804698e+09	0.9
99	POLYGON ((98.18586 11.56174, 98.27569 11.56174...	0.607082	6.070816e+07	1.865406e+09	0.9
93	POLYGON ((98.18586 11.46949, 98.27569 11.46949...	0.712497	7.124972e+07	1.936656e+09	1.0

Calculate AOO

- Calculate AOO by counting the number of cells with a 'cumulative proportion' greater than 0.01 (i.e. exclude cells that in combination account for up to 1% of the total mapped extent of the ecosystem type).

```
aoo_grid_cells = fractional_coverage_gdf[fractional_coverage_gdf["cumulative_proportion"] > 0
print(f"AOO (number of cells with cumulative proportion > 0.01): {len(aoo_grid_cells)}")
```

```
AOO (number of cells with cumulative proportion > 0.01): 139
```

```
aoo_grid_cells_dropped = fractional_coverage_gdf[fractional_coverage_gdf["cumulative_proporti
```

Display the layers

```
aoo_grid_cells_layer = PolygonLayer.from_geopandas(
    aoo_grid_cells,
    get_fill_color=[0, 255, 0, 63],
)

aoo_grid_cells_layer_dropped = PolygonLayer.from_geopandas(
    aoo_grid_cells_dropped,
    get_fill_color=[255, 0, 0, 63],
)

m = Map(
    layers=[
```

```
        tile_layer,
        aoo_grid_cells_layer,
        aoo_grid_cells_layer_dropped
    ],
)

m
```

```
<lonboard._map.Map object at 0x1737827d0>
```

Verify that the step-by-step results are consistent

```
# # Direct call to `make_aoo()`
# aoo_cells_direct_call = make_aoo(class_img)

# print(f'AOO: {aoo_grid_cell_count_direct_call} grid cells')
```

```
# assert aoo_grid_cell_count == aoo_grid_cell_count_direct_call
```

Criterion B Summary

```
from IPython.display import Markdown, display
display(
    Markdown(f'AOO and EOO were measured as '
      f'{aoo_grid_cell_count} 10 x 10 km grid cells '
      f'and {aoo_area_km2:.0f} km², respectively. '
      f'See [Criterion B Details](mmr-t1-1-1-crit-b-test) for more information. '
      f'There is no evidence that suggests this ecosystem should meet the criteria to '
      f'be listed as Near Threatened. The ecosystem is assessed as Least Concern under '
      f'Criterion B1 and B2. '
      f'**Least Concern.**'
    )
)
```

AOO and EOO were measured as 206 10 x 10 km grid cells and 50141 km², respectively. See Criterion B Details for more information. There is no evidence that suggests this ecosystem should meet the criteria to be listed as Near Threatened. The ecosystem is assessed as Least Concern under Criterion B1 and B2. **Least Concern.**

Tanintharyi limestone tropical evergreen forest

Authors: N.J. Murray, R. Tizard, D.A. Keith

Ecosystem names: Tropical rainforest (Kress et al. 2003), Lowland evergreen rainforest (G. Connette et al. 2016), Forest on Limestone [Whitten et al., 1997]

Biome: Tropical-subtropical forests biome (T1)

Functional Group: Tropical/Subtropical lowland rainforests (T1.1)

Global classification: MMR-T1.1.3

IUCN Status: Endangered

Ecosystem Map:

Distribution: Occurs in karst landscapes in southern Tanintharyi. We used a global karst layer to refine our maps of this ecosystem type, and further work to map karst landscapes in southern Myanmar is recommended.

Characteristic Native Biota: Characteristic species of this ecosystem remain relatively unknown. Stamp (1925) lists the tree species occurring in this ecosystem as including Dipterocarpus alatus, D. grandiflorus, and D. turbinatus, Shorea spp, Anisoptera sp., Hopea odorata, and Parashorea stellata. This ecosystem occurs in isolated fragments and has high physical complexity, a suite of microhabitats, and relatively stable climate, this ecosystem provides habitat for a large number of endemic species, including gekkos and molluscs (Whitten et al., 1997; Grismer et al., 2018). This ecosystem supports some of the remaining populations of sundaic avifauna in Myanmar. This includes Great Argus Argusianus argus (NT), Storm's Stork Ciconia stormi (EN), White-crowned Hornbill Berenicornis comatus (EN), Helmeted Hornbill Rhinoplax vigil (CR), Red-throated Barbet Psilopogon mystacophanos (NT), Blue-rumped Parrot Psittinus cyanurus (NT), Banded Broadbill Eurylaimus harterti, Black-and-yellow Broadbill Eurylaimus ochromalus (NT), Green Broadbill Calyptomena viridis (NT), Crested Jay Platylophus galericulatus (NT), as well as a range of Bulbuls (Pycnonotidae) and Ground Babblers (Pellorneidae). The mammalian fauna is equally impressive with populations of Banded Langur Presbytis femoralis robinsoni (NT), Dusky Langur Trachypithecus obscurus (NT), Lar Gibbon Hylobates lar (EN), Banded Civet Hemigalus derbyanus (NT), Tiger Panthera tigris (EN), Mainland Clouded Leopard Neofelis nebulosa (VU), Asian Elephant Elephas maximus (EN) and Malayan Tapir Tapirus indicus (EN; Eames et al. (2005)).

Abiotic environment: Shallow soils that can be fairly acidic, topographically complex and reliable year-round rainfall of >100 mm per month and warm temperature that rarely fall below 10° C.

Key processes and interactions: Distribution is largely defined by the occurrence of Karst landscapes coinciding with a mean monthly rainfall of around 100 mm per month. This ecosystem may periodically become very dry, but a dense evergreen canopy can support humid microclimates throughout these periods (Whitten et al., 1997).

Major threats: Unregulated quarrying is considered a primary threat to this ecosystem (Grismer et al., 2018). In addition, deforestation is widespread in this region, primarily for the development of oil palm plantations, rubber plantations and other agroforestry, with deforestation rates reaching 7.85% in some areas of Tanintharyi, the highest rate of forest loss so far recorded in Myanmar (G. M. Connette et al. 2017).

Ecosystem collapse definition: This ecosystem is regarded as collapsed when its area has declined to zero, or when the proportion of the ecosystem considered primary forest declines to 0.

Assessment summary: **This ecosystem is highly restricted to limestone substrates and ongoing threats, particularly from quarrying, suggest that this ecosystem is undergoing a continuing decline.**

Assessment information:

Criteria

Status

Criterion A

A1

DD

A2a

DD

A2b

DD

A3

DD

Criterion B

B1

EN

B2

LC

subcriteria

B1a(i), B1a(iii)

B3

LC

Criterion C

C1

DD

C2a

LC

C2b

DD

C3

DD

Criterion D

D1

DD

D2a

DD

D2b

LC

D3

LC

Criterion E

E

NE

Assessment outcome: **Endangered**

Year published: 2020

Date assessed: 24th January 2020

Assessment credits:

Assessed by: Nicholas Murray

Reviewed by: David Keith

Contributions by: Lee Grismer

Criterion A: No time-series map data was available for assessing reduction in distribution of this ecosystem over any of the assessment time frames. **Data Deficient**.

Criterion B: {embed}`mmr-t1.1.1-crit-b-summary`

This ecosystem is highly restricted in limestone landscapes and has an AOO of 56 10 x 10 km grid cells and an EOO of 3,796 km2 There is evidence that limestone quarrying and other threats are leading to continuing decline, meeting subcriteria a(i) and a(iii). The ecosystem is assessed as **Endangered**.

Criterion C: Climate simulation models suggest that environmental conditions within the limestone landscapes of southern Myanmar are unlikely to reduce suitable areas sufficiently to result in this ecosystem becoming threatened by 2050. It should be noted that the occurrence of Karst landscapes is a key distributional driver of this ecosystem, and the scale at which the suitability models were run may not adequately depict the fine-scale changes expected over the next three decades. We recommend further work to refine maps of Karst landscape to better limit the distribution of our model. **Least Concern**.

Criterion D: Remote sensing analyses suggest that 72.4% of the remaining extent of this ecosystem meets criteria to be classified as primary forest (Potapov et al., 2019). If 100% of the ecosystem is assumed to be primary forest in 1750, there has been an 27.6% loss in primary forest extent since 1750. We assume that loss of primary forest has a relative severity of >90%, and use the extent of primary forest loss as a biotic variable for assessing Criterion D. With an 27.6% loss of primary forest extent, the ecosystem is assessed as Least Concern under Criterion D3. Analyses of the time-series of primary forest data (n = 18 time points) indicate that there has been 8.4% reduction in primary forest cover over the period 2000-2017. A linear model fit to this dataset, assuming that collapse occurs at 100% loss of primary forest cover, suggests that primary forest loss in this ecosystem will not occur to an extent to meet any category thresholds over a 50 year period (1984- 2034). The ecosystem is assessed as Least Concern under Criterion D2b. **Least Concern**.

Criterion E: No models were used to assess Criterion E. **Not Evaluated**.

Assessment Outcomes

Assessment Outcomes

Overall status of Myanmar ecosystems

A total of 64 ecosystem types were identified and evaluated ...

Recommendations

Recommendations

yada yada yada...

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Glossary

Area of occupancy (AOO) A standardised measure of the area that is occupied by an ecosystem type.

Extent of occurrence (EOO) A standardised measure of the area within which all occurrences of an ecosystem type exist

Tropical-subtropical forests biome (T1) The Tropical-subtropical forests biome includes moderate to highly productive ecosystems with closed tree canopies occurring at lower latitudes north and south of the equator. *(source: IUCN Global Ecosystem Typology)*

Tropical/Subtropical lowland rainforests (T1.1) These closed-canopy forests are renowned for their complex structure and high primary productivity, which support high functional and taxonomic diversity. *(source: IUCN Global Ecosystem Typology, T1.1)*

Criterion A Reduction in geographic distribution

Criterion B Restricted geographic distribution

Criterion C Criterion C assesses declines in ecosystem functions or processes based on symptoms of abiotic (environmental) degradation.

Criterion D Criterion D assesses declines in ecosystem functions or processes disruption of biotic processes, including declines of biota with key functional roles.

Criterion E Quantitative risk analysis

Sources

- Guidelines for the application of IUCN Red List of Ecosystems Categories and Criteria: version 2.0.

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Expert group on Myanmar Ecosystem Assessment

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Earth Engine Authentication Setup for GitHub Actions

This document explains how to configure Workload Identity Federation for Earth Engine authentication in GitHub Actions.

Overview

The project uses **Workload Identity Federation** to authenticate with Google Earth Engine in CI/CD workflows. This approach is more secure than using service account keys because:

- No long-lived credentials are stored in GitHub
- Short-lived tokens are generated on-demand
- Fine-grained access control via IAM
- Google's recommended best practice

Prerequisites

- Access to the `goog-rle-assessments` Google Cloud project
- Permissions to create service accounts and configure Workload Identity
- GitHub repository admin access to add secrets

Setup Instructions

1. Create a Service Account

```
# Set your GCP project
export PROJECT_ID="goog-rle-assessments"

# Create a service account for GitHub Actions
gcloud iam service-accounts create github-actions-ee \
```

```
  --display-name="GitHub Actions Earth Engine" \
  --project=$PROJECT_ID
```

2. Grant Earth Engine Permissions

```
# Get the service account email
export SA_EMAIL="github-actions-ee@${PROJECT_ID}.iam.gserviceaccount.com"

# Grant Service Usage Consumer role (required to use the project's services)
gcloud projects add-iam-policy-binding $PROJECT_ID \
  --member="serviceAccount:${SA_EMAIL}" \
  --role="roles/serviceusage.serviceUsageConsumer"

# Grant Earth Engine API access
# Note: You may need to grant specific Earth Engine roles or permissions
# depending on your organization's setup
gcloud projects add-iam-policy-binding $PROJECT_ID \
  --member="serviceAccount:${SA_EMAIL}" \
  --role="roles/earthengine.viewer"

# If you need write access for EE assets:
# gcloud projects add-iam-policy-binding $PROJECT_ID \
#   --member="serviceAccount:${SA_EMAIL}" \
#   --role="roles/earthengine.writer"
```

3. Create Workload Identity Pool

```
# Create a Workload Identity Pool
gcloud iam workload-identity-pools create "github-actions-pool" \
  --location="global" \
  --display-name="GitHub Actions Pool" \
  --project=$PROJECT_ID

# Create a Workload Identity Provider for GitHub
gcloud iam workload-identity-pools providers create-oidc "github-provider" \
  --location="global" \
  --workload-identity-pool="github-actions-pool" \
  --display-name="GitHub Provider" \
```

```
  --attribute-mapping="google.subject=assertion.sub,attribute.actor=assertion.actor,attribute
  --attribute-condition="assertion.repository_owner == 'VorGeo'" \
  --issuer-uri="https://token.actions.githubusercontent.com" \
  --project=$PROJECT_ID
```

4. Allow GitHub to Impersonate the Service Account

```
# Get the project number
export PROJECT_NUMBER=$(gcloud projects describe $PROJECT_ID --format="value(projectNumber)")

# Allow the specific GitHub repository to impersonate the service account
gcloud iam service-accounts add-iam-policy-binding "${SA_EMAIL}" \
  --role="roles/iam.workloadIdentityUser" \
  --member="principalSet://iam.googleapis.com/projects/${PROJECT_NUMBER}/locations/global/wo
  --project=$PROJECT_ID
```

5. Get the Workload Identity Provider Resource Name

```
# Get the full provider resource name
gcloud iam workload-identity-pools providers describe "github-provider" \
  --location="global" \
  --workload-identity-pool="github-actions-pool" \
  --project=$PROJECT_ID \
  --format="value(name)"
```

This will output something like:

```
projects/123456789/locations/global/workloadIdentityPools/github-actions-
pool/providers/github-provider
```

6. Configure GitHub Secrets

Add the following secrets to your GitHub repository (Settings → Secrets and variables → Actions → New repository secret):

1. `WIF_PROVIDER`
    - Value: The full Workload Identity Provider resource name from step 5

    - Example: `projects/123456789/locations/global/workloadIdentityPools/github-actions-pool/providers/github-provider`
2. `WIF_SERVICE_ACCOUNT`
    - Value: The service account email
    - Example: `github-actions-ee@goog-rle-assessments.iam.gserviceaccount.com`

How It Works

Once configured, the authentication flow is automatic:

1. The `google-github-actions/auth@v2` action authenticates with GCP using Workload Identity Federation
2. It sets the `GOOGLE_APPLICATION_CREDENTIALS` environment variable to point to temporary service account credentials
3. When your Python code calls `google.auth.default()`, it loads these Application Default Credentials (ADC)
4. The credentials are then passed to `ee.Initialize(credentials=credentials, project='goog-rle-assessments')`
5. **No separate `earthengine authenticate` command is needed** - the credentials are already available

This is why the workflow does NOT include an explicit "Authenticate Earth Engine" step. The Earth Engine Python library uses the credentials set up by the GCP auth action through `google.auth.default()`.

Python Code Pattern

The code uses this pattern to initialize Earth Engine with ADC:

```python
import ee
from google.auth import default

# Load Application Default Credentials
credentials, _ = default(scopes=[
    'https://www.googleapis.com/auth/earthengine',
    'https://www.googleapis.com/auth/cloud-platform'
])

# Initialize Earth Engine with the credentials
ee.Initialize(credentials=credentials, project='goog-rle-assessments')
```

This works both locally (after running `gcloud auth application-default login`) and in CI/CD (with Workload Identity Federation).

Verification

To verify the setup works:

1. Push a commit to the `main` branch or trigger the workflow manually
2. Check the GitHub Actions run log
3. The "Authenticate to Google Cloud" step should succeed and show credential file creation
4. The "Render MyST Project" step should be able to access Earth Engine without additional authentication

Troubleshooting

"Failed to generate Google Cloud access token"

- Verify the `WIF_PROVIDER` secret contains the full resource name
- Check that the Workload Identity Pool and Provider exist
- Ensure the attribute condition matches your repository owner (`VorGeo`)

"Permission denied" errors

- Verify the service account has the necessary Earth Engine roles
- **Check for `roles/serviceusage.serviceUsageConsumer`** - this role is required to use the project's services
- Check that the IAM policy binding was created correctly
- Ensure the service account is enabled
- Wait a few minutes for IAM permission propagation

"Authentication failed" or permission errors when accessing Earth Engine

- Check that the Google Cloud authentication step completed successfully
- Verify the service account has the necessary Earth Engine roles (e.g., `roles/earthengine.viewer`)
- Ensure the service account has been registered with Earth Engine (may require admin approval)
- Check that `GOOGLE_APPLICATION_CREDENTIALS` environment variable is set in the workflow logs

- Verify the `ee.Initialize(project='goog-rle-assessments')` call uses the correct project ID

Security Considerations

- The Workload Identity Federation is configured to only allow authentication from the `VorGeo` organization
- To restrict further, update the `--attribute-condition` to specify the exact repository
- Regularly audit service account permissions
- Use least-privilege IAM roles

References

- Google Cloud Workload Identity Federation
- GitHub Actions OIDC
- google-github-actions/auth
- Earth Engine Authentication