Japan Fund for Prosperous and Resilient Asia and the Pacific (JFPR)

Knowledge and Support Technical Assistance (KSTA) 6856:

Development of New Statistical Resources and Building Capacity

in New Data Sources and Technologies.

Documentation for Physical Land Asset Accounts for Thailand for the Accounting period 2015-2019

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Introduction

This documentation report outlines the data sources and methodologies used to compile the Kingdom of Thailand's Physical Asset Accounts for Land Cover, consistent with the United Nations System of Environmental-Economic Accounting (SEEA) 2012 Central Framework (CF). The SEEA framework integrates economic and environmental data and provides a comprehensive view of the relationships between the economy and the environment. It follows a similar accounting structure and uses concepts, definitions, and classifications consistent with as the System of National Accounts (SNA) to facilitate the integration of environmental and economic statistics[1]. The framework includes a methodology to analyse the flows, stocks, and changes in flows and stocks of environmental assets, and their value.

The work was undertaken as part of the Asian Development Bank (ADB)—Japan Fund for Prosperous and Resilient Asia and the Pacific Technical Assistance (TA) 6856 project, titled "Development of New Statistical Resources and Building Capacity in New Data Sources and Technologies." The TA aims to support ADB developing member countries, including Thailand, in compiling environmental satellite accounts, which have been identified as a priority and a starting point for future initiatives in developing ecosystem accounts.

Environmental-Economic Asset Accounting

The SEEA CF captures the relationship between the economy and environment in three areas:

1. **Environmental flows.** The flows of natural inputs, products and residuals between the environment and the economy, and within the economy, both in physical and monetary terms.
2. **Stocks of environmental assets.** The stocks of individual assets, such as water or energy assets, and how they change over an accounting period due to economic activity and natural processes, both in physical and monetary terms.
3. **Economic activity related to the environment.** Monetary flows associated with economic activities related to the environment, including spending on environmental protection and resource management, and the production of "environmental goods and services".[2]

With respect to the second measurement area listed above, SEEA defines environmental assets as the naturally occurring living and non-living components of the Earth that together make up its bio-physical environment.[3] These assets provide benefits to humanity, either directly or indirectly. Examples of environmental assets include mineral and energy

[1] United Nations. System of Environmental-Economic Accounting (SEEA). Accessed December 6, 2024. https://seea.un.org/

[2] Ibid.

[3] United Nations, SEEA Central Framework, 2.17.

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resources soil, land, timber resources, and water resources. The SEEA framework provides comprehensive guidance on the measurement and accounting of these essential resources.

Environmental asset accounts systematically measure and report the value of environmental assets in both physical and monetary terms. According to the SEEA framework, the core principle behind asset accounting is to estimate and record the opening and closing stock of assets over an accounting period, along with the types of changes in those stocks. This approach captures patterns of change, rates of depletion, shifts in management or legal frameworks, and changes in asset value.

Land is a key environmental asset that underpins assessments of land cover, land use, and related policy needs. It is a major component of national wealth and the entry-point for developing forest-related accounts and ecosystem accounts, which is the intended case for Thailand.

This document discusses the process of compilation of the physical asset accounts for land cover for Thailand for the accounting period of 2015–2019. It is organized as follows: (1) Scope and coverage (2) Data sources (3) Mapping land cover classes (4) Land cover change matrix (5) Physical asset account (6) Challenges and limitations (7) Recommendations and future steps.

Scope and Coverage

Land accounts produced under the SEEA CF provide an assessment of the stocks and changes in stocks of land within a country. The accounts support analyses of natural and manmade alterations to the different aspects of land, including its cover, use, and ownership.

The draft SEEA technical note on land accounting identifies three core accounts: (1) physical asset account for land classified by land cover, (2) physical asset account classified by land use, and monetary asset account for land use.

The main types of land accounts are defined as follows [4]:

1. **Physical asset accounts:** These accounts describe the area of land over an accounting period by land cover and land use or landownership (by industry or institutional sector). They present the additions and reductions in land stocks as associated with human activity and natural processes.
2. **Monetary asset accounts:** This set of accounts provides information on the overall monetary value of land used in agriculture, forestry, and among other manmade usages, primarily due to the revaluation of land.

Besides the core land accounts, a land cover change matrix may be compiled to show how one land classification changed to other land classification within the reference period.

[4] United Nations. (2017). Draft SEEA Technical Note: Land Accounting.
https://seea.un.org/sites/seea.un.org/files/seea_technical_note_-_land_jan_2017_draft.pdf

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Similarly, a land use change matrix can be developed using the same structure to present physical changes in land use.

To determine the appropriate scope and coverage for the compilation, the ADB SEEA team, the Office of Natural Resources and Environmental Policy and Planning (ONEP) and the National Statistical Office of Thailand conducted a series of meetings after which an online questionnaire, *Assessment of Availability of Information on Thailand's Land and Forest Area*, was sent for comments to the ONEP in November 2023. The instrument, which was finalized in December 2023, was designed to assess the availability of data on stocks and changes in stocks of land as well as the existing land classification systems in the country. Given the assessment, the compilation of the physical asset accounts for land cover was deemed most feasible.

Moreover, SEEA CF recommends that countries develop estimates of the total land area classified by land cover first since land cover is directly observable and supported by widely available remote sensing data. This allows compilers to establish a consistent and comparable baseline for subsequent land accounting work. Thus, for Thailand, the Physical Asset Account for Land Cover was compiled for the calendar year starting 2015 and ending 2019, together with a land cover change matrix. The accounts cover ten land cover classes, as described in the section under *Mapping Land Cover Classes*.

Data Source

Satellite data and field surveys are the starting point for the construction of land cover accounts. The ADB team gathered several external sources for the land cover datasets. These are the Dynamic Land Cover (Land Monitoring Services) from Copernicus; Living Atlas of the World from the Environmental System Research Institute (ESRI), Impact Observatory; and Global Land Analysis and Discovery (GLAD) from the University of Maryland, United States Geological Survey, and Global Forest Watch. More details about each of these are listed in the section under *Challenges and Limitations.*

The ADB team elected to use data from the Copernicus Data Space Ecosystem, which is the Earth observation component of the European Union's Space programme[5]. Land Monitoring is among the six thematic services of the Copernicus. For this compilation, the Global Dynamic Land Cover product—which provides annual global land cover maps at 100m resolution for 2015 – 2019—was used. These 100m resolution maps are produced by the Copernicus Land Monitoring Service and are derived from PROBA-V satellite observations and ancillary datasets. These maps includes a discrete land cover classification with 23 classes aligned with UN-FAO's Land Cover Classification System (LCCS) and with the SEEA Interim Land Cover Classification.

In addition to this, the ADB team also used the official forest data in the form of shapefiles provided by the Royal Forest Department (RFD) of Thailand. **This enabled the generation of two sets of estimates** – one which uses data solely from Copernicus Global Land Cover,

[5] https://dataspace.copernicus.eu/explore-data

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and another which incorporates information on tree cover and forest area provided by RFD. The methodology for integration is also discussed below.

Data Processing

The data processing phase involved the use of open-source QGIS software to extract and analyze land cover maps for Thailand from the Copernicus Global Land Cover maps for 2015 to 2019 which generated the first set of estimates.

A second iteration integrated the shapefiles provided by RFD on tree-covered areas with the Copernicus land cover maps for 2016-2018 which generated the second set of estimates. The following steps applied in generating the two sets of estimates are outlined below:

Iteration 1: Using only Copernicus Global Land Cover datasets

1. Data Extraction and Preparation
   The land cover maps for Thailand for each year from 2015 to 2019 were extracted from the Global Land Cover maps. To ensure consistent spatial measurement, the maps were also reprojected to EPSG:32647 - UTM Zone 47N, which allows for the area calculation in meters. The extracted land cover maps for 2015 – 2019 are shown in Figure 1.

Figure 1. Copernicus Land Cover Maps for Thailand, 2015 – 2019

2. Annual and Multi-Years Comparisons
   Once the maps were extracted and reprojected, the semi-automatic classification plugin (SCP) in QGIS was used to perform cross-classification analyses. This tool requires the input of a reference raster and a classification raster to enable a pixel-by-pixel comparison of the land cover changes between years.

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The process involved setting the current year as the reference raster (e.g., 2015) and the comparison year as the classification raster (e.g., 2019). This step was repeated for each pair of consecutive years (2015 vs 2016, 2016 vs 2017, 2017 vs 2018, 2018 vs 2019) to track annual changes. Direct comparisons between the non-consecutive years were also conducted to generate 2-year to 4-year changes. The cross-classification tool generated outputs in both GeoTIFF and CSV formats.

The CSV outputs contained necessary data, including the following.

1. Reference land cover code: the code based on the land cover classification of the data source for the reference year (e.g. 40).
2. Classification land cover code: the code based on the land cover classification of the data source for the comparison year (e.g. 50).
3. Pixel sum: the total number of pixels that changed from the reference code to the classification code.
4. Area (in square meters): the area represented by the pixel sum.

3. The CSV outputs are compiled into one excel file and included the following columns for clarity: Reference year, which is the initial year of comparison (e.g., 2015); and Classification year, which is the comparison year (e.g. 2019).

4. Data Compilation and Processing
   The CSV outputs from all comparisons were compiled into one comprehensive dataset. Each land cover code was matched to its corresponding SEEA land cover class for clear interpretation. The area, initially recorded in square meters, was converted to *rai* (1 rai = 1,600 square meters) to facilitate analysis aligned with the country's land measurement practices.

Iteration 2: Integrating RFD Forest shapefiles and Copernicus Land Cover Maps

1. Data Extraction and Preparation
   The Shapefiles used for the purpose of integration was for the years 2016, 2017 and 2018. These shapefiles were rasterized to allow for comparison and integration with the CGLS data (as processed above).

2. Assess the difference between Copernicus Forest and Thailand Forest
   To assess the similarities and differences between the Forest in Copernicus and Thailand's official forest areas from the rasterized RFD Shapefiles, the two maps were overlaid, as shown in Figure 2.

Figure 2. Overlay of Copernicus Forest and Thailand Official Forest

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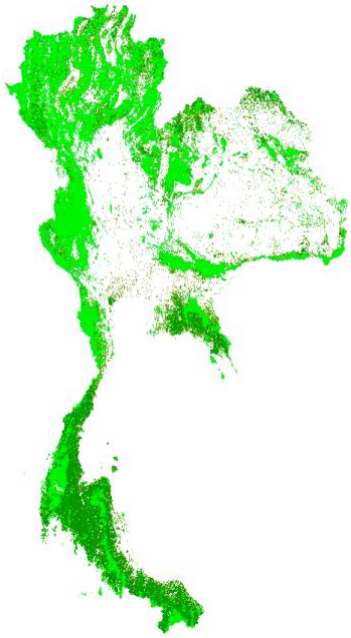
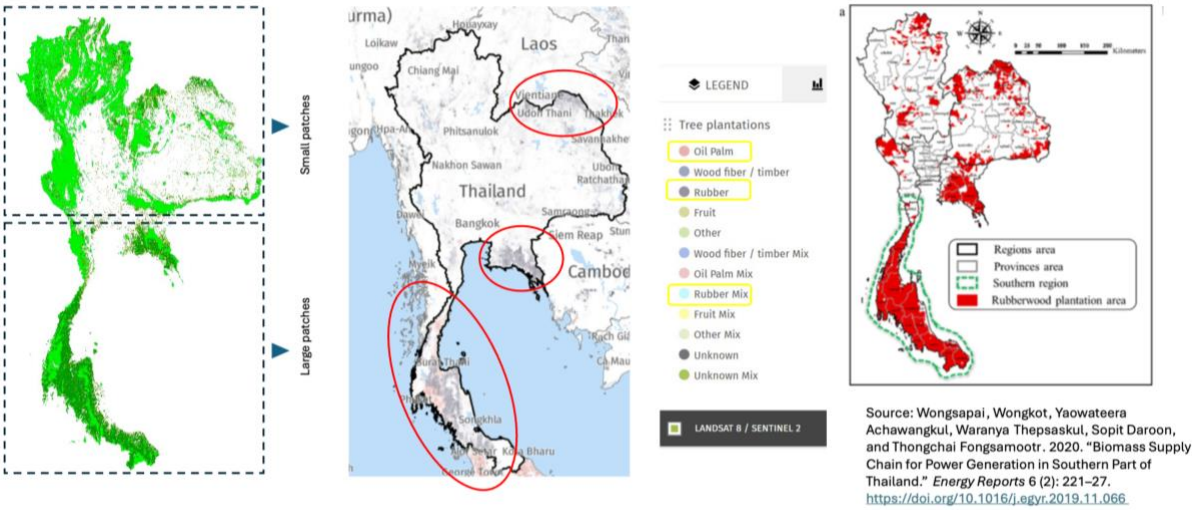


The areas shown in bright green represent the **overlap** between the Copernicus forest classifications and Thailand's official forest area. The remaining dark green patches, particularly in the southern region, indicate areas classified as forest by Copernicus but not considered official forest in the Thailand data. Based on validation exercises, these areas of difference are likely plantation forests, as supported by Global Forest Watch data and Wongsapai et al. (2020), as shown in Figure 3.

Figure 3. Understanding the differences between Copernicus Forest and Thailand's official forest area



3. Integrate THA Forest area to the Copernicus data
   Building on the assessment of where the Copernicus forest classifications and

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Thailand's official forest data align and differ, this served as the starting point for integrating the two datasets. To ensure consistency with the SEEA land cover classifications—and to enable integration with land cover data for other years—the following reclassification rules were applied:

- For all pixels classified as forest in both RFD data and the Copernicus dataset, the forest classification as per RFD shapefiles was used (Copernicus Class Code 10 = THA forest).
- For all pixels classified as forest RFD data that did not match the forest classification in Copernicus dataset, the forest classification as per RFD shapefiles was retained.
- For all pixels in RFD data that were not classified as forest but classified as forest in the Copernicus dataset, the pixels were reclassified to other wooded land (Copernicus Class Code 130 = Other Wooded Land)
- For all other land cover classes, the Copernicus land cover classifications was retained. This is because the RFD shapefiles only provided information on one land cover type – forest.

4. Similar to Option 1, once the maps were extracted, reclassified and integrated, the semi-automatic classification plugin (SCP) in QGIS was used to perform cross-classification analyses.

The next section covers the mapping exercise between the classes from the Copernicus Land Cover Maps and the SEEA framework.

Mapping Land Cover Classes

The following table presents the land cover classes, as obtained through processing Copernicus data. These are mapped to the 10 of 14 land cover classifications laid out by the SEEA, represented by the 23 Copernicus Global Land Service (CGLS) land cover map codes. Table 1A of the Appendix defines each of these classes.

Table 1 shows the mapping between classes obtained through Copernicus data product and the SEEA classification and then to the classes finally used in this account.

Table 1: Correspondence among CGLS land cover classes, SEEA Interim Land Cover Classification, and land cover classes reflected on the ADB compilation for Iteration 1

CGLS codes	CGLS Descriptor	SEEA Interim Land Cover Classification	Land covers reflected on the ADB compilation (as applicable)
20	Shrubs	8 Shrub-covered areas	Shrub-covered areas

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30	Herbaceous vegetation	5 Grassland	Grassland
40	Cultivated and managed vegetation/agriculture (cropland)	2 Herbaceous Crops	Herbaceous crops
50	Urban/built-up	1 Artificial surfaces (including urban and associated areas)	Artificial surfaces (including urban and associated areas)
60	Bare/sparse vegetation	11 Terrestrial barren land	Sparsely natural vegetated areas, including Terrestrial barren land
70	Snow and Ice	12 Permanent snow and glaciers	Permanent snow and glaciers
80	Permanent water bodies	13 Inland water bodies	Inland water bodies
90	Herbaceous wetland	9 Shrubs and/or herbaceous vegetation, aquatic or regularly flooded	Shrubs and/or herbaceous vegetation, aquatic or regularly flooded
100	Moss and lichen	5 Grassland	Grassland
111	Closed forest, evergreen, needle leaf	6 Tree covered areas	Closed forest
112	Closed forest, evergreen, broad leaf	6 Tree covered areas	Closed forest
113	Closed forest, deciduous, needle leaf	6 Tree covered areas	Closed forest
114	Closed forest, deciduous, broad leaf	6 Tree covered areas	Closed forest
115	Closed forest, mixed	6 Tree covered areas	Closed forest
116	Closed forest, unknown	6 Tree covered areas	Closed forest
121	Open forest, evergreen, needle leaf	6 Tree covered areas	Open forest
122	Open forest, evergreen, broad leaf	6 Tree covered areas	Open forest
123	Open forest, deciduous, needle leaf	6 Tree covered areas	Open forest
124	Open forest, deciduous, broad leaf	6 Tree covered areas	Open forest
125	Open forest, mixed	6 Tree covered areas	Open forest
126	Open forest, unknown	6 Tree covered areas	Open forest

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200	Open sea	14 Coastal waterbodies and intertidal areas	Coastal waterbodies and intertidal areas

Highlighting a few key points of the mapping from the table above:

Iteration 1: Using only Copernicus Global Land Cover datasets

The Copernicus definition of land cover class, *Bare/Sparse vegetation*, suggests that it may cover SEEA land cover classes, *Sparsely vegetated areas* and *Terrestrial barren land.* Therefore, we map them together, however the estimates reflected under this entry in the final table reflect estimates for *Terrestrial barren land* only.

The Copernicus datasets do not map *Mangroves* as a unique land cover class. While it may be included in the estimates of a different land cover class of tree covered areas, it is impossible to extract this as its own land cover. However, it is important to distinguish this land cover from the others, especially in the context of a country like Thailand where mangroves form an important environmental ecosystem.

The Copernicus datasets also do not map the SEEA land cover classes of *Multiple or layered crops*, and *Woody crops* individually. Denotatively, these can be categorized under CGLS class 40, *Herbaceous Crops* which is "Lands covered with temporary crops followed by harvest and a bare soil period (e.g., single and multiple cropping systems)." The definition of CGLS class 40, *Herbaceous Crops*, also notes that perennial woody crops can be classified as the appropriate *Forest* or *Shrubland* cover type.

This is why Copernicus classifications of *Closed forest* and *Open forest* were retained rather than the SEEA classification of mapping both types of forests to *Tree-covered areas,* since these Copernicus classes can include mangroves, multiple or layered crops and woody crops. Mapping them to only Tree cover might over-estimate that land cover class.

Some classes might not always be relevant to each country. For example, the class, *Coastal waterbodies and inter-tidal areas,* may not be relevant for the land accounts of a land-locked country. Similarly, for Thailand, the class, *Permanent snow and glaciers,* is not relevant as it pertains to any geographical area covered by snow or glaciers persistently for 10 months or more. Therefore, this class is excluded in this compilation.

Iteration 2: Integrating RFD Forest shapefiles and Copernicus Land Cover Maps

Since iteration 2 uses official forest area data from the Royal Forest Department, it was more possible to ascertain the SEEA land cover class for tree-covered areas. Therefore, tree-covered areas of RFD were given precedence over the open or closed forest areas of Copernicus as opposed to the mapping used iteration 1.

Moreover, Copernicus areas that are classified as *Open Forest* or *Closed Forest*, but not identified as forest area in RFD data, are reclassified to *Other Wooded Land* which includes woody crops and mangroves. Woody crops include plantations which, based on the

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validation exercises, are likely the areas where discrepancies between the Copernicus and RFD maps occur.

In addition, because RFD-classified forests do not include *Mangroves*, these areas are also likely captured under the *Other Wooded Land* category. It should be noted that the *Other Wooded Land* classification used in this iteration does not correspond to the *Other Wooded Land* category in the SEEA Forest Accounts. In this context, the label is applied solely to denote areas that are identified as wooded but not classified as forest by RFD—specifically plantation areas indicated by validation exercises, as well as *Mangroves*, which are not included in the RFD forest classification.

Table 2: Correspondence among CGLS land cover classes, Thailand Official Forest, SEEA Interim Land Cover Classification, and land cover classes reflected on the ADB compilation for Iteration 2

CGLS codes	CGLS Descriptor	SEEA Interim Land Cover Classification	Land covers reflected on the ADB compilation (as applicable)
20	Shrubs	8 Shrub-covered areas	Shrub-covered areas
30	Herbaceous vegetation	5 Grassland	Grassland
40	Cultivated and managed vegetation/agriculture (cropland)	2 Herbaceous Crops	Herbaceous crops
50	Urban/built-up	1 Artificial surfaces (including urban and associated areas)	Artificial surfaces (including urban and associated areas)
60	Bare/sparse vegetation	11 Terrestrial barren land	Sparsely natural vegetated areas, including Terrestrial barren land
70	Snow and Ice	12 Permanent snow and glaciers	Permanent snow and glaciers
80	Permanent water bodies	13 Inland water bodies	Inland water bodies
90	Herbaceous wetland	9 Shrubs and/or herbaceous vegetation, aquatic or regularly flooded	Shrubs and/or herbaceous vegetation, aquatic or regularly flooded
100	Moss and lichen	5 Grassland	Grassland
10	Thailand Official Forest	6 Tree covered areas	Tree-covered areas
130	Other Wooded Land	3 Woody Crops 7 Mangroves	Woody Crops

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200	Open sea	14 Coastal waterbodies and intertidal areas	Coastal waterbodies and intertidal areas

Land Cover Change Matrix

The land cover change matrix shows land cover at two different points in time. It shows the area of different land cover types at the beginning of the reference period (opening area), the increases and decreases of this area according to the land cover type it was converted from (in the case of increases) or the type it was converted to (in the case of decreases) and, finally, the area covered by different land cover types at the end of the reference period (closing area). (SEEA Central Framework, 2012)

The matrix is organized with land cover classes as both rows and columns. The rows represent the land cover classes in the initial year (e.g. 2015), while the columns represent the land cover classes in the final year (e.g. 2019). Each cell in the matrix represents the area of land that changed from a particular land cover class to another between the two time periods. Table A2 of the Appendix section shows the Land Cover Change Matrices (Gross Changes) for Thailand between 2015 and 2019[6].

Two change matrices were constructed: one for gross changes and another for net changes. The opening area, closing area, and changes in area were estimated as follows:

- Opening area: This is the total area of each SEEA land cover class at the beginning of the accounting period, derived from the land cover map of the reference year.
- Closing area: This is the total area of each land cover class at the end of the accounting period, derived from the classification map of the subsequent year. This is also equal to the sum of the opening area and net changes.
- Gross Changes: This is the total change in area between land cover classes, estimated by getting the total area of a land cover class that was converted into another land cover class, or the total area that was converted from a specific land cover class to another land cover class over the identified accounting period.
- Net Changes: This is the change in area considering the addition and reduction per land cover class. It may either have a positive or a negative value. Once the matrix for gross changes was set up, the net changes were derived by getting the difference between the total additions and the total reductions for each land cover class. This is summarized by the formula below:

$$Net\ change\ (LC_i to\ LC_j) = \left(Additions\ to\ LC_i\ from\ LC_j\right) - \left(Reductions\ from\ LC_i\ to\ LC_j\right)$$

$where$:

$Additions\ to\ LC_i\ from\ LC_j is\ the\ gross\ change\ from\ jth\ land\ cover\ class\ to\ the\ ith\ land$

[6] Note: for Land Cover Change Matrix (Net Changes) please review workbook tab *Step-5 Land Cover Change Matrix* in workbook *Physical Asset Accounts for Land Cover (2015-2019, in rai)_Copernicus_Final.xlsx;* Land Cover Change Matrix for Iteration 2 is available in the workbook *Physical Asset Accounts for Land Cover (2016-2018, in rai)_CopernicusxTHA forest_Final.xlsxxs*

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Reductions from LC_i to LC_j is the gross change from ith land cover class to the jth lar

Physical Asset Accounts for Land Cover

A physical environmental asset account has three main components: the opening stock, the closing stock, and the changes—additions or reductions—in the stock.

Physical asset accounting for land cover comprises of two main components:

1. Identifying net changes in area of each land cover class and
2. Classification of the observed changes.

The draft SEEA technical note on land accounting cites the following standard classifications of land cover changes:

a) Managed expansion represents an increase in the area of a land cover type due to human activity.
b) Natural expansion is an increase in area resulting from natural processes including seeding, sprouting, suckering or layering.
c) Managed regression represents a decrease in the area of a land cover type due to human activity.
d) Natural regression should be recorded when the area of a land cover type reduces for natural reasons.
e) Reappraisals can be upward or downward and reflect changes due to the use of updated information that permits a reassessment of the size of the area of different land covers.

Assigning changes to the categories of managed or natural often requires the combined use of administrative data and site validation. The CGLS dataset, or any other spatially referenced data, is not designed to inform this fundamental step.

Steps in Accounting for Land Cover Changes

The same accounting period, 2015–2019 for Iteration 1 and 2016 – 2018 for Iteration 2, were observed for this compilation's land cover change matrix and physical asset account for land cover. Thus, the physical asset account entries for opening stocks, closing stocks, and net changes across land cover classes were fully informed by the land cover change matrix. Table A4 of the Appendix section, and tab *Step 6-Land Account* in the excel workbook shared as part of this submission is the estimated Physical Land Asset Account.

The following steps were carried out to validate and characterize the changes that were computed from the land cover change matrix:

a) The ADB team independently gathered data on common land cover changes (e.g., afforestation, deforestation, reforestation, forest fires) from Thailand government websites, third-party sources, and published papers while ONEP administered the data assessment questionnaire to the relevant agencies. Lack of corresponding spatially georeferenced information and inconsistencies in the definitions of these

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different data sources limited the ability to integrate this information with CGLS.

b) The ADB SEEA team reviewed the land accounts of Australia, Denmark, Canada, Sweden, and the United Kingdom for the estimation of land cover changes and approaches to the assignment of those into managed or natural changes. The methodology of the Philippines was also reviewed, in view of the country's similarity with Thailand in terms of geography and data limitations.

c) This compilation took after the methodology of Australia on two respects. First, it relied on the area changes that are captured by the land cover change matrix. Limited administrative reports on activities that alter land cover (e.g, logging, agricultural land conversion, afforestation) were put aside. Second, the nature of causes of specific land cover change combinations was assumed.

d) Desk research and the practices of other countries informed assumptions on the nature of causes of specific land cover change combinations. If human activities were the probable reason for a specific land cover change combination, the change was considered *managed*. A land cover change combination arising mainly from natural processes was classified as *natural*. Where a land cover change may be brought about by both anthropogenic and natural causes, it was reported as *other*.

   Table A3 of the Appendix shows how the different land cover change combinations were assigned into managed, natural, and other changes. Physical asset accounting records positive net changes as expansion and negative net changes as reductions.

   This report does not reflect reappraisals, since the dataset does not warrant reassessment of land cover areas during the reference period.

e) Finally, once all of these are calculated, it is important to check the consistency of the figures: the closing stock of the current year must equal to the opening stock of the current year plus the net change for each land cover class; and the closing stock of the current year must equal to the opening stock of the following year. No discrepancies were observed in the estimates.

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Challenges and Limitations

The compilation exercise demonstrated that Thailand's land cover accounts can be produced using available data sources—whether relying solely on publicly accessible datasets or through integration with official national data.

Along the way, the process also highlighted challenges and technical considerations that can guide future improvements.

First, selecting the most suitable land cover datasets required extensive review, as available products differed in classification systems, spatial resolution, temporal coverage, and methodological approaches. The ADB SEEA team researched several external datasets to compile information for land cover. Namely, these were the Global Land Cover (Land Monitoring Services) from Copernicus; Living Atlas of the World from the ESRI, Impact Observatory; and GLAD from the University of Maryland, United States Geological Survey, and Global Forest Watch. Each of these had different features, as summarised under table 3.

Table 3. Preliminary assessment of alternative sources of land and forest extent data

Database	Associated organization/s	Period covered	Resolution	Original format	Accuracy rate
Global Land Cover (Land Monitoring Services)	Copernicus	2015-2019	100m	Raster GeoTIFF	80.3%
Living Atlas of the World	Environmental Systems Research Institute (ESRI), Impact Observatory	2017-2021	10m [ESA Sentinel-2]	Raster GeoTIFF	75%
Global Land Analysis and Discovery	University of Maryland, United States Geological Survey, Global Forest Watch	2000, 2012, 2022	30m (2010 tree cover)	Raster GeoTiff	75.2%

Although the ESRI Sentinel-2 has the highest resolution (shown in Table 2), the year 2017 dataset had less accurate land cover classes as it has fewer images than the other years (ArcGIS, 2022). The years 2018-2023 have a more complete set of imagery, but fewer classification than Copernicus data. GLAD datasets are only available for the years 2000,

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2012, and 2022, periods that may have insufficient data for validating land cover/land use changes. Ultimately, the Copernicus dataset was selected for its overall usability and alignment with SEEA requirements, as described in the *Data Source* section above.

Second, bridging the land cover classification from the Copernicus data to the combined land use/land cover classification in Thailand, and mapping to the SEEA CF land cover classes was a significant challenge as well. Although satellite images serve as the primary dataset required for the compilation of physical asset accounts for land, other datasets can greatly supplement this information. Table 4 highlights some examples. These datasets can supply and validate the changes in stocks of land for any reference period.

Table 4. Land asset accounts data requirements

Datasets	Generic government departments
Protected areas, habitat types, ecological classification	Department of Environment or Parks
Hydrology, remote sensing data (land cover)	Department of Natural Resources
Agricultural land use, soil type, farm locations	Department of Agriculture
Forest land use, forest land cover, forest concessions	Department of Forestry
Coastal and marine characteristics (habitat types)	Department of Fisheries
Road networks, power transmission lines, pipelines	Department of Public Works and Transportation
Population and housing census, agriculture survey and census, business survey, settlement areas	National Statistical Offices
Cadastral	Land registries

Source: SEEA Technical Note: Land Accounting, 2017

The ADB team used the Global Forest Assessment (FRA) datasets from the UN Food and Agriculture (FAO), along with the FAOSTAT Agri-environmental indicators, to verify the extent, additions, and reductions for the land cover changes. Table 5 summarises the data that was referenced in the compilation of these accounts.

Table 5. Use of additional data sources for reference

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Data requirements	Availability	Remarks
Land cover data		
Satellite images	✓	**Copernicus**
Aerial photography		
Field research		
Hydrological		
Topographic (rivers, drainage areas, elevation, coastlines)		
Land use data		
Agriculture census		
Population census		
Administrative	✓	**ONEP**
Forest inventories	✓	**FAO FRA**
Ownership data		
Cadastral (ownership, tenure, zoning, tax, price)		

The forest inventories and administrative data from the FAO FRA and ONEP, respectively, can be used for validation exercises of land cover areas classification from the Copernicus satellite imagery. Although, it might be insufficient for validating the agricultural and built-up areas by utilizing the other complementary datasets such as agriculture census, and population census from the NSO, as well as cadastral data from the land registries,

Third, these challenges influenced the ability to attribute the type of change of land cover, addition or reduction, as a managed change, natural change or reappraisal. in a way that will be consistent with land use and land change practices most observed in Thailand. As the SEEA CF notes "An additional step in the analysis of land cover change might be the construction of tables showing reasons for land cover change. For example, changes in land cover might be classified to show whether the change relates to urban growth and development of infrastructure (through conversion of crops or tree-covered area), intensification and industrialization of agriculture (through conversion of family farming and mosaic landscapes), extension of agriculture in general (through conversion of tree-covered land), drainage of regularly flooded areas (wetlands) for crops or artificial surfaces

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(urban land), deforestation (of tree-covered areas for timber production or agriculture development), and desertification (at the expense of formerly vegetated areas)."[7]

Lastly, converting the official forest shapefiles from RFD into raster format introduced minor discrepancies (less than 1%) in the estimated forest area—an expected outcome of rasterization processes. Nonetheless, the results remain a strong representation of Thailand's forest cover. When comparing the official forest area to its share of total land area, the rasterized estimates yield nearly identical proportions, indicating that the forest area derived from this process provides a reliable and indicative measure of forest extent in Thailand.

Recommendations and Future Steps

The two iterations of physical asset accounts for land cover compiled for Thailand provide a strong baseline for understanding land cover patterns and changes during the given reference periods. Moving forward, strengthening data availability and integration will be essential—particularly by leveraging publicly accessible satellite datasets such as Copernicus and validating these with national and administrative records, including forest inventories, cadastral maps, and agricultural statistics. Validated georeferenced data and clearly defined land cover classes that align with Thailand's priorities and context are important pre-requisites for the institutionalization of these accounts

With the increasing availability of satellite data, new data products and time periods may also be explored to further enhance the coverage and robustness of future land cover assessments. The integration of Copernicus data with Thailand's official forest map also demonstrates that, as official land cover datasets for individual classes become available, these can serve as building blocks for developing a progressively more detailed and nationally consistent land cover map grounded in official data.

Clear definitions of land cover classes, as they exist in Thailand to ensure that they accurately represent the national landscape and align with SEEA standards can help in further refining the estimates provided. Validation exercises will also help to accurately assess the changes in land cover over multiple time periods, and characterise them as natural, manmade or owing to other causes.

ONEP may continue to gather datasets based on the data assessment questionnaire sent by the ADB team. The ONLB's ongoing initiative to consolidate land related datasets among partner agencies can also support the institutionalization of land and forest extent accounts compilation.

Land cover accounts serve as an important starting point for the compilation of ecosystem extent accounts as they define the relevant spatial areas in the country that can be covered by ecosystem accounts. Land cover is also one of FAO's *agri-environmental indicator*s capturing the changes in the environment that can be attributed in whole or in part to agricultural activity.

[7] SEEA CF 5.278

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Once a robust physical asset account for land cover is in place, further extensions—such as physical asset accounts classified by land use or land ownership—may be developed. These can serve as key inputs to analyzing the supply of ecosystem services and identifying the beneficiaries of those services, thereby strengthening Thailand's natural capital accounting framework

Ultimately, the institutionalization of these accounts can serve as an important first step to producing estimates for forest-related accounts, ecosystem accounts and other agri-environmental indicators, which can aid in understanding, valuing and preserving Thailand's unique and varied environment.

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Appendix

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Table A.1: SEEA Land Cover Classifications as Developed by UN FAO
Artificial surfaces (including urban and associated areas) The class is composed of any type of areas with a predominant artificial surface. Any urban or related feature is included in this class, for example, urban parks (parks, parkland and laws). The class also includes industrial areas, and waste dump deposit and extraction sites.
Herbaceous crops The class is composed of a main layer of cultivated herbaceous plants (graminoids or forbs). It includes herbaceous crops used for hay. All the non-perennial crops that do not last for more than two growing seasons and crops like sugar cane, where the upper part of the plant is regularly harvested while the root system can remain for more than one year in the field, are included in this class.
Woody crops The class is composed of a main layer of permanent crops (trees or shrub crops) and includes all types of orchards and plantations (fruit trees, coffee and tea plantation, oil palms, rubber plantation, Christmas trees, etc.).
Multiple or layered crops This class combine two different land cover situations: Two layers of different crops. A common case is the presence of one layer of woody crops (trees or shrubs) and another layer of herbaceous crop, e.g., wheat fields with olive trees in the Mediterranean area and intense horticulture, or oasis or typical coastal agriculture in Africa, where herbaceous fields are covered by palm trees. Presence of one important layer of natural vegetation (mainly trees) that covers one layer of cultivated crops. Coffee plantations shadowed by natural trees in the equatorial area of Africa are a typical example.
Grassland This class includes any geographical area dominated by natural herbaceous plants (grasslands, prairies, steppes and savannahs) with a cover of 10 per cent or more, irrespective of different human and/or animal activities, such as grazing or selective fire management. Woody plants (trees and/or shrubs) can be present, assuming their cover is less that 10 per cent.
Tree covered areas This class includes any geographical area dominated by natural tree plants with a cover of 10 per cent or more. Other types of plants (shrubs and/or herbs) can be present, even with a density higher than that of trees. Areas planted with trees for afforestation purposes and forest plantations are included in this class. This class includes areas seasonally or permanently flooded with freshwater. It excludes coastal mangroves (→07).
Mangroves This class includes any geographical area dominated by woody vegetation (trees and/or shrubs) with a cover of 10 per cent or more that is permanently or regularly flooded by salt and/or brackish water located in the coastal areas or in the deltas of rivers.

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Shrub covered areas
This class includes any geographical area dominated by natural shrubs having a cover of 10 per cent or more. Trees can be present in scattered form if their cover is less than 10 per cent. Herbaceous plants can also be present at any density. The class includes shrub-covered areas permanently or regularly flooded by inland fresh water. It excludes shrubs flooded by salt or brackish water in coastal areas (→07).

Shrubs and/or herbaceous vegetation, aquatic or regularly flooded areas
This class includes any geographical area dominated by natural herbaceous vegetation (cover of 10 per cent or more) that is permanently or regularly flooded by fresh or brackish water (swamps, marsh areas, etc.). Flooding must persist for at least two months per year to be considered regular. Woody vegetation (trees and/or shrubs) can be present if their cover is less than 10 per cent.

Sparsely natural vegetated areas
This class includes any geographical areas were the cover of natural vegetation is between 2 per cent and 10 per cent. This includes permanently or regularly flooded areas.

Terrestrial barren land
This class includes any geographical area dominated by natural abiotic surfaces (bare soil, sand, rocks, etc.) where the natural vegetation is absent or almost absent (covers less than 2 per cent). The class includes areas regularly flooded by inland water (lake shores, river banks, salt flats, etc.). It excludes coastal areas affected by the tidal movement of saltwater (→14).

Permanent snow and glaciers
This class includes any geographical area covered by snow or glaciers persistently for 10 months or more.

Inland water bodies
This class includes any geographical area covered for most of the year by inland water bodies. In some cases, the water can be frozen for part of the year (less than 10 months). Because the geographical extent of water bodies can change, boundaries must be set consistently with those set by class 11, according to the dominant situation during the year and/or across multiple years.

Coastal waterbodies and inter-tidal areas
The class is defined on the basis of geographical features of the land in relation to the sea (coastal water bodies, i.e., lagoons and estuaries) and abiotic surfaces subject to water persistence (intertidal areas, i.e., coastal flats and coral reefs).

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Table A.2: Land Cover Change Matrix (Gross Changes) 2015-2019 – Iteration 1

To From	Opening area	Artificial surfaces	Coastal water and intertidal areas	Herbaceous Crops	Grassland	Inland water bodies	Shrub-covered areas	Shrubs and/or herbaceous vegetation, aquatic or regularly flooded	Sparsely natural vegetated areas including Terrestrial barren land	Closed forest	Open forest	Closing area
Artificial surfaces	13,035,181		0	14	14	576	0	1,066	0	0	0	13,079,370
Coastal water and intertidal areas	802,549	0		0	0	0	0	0	0	0	0	802,549
Herbaceous Crops	139,294,614	26,759	0		12,094	169,601	1,450	726,748	2,977	13,579	29,921	138,373,531
Grassland	688,869	3,212	0	3,617		46,989	306	191,883	220	7	171	457,308
Inland water bodies	2,749,336	540	0	6,331	185		21	90,332	1,712	43	441	3,042,458
Shrub-covered areas	313,991	234	0	1,869	320	10,388		122,520	92	14	142	180,778
Shrubs and/or herbaceous vegetation, aquatic or regularly flooded	994,149	689	0	12,840	910	121,589	348		774	163	675	2,118,214
Sparsely natural vegetated areas including Terrestrial barren land	39,578	99	0	121	57	16,108	0	2,274		0	7	26,816
Closed forest	136,503,036	2,736	0	12,413	441	6,153	36	6,061	0		8,832	136,491,574
Open forest	28,159,209	11,589	0	24,841	824	21,324	206	121,170	128	11,404		28,007,912
Total Additions		45,859	0	62,045	14,843	392,727	2,366	1,262,053	5,905	25,210	40,189	

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Table A.3. Classification of land cover change combinations

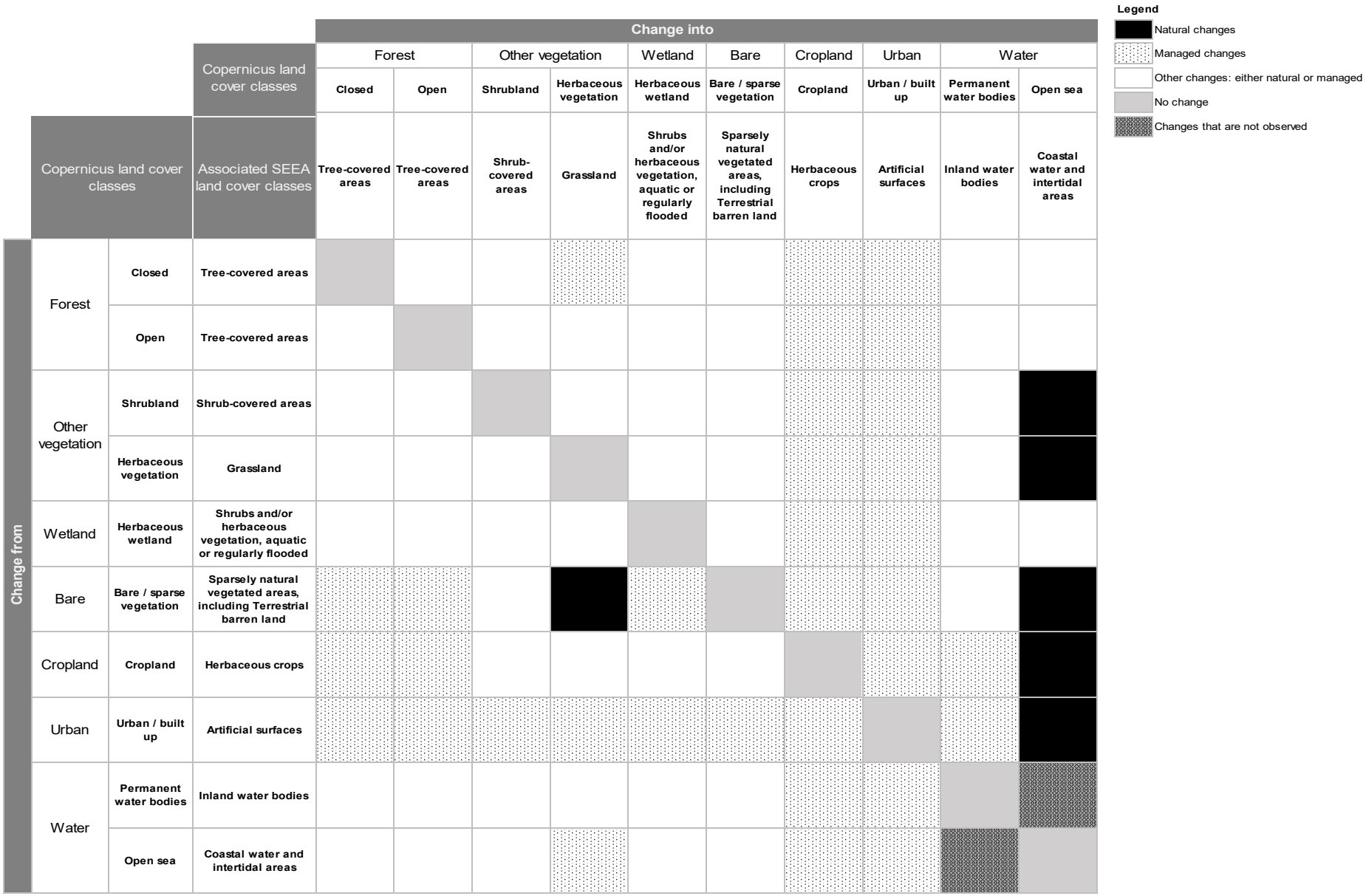

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Table A.4: Physical Land Asset Account – Iteration 1

	Artificial surfaces	**Coastal water and intertidal areas**	**Herbaceous Crops**	**Grassland**	**Inland water bodies**	**Shrub-covered areas**	**Shrubs and/or herbaceous vegetation, aquatic or regularly flooded**	**Sparsely natural vegetated areas including Terrestrial barren land**	**Closed forest**	**Open forest**	**TOTAL**
Opening Stock	13,035,181	802,549	139,294,614	688,869	2,749,336	313,991	994,149	39,578	136,503,036	28,159,209	322,580,511
Additions to Stock											
Managed expansion	45,859	-	62,045	334	170,176	-	3,340	-	13,579	29,928	325,260
Natural expansion	-	-	-	57	-	-	-	-	-	-	
Other expansions	-	-	-	14,453	222,551	2,366	1,258,714	5,905	11,632	10,260	1,525,880
Upward reappraisals											-
Total additions to stock	45,859	-	62,045	14,843	392,727	2,366	1,262,053	5,905	25,210	40,189	1,851,197
Reductions in Stock											
Managed regression	1,670	-	239,860	6,828	6,871	2,423	13,529	2,501	15,149	36,430	325,260

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Natural regression	-	-	-	-	-	-	-	57	-	-	
Other regressions	-	-	743,268	239,575	92,734	133,157	124,460	16,108	21,522	155,056	1,525,880
Downward reappraisals											-
Total reductions in stock	1,670	-	983,128	246,404	99,605	135,580	137,988	18,666	36,671	191,485	1,851,197
Closing Stock	13,079,370	802,549	138,373,531	457,308	3,042,458	180,778	2,118,214	26,816	136,491,574	28,007,912	322,580,511

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