A Register of Ecosystem Assets for Canada

Jonathan Whiteley, François Soulard

Statistics Canada

Introduction

Canadians are increasingly concerned about the economic, social and health risks associated with climate change and biodiversity degradation. However, knowledge gaps and data fragmentation make the socio-ecological impacts difficult to understand, let alone track over time. Cataloguing ecosystems is an important step in helping to resolve this, enhancing Canadians' ability to make evidence-based decisions to protect, rehabilitate, enhance and sustain our living environment. While policymakers currently have access to a wealth of economic and socio-economic information when making critical decisions, it is much more difficult to obtain the full picture on Canada's ecosystems and their benefits. That is why the Government of Canada, in its 2021 budget, provided ongoing funding to Statistics Canada to create the "Census of Environment".[1]

The Census of Environment builds on previous work towards the development of ecosystem accounts. This work follows the United Nations System of Environmental-Economic Accounting (UN SEEA) Ecosystem Accounting (EA) framework. A key feature of ecosystem accounting is an explicit focus on spatially referenced information about ecosystems and how they change over time. Building the accounts therefore requires compiling information on a wide variety of ecosystem characteristics, condition variables, as well as socio-economic data on beneficiaries of ecosystem services, and monetary values. The SEEA EA recognizes that such an undertaking will require the organization of multiple data sets, creating an opportunity to establish a rich data base of integrated spatial information.[2]

In order to achieve this, we concluded that a Register of Ecosystem Assets should be part of the foundation of the Census of Environment program, to provide an organizing framework for integrating data from various sources for use in ecosystem accounting and related statistics. This paper describes the initial conceptual framework for the Register, and is currently the focus of discussions with internal and external partners.

Purpose

The purpose of the Register of Ecosystem Assets ("Register") is to provide a common framework for organising spatially-explicit data on ecosystems, allowing aggregation by standard geographies at a range of scales, as well as providing authoritative delineation of ecosystem assets for the purpose of compiling ecosystem accounts.

At its core, the Register defines a standard spatially-referenced grid (see 'Key Concepts and Structure'). Each grid cell provides a spatial reference for linked data. Each grid cell is assigned to an ecosystem type, according to a standard national classification. Although ecosystems are continuous phenomena in

[1] Census of Environment: A roadmap to environmental and economic sustainability (statcan.gc.ca)
[2] SEEA-EA, S3.5.3

nature, the Register will provide a discrete representation, which is more amenable to the production of statistics. The particular representation of ecosystems in the Register of Ecosystem Assets may differ from others intended for different scientific or policy applications.

A spatially-explicit delineation of ecosystem types following a standard grid provides the basis for official accounts of ecosystem extent. For a given accounting area, the number of cells of each type can simply be counted to provide estimates of the extent of each ecosystem type. Ecosystem delineation and classification is therefore fundamental to compiling integrated ecosystem accounts, starting with extent, but also condition, flows of services, and how the ecosystems ultimately benefit human well-being and the economy.

Other variables, such as condition variables, and measures of ecosystem services flows, can also be assigned to the same spatial grid as the Register, creating a system of integrated data on ecosystems that is needed to compile integrated accounts and other products, such as regional profiles. Data on additional variables, beyond ecosystem types, can also be linked to the grid cells defined in the Register, but these can be organized and stored separately from the Register, in a repository of related data.

Each grid cell in the Register is also linked to geographic units in standard geographic classifications used for dissemination of statistics on the environment, economy, and society. This allows any variables linked to grid cells, including data sets outside the Register, to be easily aggregated to the same units used for dissemination of statistics from a wide variety of sources.

Any data formatted to the Register's grid can be easily linked to ecosystem types, or standard geographical units used for dissemination, such as those used by the Census of Population, or the Ecological Land Classification. This provides a framework for integrating socio-economic data aggregated by standard dissemination geographies, with spatially-explicit information on ecosystems, at a range of scales. It also allows for aggregation of values linked to the standard grid by arbitrary geographical boundaries (including administrative boundaries such as municipalities, or geographical boundaries not defined by current standards), providing a mechanism for responding to custom requests and analyses.

Furthermore, as the Statistical Register Infrastructure (SRI) develops further at Statistics Canada,[3] it may become possible to link spatially-explicit socio-economic data at finer geographic detail, by linking de-identified microdata on businesses, populations, and activities to locations in the Statistical Building Register and Business Register. This level of linkage would create many opportunities for environmental-economic analysis.

The Register will define a standard spatially-referenced grid for a suite of related datasets that are directly comparable, and compatible with standard GIS tools. By assigning ecosystem types to grid cells, the Register will provide an authoritative definition and delineation of ecosystem types for Canada, which will form the basis of SEEA Ecosystem Accounting and other statistics on ecosystems (see Figure 1). Data on other variables can be linked to the same standard grid, organized in a separate data repository. All variables linked to the standard grid will be directly comparable and available to users at increasingly finer scales, while remaining nationally comparable, following a Data Quality and Assessment Framework. Finally, by linking each grid cell to standard geographical units used for

[3] https://www.statcan.gc.ca/eng/conferences/symposium2018/program/09b3_pignal-eng.pdf

dissemination of statistics from a variety of sources, the Register will allow for easy aggregation of gridded data to areas that are directly comparable to data on society and the economy.

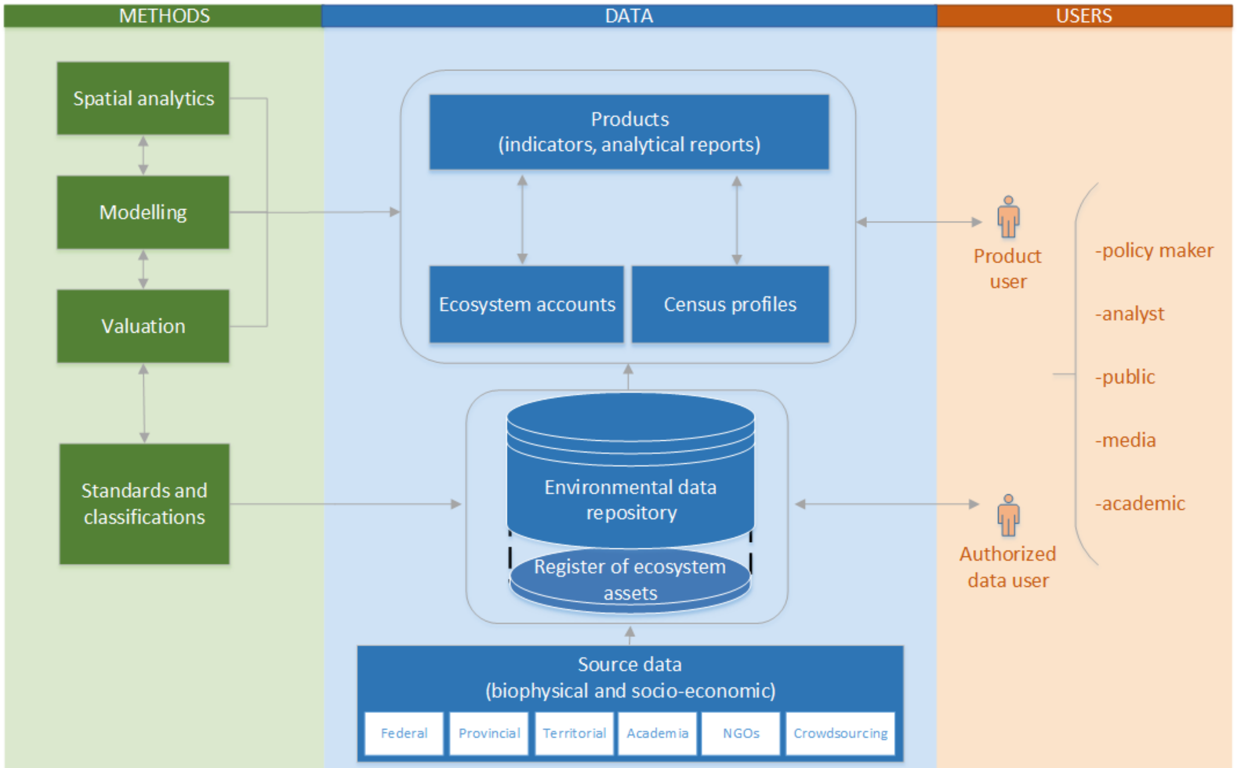

Figure 1 Relationship between the Register of Ecosystem Assets and other components of the Census of Environment.

This framework therefore supports the integration of spatially-explicit data on ecosystems with socio-economic data for use in natural capital accounting and the production of integrated environmental and economic statistics at local, regional, and national scales. Such a framework could also facilitate the compilation of statistics for national and international reporting frameworks, such as Sustainable Development Goals (SDG) indicators, post-2020 global biodiversity framework, and others.

Scope

Conceptual Scope

The Register of Ecosystem Assets includes the following core elements:

1. A standard spatially-referenced grid of spatial units covering all of Canada's land, freshwater, and oceans.
2. Each grid cell is linked to standard geographical units used for dissemination by Statistics Canada and other data producers. Multiple geographical classifications can be supported.
3. Each grid cell is assigned to an ecosystem type, according to a standard classification.

Additional variables related to ecosystems will be necessary to compile ecosystem accounts and other statistics, however. These additional variables can be formatted to follow the grid defined in the Register (by assigning values to the same grid cells), benefitting from all the advantages of a common grid and linked information on ecosystem types and standard geographies included in the Register.

Nevertheless, data on additional variables will be stored separately from the Register, in a repository of environmental data.

In this way, the Register provides a foundation and organizing framework for data on multiple ecosystem variables in the Environmental Data Repository (see Figure 1). Keeping the scope of the Register fairly small reduces complexity while creating a modular structure that is more flexible and adaptable to changing needs or available tools in the future. Files defining the Register may conceivably be stored within an Environmental Data Repository, but that will depend on user requirements and IT resources. The Environmental Repository will also include data that is not formatted on the standard grid defined in the Register, such as aggregated statistics by geographical areas, input data in its original format and resolution used to derive additional variables that are then resampled to the Register grid, or other environmental data not specific to the ecosystems in the Register. The structure of the Register will allow such data to be integrated with data on ecosystems.

Geographic Scope

The Register of Ecosystem Assets will cover all of Canada's land, freshwater, and ocean areas. The vertical scope of these areas include everything from bedrock to the atmosphere, in line with the conceptual model of ecosystems used by SEEA EA,[4] which are represented by two-dimensional footprints for analysis and accounting purposes.[5] The horizontal geographic scope may extend somewhat beyond Canada's borders, to allow for certain spatial analyses that require information on neighbouring cells in a grid, for example in cases where geographical features or ecosystems cross international borders. It may be preferable to integrate data sets on entire transboundary ecosystems, rather than only the portions within Canada's borders. The Census of Environment is only responsible for publishing statistics covering Canadian territory, but input data on some areas beyond these borders may improve the quality of such statistics.

Key Concepts and Structure

The Register of Ecosystem Assets is composed primarily of *Basic Spatial Units* (BSUs), represented by cells of a spatial grid covering all of Canada, including land, freshwater, and oceans (see 'Geographic Scope'). A spatial grid is compatible with Geographic Information Systems (GIS), providing a structure suitable for geospatial data storage and analysis.

Basic attributes of each BSU are described in Figure 2. The size of BSUs and other details of the data structure will be determined based on further research and development. Each BSU will be linked to units in standard geographic classifications, providing a direct concordance between them, and allowing rapid aggregation of cell values to standard dissemination areas.

[4] SEEA EA, S3.2.1
[5] SEEA EA, S3.2.2

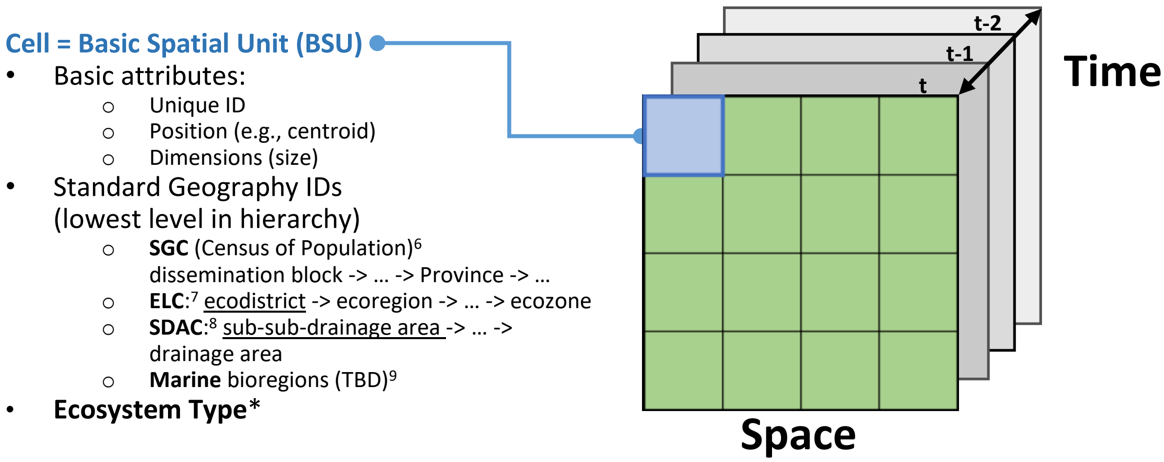

Figure 2 Basic structure of the Register of Ecosystem Assets represented as a "data cube". A "fact" (data point) is a variable (BSU attribute) in space (defined by BSU position)) at a point in time. Additional data sets may follow the same grid defined by the Register, allowing additional variables to be linked to the same BSUs (by their unique IDs), and aggregated to standard geographies[6,7,8,9] and ecosystem types defined in the Register.
** Ecosystem Type may include more than one value: these may represent depth layers in the ocean, or values for different applications, such as reporting under different frameworks (FAO, IPCC, etc.), which may differ from the value used to compile integrated ecosystem accounts. The final structure will be determined during development.*

Most importantly, the Register will also contain information on ecosystem types for each BSU, at multiple points in time (i.e., a time series). In some cases, BSUs may be linked to multiple ecosystems, such as ocean ecosystems at multiple depths. The grid of BSUs thus provides a spatially-explicit framework for geographic information, at a scale relevant to delineation of ecosystem assets. An *Ecosystem Asset* is defined in the same way as in the SEEA EA standard, as a contiguous area of a specific ecosystem type (i.e., one or more neighbouring BSUs assigned to the same ecosystem type), usually homogeneous in terms of condition.[10]

Individual assets may not be identified explicitly in the Register itself. Although they are an important unit for accounting, ecosystem asset boundaries can be unstable between time points, changing due to ecosystem conversions or inconsistent source data, making it difficult to identify and track an individual asset over time. If ecosystem assets are defined as contiguous areas of the same ecosystem type, they can be derived dynamically as needed. Further research will investigate the practicality and necessity of identifying individual assets across multiple time points. If necessary, ecosystem assets, or other large-scale units, can be defined as geographical units and assigned to BSUs in the same way that standard geographies are assigned within the Register.

[6] **SGC** = Standard Geographical Classification (https://www.statcan.gc.ca/en/subjects/standard/sgc/2016/index), used by the Census of Population for Canada. It is a hierarchical classification, where larger units are aggregations of smaller units, often corresponding to administrative boundaries.
[7] **ELC** = Ecological Land Classification (https://www.statcan.gc.ca/en/subjects/standard/environment/elc/elc2017)
[8] **SDAC** = Standard Drainage Area Classification (https://www.statcan.gc.ca/en/subjects/standard/sdac/sdac)
[9] **Marine bioregions** (https://www.dfo-mpo.gc.ca/oceans/maps-cartes/bioregions-eng.html) are used by Fisheries and Oceans Canada for marine planning, and represent an example of marine dissemination areas that could be included for reference in the Register of Ecosystem Assets.
[10] SEEA EA, S3.2.1, 5.2.1

One advantage of the proposed structure is that it can store spatially-explicit information in a tabular format, with unique identifiers of each BSU being used to link variables across multiple tables (see Figure 3), and to the spatial reference frame of a standard grid system. Tabular data can be aggregated efficiently in a variety of analytical platforms and systems, without requiring GIS tools. Nevertheless, GIS infrastructure will be needed to analyze input data and produce official versions of the Register of Ecosystem Assets.

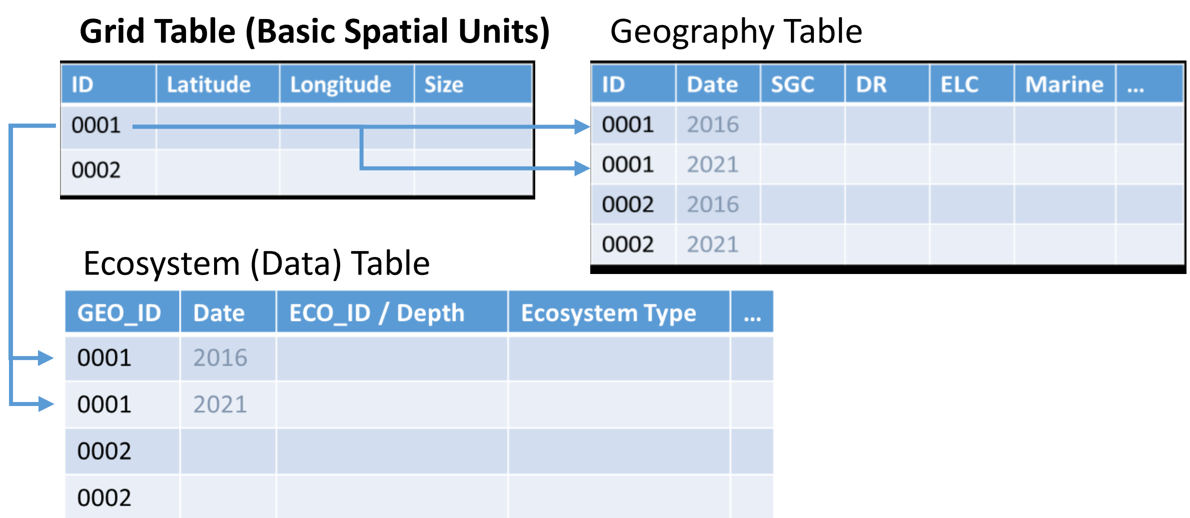

Figure 3 Example tabular structure of a Register of Ecosystem Assets. A primary table would define the BSUs (grid cells) in terms of position and size. Unique IDs could link each BSU to standard geographical boundaries and ecosystem types in separate tables. Depending on performance requirements and reliability of data sources, time series may be included in a single table, or separate tables, or different variables could be in separate tables. The key point is that the unique IDs of each BSU would link them all together across tables, like in a relational database.

Grid Shape

Rectangles (squares), triangles, and hexagons are each able to tesselate to form a regular grid, but each shape has different properties that may be better suited to particular applications. Hexagonal grids are often better for neighbourhood analysis, representation of curves, and are less affected by distortion over the surface of a sphere (i.e., the surface of the Earth). The Census of Environment, however, prefers a rectilinear grid, which is easier to subdivide cleanly into smaller cells (to add more detail), and for compatibility with satellite Earth observation data, which is produced on a rectangular grid, and represents the source of a large proportion of biophysical data used for ecosystem accounting.

Grid Size

A smaller grid size allows for higher-resolution data and greater geographic detail, but also requires more storage for the additional information. Not surprisingly, reducing the size of each grid cell increases the number of cells needed to cover Canada's territory exponentially. Canada is the second largest country in the world by land area, in addition to being responsible for several million square km of ocean. There may be a practical limit to the number of cells that can be managed with available computing resources and tools. There are also operational requirements to consider when determining the appropriate grid size.

An optimal cell size will depend in part on factors such as the spatial variability of characteristics, such as soils, hydrology, climate, structural elements such as topography and vegetation cover, and functional processes such as productivity, disturbances, and flows of water, nutrients, or organisms. Ideally, a BSU is also smaller than the smallest supported dissemination, to avoid situations where a single BSU would have to link to multiple geographical units within the same classification. The resolution of available data sources will also be an important factor to determining the spatial scale at which ecosystem assets can be reliably delineated and classified. Most available data is based on a resolution between 10 m (e.g., Sentinel satellites) and 250 m (e.g., MODIS), with a large proportion based on pixels about 30 m in each dimension (e.g., LANDSAT).

Given the range of resolutions for available data, and the large area to cover, we are investigating the use of systems of nested grids, rather than a single grid of a set size. A nested grid system would allow flexibility of grid sizes for given variables or applications, with the option of using lower resolutions (and less storage space) when possible, as well as the option to add more detail by using smaller cells when necessary and as such data becomes available. Nesting grid cells within each other creates a hierarchical relationship between cells of different sizes, making it conceptually and computationally easier to aggregate data to larger cells, or ‘downscale’ coarse data to smaller cells, to combine data into a single common resolution for analysis and processing.

Grid Structure and BSU Identifiers

Every Basic Spatial Unit (BSU) will require a unique identifier (ID), to link related data, including standard dissemination geographies and ecosystem types. Ideally, the IDs can be used to identify neighbours, and parent-child relationships in a nested grid system. While ecosystems will be delineated at a standard size of BSUs in the Register of Ecosystem Assets, related environmental data, including input variables used to delineate ecosystem assets, may include data at higher or lower resolutions. It would also be convenient if BSUs in the Register, or data in the repository, could be easily grouped together to a matching resolution for analysis and comparison with other geospatial (gridded) data.

One method to achieve this would be to have a series of nested grids at multiple resolutions, allowing fine resolution for some data, and coarse resolution for others, where each resolution is a perfect multiple or sub-division of a BSU in the Register.

The Census of Environment is currently exploring existing well-described systems of nested grids with IDs to evaluate their suitability, or potential to be adapted for the Register of Ecosystem Assets. Current research is focusing on examples such as Plus Codes used by Google Maps[11], and Discrete Global Grid Systems (DGGS)[12,13], such as an implementation of the rHEALPix DGGS.[14,15] DGGS is a standard developed by the Open Geospatial Consortium to address many challenges related to storing, managing,

[11] https://maps.google.com/pluscodes/
[12] http://www.opengis.net/doc/AS/dggs/1.0
[13] https://www.ogc.org/projects/groups/dggsswg
[14] Gibb, R. G. 2016. "The rHEALPix Discrete Global Grid System." IOP Conference Series. Earth and Environmental Science 34 (1): 12012-12019. doi:10.1088/1755-1315/34/1/012012.
[15] Bowater, David and Emmanuel Stefanakis. 2018. "The rHEALPix Discrete Global Grid System: Considerations for Canada." Geomatica (Ottawa) 72 (1): 27-37. doi:10.1139/geomat-2018-0008.

and analyzing large heterogeneous geospatial datasets.[16] In general terms, a DGGS partitions the Earth surface into a series of cells of equal size, which can be subdivided to finer resolutions. Data values are assigned to each grid cell, which represents an area of standard size. DGGS is an open global standard, offering several advantages for managing data for large areas like Canada, and international comparisons, as described in the Global Statistical Geospatial Framework.[17]

Users and Outputs

The Register of Ecosystem Assets is designed to support a range of outputs, for a range of users.

Statistics Canada analysts will be able to use the contents of the Register to compile accounts of ecosystem extent, according to the methods and definitions defined in the UN SEEA EA framework. They will also be able to compile other datasets using the same standard grid defined in the Register, adding variables and dimensions—or layers—without having to replicate a geospatial reference frame with every new dataset. These spatial layers can include data on ecosystem condition, flows of ecosystem services, or information on users and beneficiaries of ecosystem services. These spatially-explicit data layers can be summarized into aggregate statistics presented in tabular format, including SEEA ecosystem accounts. Spatial and non-spatial data can also be further analyzed for products such as dashboards, data visualizations, or analytical papers, to highlight key indicators, or inform important policy discussions.

These products will appeal to a range of users outside Statistics Canada and the general public. Users comfortable with analyzing and manipulating geospatial data will be able to use detailed outputs from the Register of Ecosystem Assets to compile locally-relevant accounts and related statistics, or link to other geospatial data for analysis. Policy analysts, planners, or other users will be able to use tables of summary statistics to inform policy decisions at multiple orders of government (municipal, provincial, national). Economists will be able to link Ecosystem Account tables to tables from the System of National Accounts (SNA) for extended analyses of the links between the economy and the environment. Analytical products and data visualizations should be more accessible to decision-makers and public users, providing high-quality information relevant to important policy issues such as climate change impacts and mitigation, environmental impacts of economic activity, and impacts of different policy approaches on the potential value of ecosystem services received by society.

Conclusion

The compilation of ecosystem accounts has the potential to integrate information on ecosystems into economic analysis and decisions. But it requires the integration and analysis of geospatial data from a variety of sources, such as in-situ and satellite Earth observations, administrative data sets, citizen science and other data sources. The Register of Ecosystem Assets proposes a framework and system for organizing the data needed to compile SEEA EA accounts for Canada. It includes a standard spatially-referenced grid covering all of Canada’s land, water, and ocean territory, where each grid cell is a Basic Spatial Unit (BSU); each BSU is linked to alternative standard dissemination geographies for easy aggregation, depending on the area of interest; each BSU is also assigned to an ecosystem type. This

[16] Bowater, David and Emmanuel Stefanakis. 2018. "The rHEALPix Discrete Global Grid System: Considerations for Canada." Geomatica (Ottawa) 72 (1): 27-37. doi:10.1139/geomat-2018-0008.
[17] https://unstats.un.org/unsd/statcom/51st-session/documents/The_GSGF-E.pdf

spatially-referenced list of ecosystems on a standard grid creates a foundation to link a range of other spatial data, including ecosystem conditions, flows of ecosystem services, and even characteristics of the users and beneficiaries of these services. A standard grid facilitates integration of multiple variables for analysis and compilation of aggregate statistics. This will enable efficient production of a range of outputs and products that will be accessible to users from specialized data analysts to policy and decision-makers and the general public. In this way, the Census of Environment hopes to better connect ecosystem information with economic data, to help Canadians better understand the ways in which they are related and the benefits we receive from our abundant natural assets.