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Classification of ecosystem types: Experiences and perspectives from Statistics Canada

Prepared for

Forum of Experts in SEEA Experimental Ecosystem Accounting 2018

18 – 20 June 2018

Glen Cove, New York, USA

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Working paper, June 14, 2018.

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Introduction

This paper is written in response to the request for input on Research area 1: Spatial areas in the *SEEA Experimental Ecosystem Accounts (EEA) Revision 2020: Revision Issues Note.*

It focuses on Statistics Canada's initial work to measure ecosystem extent, discussing what has been done and why. We note many similarities in terminology, but identify potential difficulties in adapting Canada's existing broad ecosystem classification system—that includes ecological characteristics in the delineation of ecosystems—with the intent of the SEEA EEA delineation of ecosystem types.

The paper also provides comments on the issues identified for further research in the *SEEA-EEA Revision 2020: Revision Issues Note*, especially with regards to the ecosystem types classification structure and potential issues with the proposed land cover proxy ecosystem types, for example, the inability to fully capture specific ecosystem types (e.g., wetlands) in the land cover-based delineation. Also identified are issues related to scale and potential topics for consideration in the development of a multi-dimensional hierarchy including possible integration of anthropogenic influences.

Initial work on measuring ecosystem extent in Canada

Ecological classification in Canada

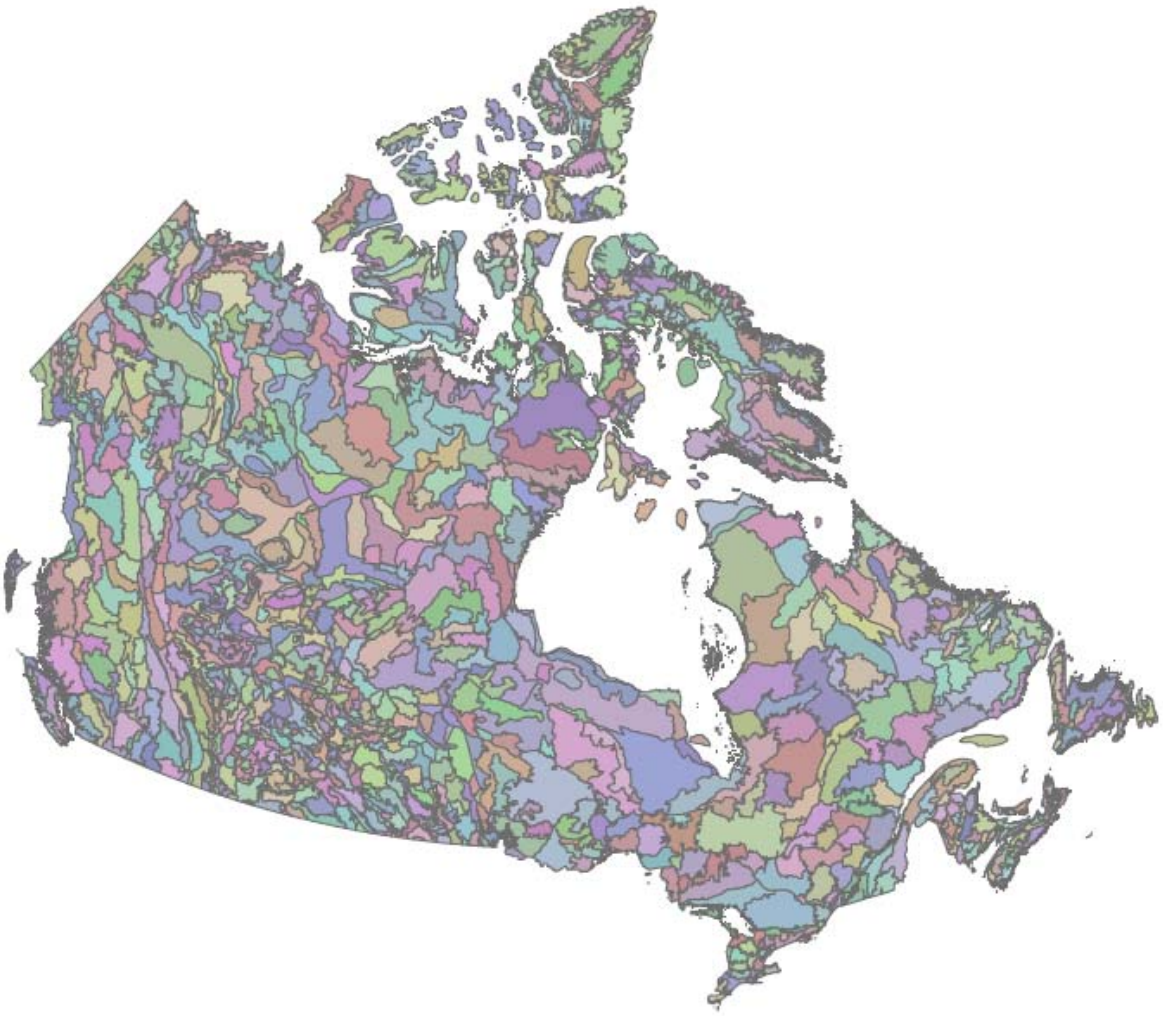
Statistics Canada has long used, and has now formally approved, the Ecological Land Classification 2017 as the official classification for reporting on ecological areas (excluding marine areas) in Canada (Statistics Canada, 2017). This classification is based on the Ecological Framework for Canada (Ecological Stratification Working Group, 1995; Environment Canada, n.d.) and is a hierarchical framework that classifies ecological areas into four nested levels including 15 ecozones, 53 ecoprovinces, 194 ecoregions and 1,027 ecodistricts (Table 1, Map 1).

Table 1. Ecological framework levels

Level	Definition
Ecozone	At the top of the hierarchy, it defines the ecological mosaic of Canada on a sub-continental scale. Ecozones represent areas of the earth's surface representative of large and very generalized ecological units characterized by interactive and adjusting abiotic and biotic factors (See Appendix A).
Ecoprovince	A subdivision of an ecozone characterized by major assemblages of structural or surface forms, faunal realms, vegetation, hydrology, soil and macro climate.
Ecoregion	A subdivision of an ecoprovince characterized by distinctive regional ecological factors, including climate, physiography, vegetation, soil, water and fauna.
Ecodistrict	A subdivision of an ecoregion characterized by distinctive assemblages of relief, landforms, geology, soil, vegetation, water bodies and fauna.

Source: Marshall, I.B., Schut, P.H., and Ballard, M. 1999.

Map 1. Ecodistricts of Canada



The classification represents a national approach to terrestrial ecosystem classification based on biophysical characteristics. It is an integrative classification incorporating air, water, land and biota components, though the number and importance of these factors in delineating units varies from one area to another. Datasets on the following topics are available for the highest four levels of the ecological framework: elevation, total land and water area, land cover (1-km), landform, permafrost, surficial geology, soil development, soil texture, surface material and surface form (Agriculture and Agri-Food Canada [AAFC], 2013). Detailed textual descriptions of ecosystem characteristics (e.g., climate, physiography and drainage, soils, vegetation, water and use) are available for the higher levels of the classification and for some ecodistricts (See Appendix A and B).

Canada's terrestrial areas (including inland waters) extend over more than 9.9 million km^2. All boundaries in the terrestrial ecological framework are matched to 'soil landscape polygons' from the Soil Landscapes of Canada, which provides cartographic base information with linkages between soil components and land positions. The 1,027 ecodistricts in the framework range in size from 46 km^2 to

109,960 km^2 and are linked to almost 13,000 soil landscape polygons[2] that range in size from 2 km^2 to 560,643 km^2—the smaller sizes reflecting the availability of more detailed soil mapping in southern Canada, particularly in agricultural areas (Smith et al., 1998, p.10).

The 1995 Ecological Framework for Canada focused on three priority levels of stratification (ecozone, ecoregion and ecodistrict) that were identified by the Canada Committee on Ecological Land Classification (CCELC) starting in the mid-1970s (Environment Canada, n.d.). Additional materials were developed for several provinces through the 1990s and the integrated North American continental perspective was released in 1999 (Commission for Environmental Cooperation). A 1999 revision provided attribute data, including at the ecoprovince level (AAFC, 1999). The original CCELC hierarchical classification included seven levels including, below the ecodistrict level: ecosections, ecoelements and ecosites. However, these levels of hierarchy have not been comprehensively mapped for Canada.[3]

Marine and coastal waters in Canada cover approximately 5.6 million km^2, equivalent to about 56% of Canada's land mass (Statistics Canada, 2013). These waters, in 3 oceans, have been classified into 12 marine ecozones based on oceanographic and depth similarities and general ecological features (Fisheries and Oceans Canada, 2009). This marine classification is based on guiding principles and a framework developed following review of various global and regionally-focused biogeographic classification systems. Guidance on the subdivision of these 12 marine biogeographic units is also provided, including a focus on delineation of functional food webs and major water mass and/or bathymetric features. As well, it recognized that there is a greater need for finer scale biogeographic subdivisions in near-coastal areas than in offshore areas.

The Canadian Council on Ecological Areas (CCEA) released an update to the Canadian Ecological Framework in 2014. This new map includes 18 terrestrial, 12 marine and 1 freshwater ecozone (i.e., the Great Lakes) (CCEA, 2014). The update is limited to the ecozone-level and facilitates integration with the North American ecological framework for the Commission for Environmental Cooperation (CEC). Statistics Canada has not yet adopted this version of the ecological framework, but will continue to assess this new national-scale map for use in future.

As well, various jurisdictions maintain detailed data for regional ecosystem classification. For example, the province of British Columbia maintains two complementary ecosystem classification systems: the Ecoregion Classification, in which ecosections are analogous to the ecodistricts of the Canadian Ecological Framework, and the Biogeoclimatic Ecosystem Classification, which delineates ecological zones based on vegetation, soils and climate, and specific site characteristics based on mature successional stages of forest (British Columbia Forest Service, n.d.). The province of Quebec produces the "Classification écologique du territoire" [Ecological land classification] with eight hierarchical levels for describing the ecological diversity of forest areas, with additional information (species type, age class etc.) at the stand level (Forêts, Faune et Parcs Québec, n.d.).

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[2] Including inland water.

[3] One example is the 1983 report, *Ecological (Biophysical) Land Classification Of Banff and Jasper National Parks*, which characterizes the ecosystem (surface expression, genetic material unit, soils, vegetation and wildlife) at the ecoregion, ecosection and ecoecosite levels) for the 17,520 km^2 of Banff and Jasper National Parks. Three ecoregions, 55 ecosections and 124 ecosites are described and mapped. This work predates the National Ecological Framework.

Measuring ecosystem goods and services

Work to develop ecosystem accounts began at Statistics Canada in 2011 with the "Measuring ecosystem goods and services" project, the results of which were subsequently published in 2013 in the annual report *Human Activity and the Environment* (HAE).

One of the outputs of the project was a geodatabase that integrated several publicly available spatial datasets including land cover and elevation, as well as socio-economic data such as land use and income. The base layer of the geodatabase was the Canada Centre for Remote Sensing's 25 class land cover, based on Moderate Resolution Imaging Spectroradiometer (MODIS) at a 250 m resolution, although a 30 m land cover product from Agriculture and Agri-Food Canada (AAFC) was integrated to provide more detail for southern Canada. This geodatabase included selected ecological characteristics for delineating ecosystem assets (previously termed 'land cover ecosystem units') across the country.

The report included a land cover table for Canada and for southern Canada using, respectively, 250 m and 30 m resolution data. However, the results were preliminary due to issues with methodology and data quality, and future work will build on lessons learned and new data sources, both global and regional. It also included data on wetland extent and drivers of change and an assessment of the main marine ecosystem goods and services for which data were available—the landed weight and value of commercial fishery catches for the Pacific and Atlantic costs, by statistical area.

Ecosystem extent accounts

Initial ecosystem extent accounts for urban areas were published in 2015 in the HAE report "The changing landscape of Canadian metropolitan areas." These ecosystem extent accounts were produced for the areas around 33 census metropolitan areas (CMAs) from 1971 to 2011.

The initial asset accounts provided data for aggregated ecosystem types including built-up (settled area and roads), arable land and natural and semi-natural land. This latter category was defined by subtracting built-up and arable land from the total area. The natural and semi-natural category for 2011 included subdivisions for forests (using 30 m data from the AAFC Crop Inventory), water (from Natural Resource Canada's (NRCan) CANVEC product) and other land (residual of total). These highly aggregated ecosystem types were used due to data quality and availability.

While built-up data were produced for CMAs and a newly-created geography termed CMA-ecosystem (CMA-E), which combines the CMA with included and intersecting soil landscape of Canada polygons, arable land and the residual variable natural and semi-natural land were only available for the CMA-Es. Data on arable land was based on the variables for cropland, tame or seeded pasture and summerfallow land from the Interpolated Census of Agriculture for 1971, 1991, 2001 and 2011, a product that reallocates data from Statistics Canada's Census of Agriculture to SLC polygons. These data do not have the spatial granularity required to be mapped within SLCs.

This work has since been expanded to cover smaller areas—selected census agglomerations (CAs)—and data are available in Statistics Canada's online database (CANSIM Table 153-0164). Note, however, that the resulting data at the CMA-E and CA-E geographies are not mutually exclusive—they overlap where a SLC polygon crosses more than one CMA or CA boundary, which occurs particularly around the largest areas including Toronto and Vancouver. For this reason the accounts for each metropolitan region (ecosystem accounting area) are standalone and data cannot be aggregated.

Discussion issues

The *SEEA-EEA Revision 2020: Revision Issues Note* identifies several areas of focus, specifically:

1) establishing statistically and accounting relevant classifications for land use, land cover and ecosystem types, with review and application of existing classifications; development of clear principles to define classes that are appropriate at the international level and ensuring alignment with *SEEA-Central Framework* (SEEA-CF) land use and land cover classifications, and ecosystem services
2) describing and classifying marine areas
3) articulating a connection to atmospheric units
4) distinguishing urban areas

Statistics Canada provides some comments here related to issues 1 and 4. The Fisheries and Oceans (2009) document cited above provides a review of existing biogeographical classification for marine areas, principles and a framework for Canada. Further information should be provided related to issue 3 as this topic is unclear.

Ecological classification

The *Technical Recommendations in support of the SEEA-EEA* indicate that organizing information on the area of different ecosystem types within a country is the starting point for all ecosystem accounting (UN, 2017, p. 22). Ecosystem assets are defined as "contiguous areas covered by a specific ecosystem." (p. 34). A basic principle associated with the delineation of ecosystem asset areas is that their extent provides a complete and non-duplicative set of assets that make up the ecosystem accounting area (p. 35-36). Ecosystem types meanwhile are defined as "aggregations of individual ecosystem assets of a specific type of ecosystem" (p. 34).

The *Technical Recommendations* indicate that delineation of ecosystem assets should be based on ecological and ecosystem use factors; however, where these characteristics are not available, it indicates that a delineation based on the land cover may be used (p. 37-38). They provide an initial example of possible ecosystem types, nested in land cover classes from the SEEA CF (p. 39-40).

While this method of using land cover to delineate ecosystem assets and type may be practical, we note basic shortcomings in this approach in terms of congruency with the complexity of ecosystems, including the interaction of their plant, animal and micro-organism communities and non-living environments. SEEA EEA indicates that an assessment of ecosystems should consider the key characteristics and location including structure (food webs), composition (biotic and abiotic), processes and functions (p.15). Given this broader view, land cover is just one of several variables that should be used to classify and delineate ecosystems.

On the other hand, the existing Ecological Land Classification cannot be easily used for the purposes identified in the SEEA EEA. Canada's existing ecological area classification "boundaries reflect factors that control ecosystems distribution at various scales, such that they can be recognized, compared and applied regardless of human activities and other natural disturbances" (Environment Canada, n.d.) It largely excludes current land use, makes no mention of ownership, and focuses on what are termed the more "enduring components" of ecosystems—i.e. relatively stable components such as soil, landform or major vegetation type (CEC, 1997).

This hierarchical classification of ecological areas has been developed using a top-down approach to identify broad regional areas sharing the same ecosystem characteristics, and boundaries have not been comprehensively spatially delineated at the lowest conceptual levels (i.e. ecosection, ecoelement, ecosite) that might more easily be linked to specific ecosystem types and ecosystem services.

Attribute data from the ecodistrict level might be used to define ecosystem types for some regions, but only if the type classes are broadly defined and a high level of detail is not required—note that Canada has many remote ecodistricts and soil landscape polygons that exceed the size of countries in Europe. Given the size and potential diversity of ecosystem types within some individual ecodistricts, as well as the different conceptual bases of the systems, there will be some challenges in adapting this existing ecological classification to a potential new SEEA classification of ecosystem types based on ecological characteristics, land cover and land use.

Detailed land cover maps are not available for the whole of Canada. Newer, higher resolution land cover data sets would need to be included and other ecosystem characteristics would need to be downscaled to more local levels in order to delineate smaller (e.g., urban) ecosystems. Currently the ecological areas identified in the Ecological Land Classification might be more usefully considered as ecosystem accounting areas containing a potentially wide range of ecosystem types (See Appendix A and B).

Identifying ecosystem types

A key research item in the *SEEA-EEA Revision 2020: Revision Issues Note* is "establish[ing] clear principles for defining ecosystem type classes" (p.3). A basic principle in developing these statistical classifications includes the use of mutually exclusive and exhaustive categories. It is also important to consider the level of detail required for various uses including understanding links to ecosystem services and countries' needs to adapt classifications and ability to add or remove levels of detail or aggregations.

The SEEA EEA and *Technical Recommendations* indicate that the preferred approach to identify ecosystems is to use ecological characteristics and ecosystem use. Underlying this classification would be the development of an appropriate structure for ecosystem types that recognizes the preferred approach of delineating ecosystem assets based on a broad set of ecological characteristics where available (e.g., climate, terrain, soils), but with the flexibility to allow a more basic land cover-based approach as a starting point (see Table 2 and Appendix D).

Data for each cell—the basic statistical unit (BSU) would ideally link all relevant characteristics allowing similar units to be categorized according to the accounting need to answer specific policy questions. A multi-dimensional hierarchy would allow for inclusion of underlying detail and potential aggregation at a range of levels. For example, in a normalized database, the areas could be stratified or filtered to aggregate based on the desired characteristics and context specific sub-categories. In essence, we refer to the need for a spatial data infrastructure based on a data cube of ecosystem data.

It is not clear, however, how the various identified characteristics should be aggregated into a relatively small number of internationally relevant ecosystem types. An approach that reasonably follows from the use of this system is to identify all similar polygons/grid cells with the same characteristics as an ecosystem type (e.g., cold/moist, plain, organic soil, black spruce/lichen, boreal/taiga forest); however, the result is likely an unworkable number of types, which will require aggregation. Including a larger number of characteristics will complicate the matching and aggregating of types.

An alternative approach would be to place greater emphasis on specific characteristics or use expert synthesis of the characteristic information in order to allocate the areas to a select number of predefined ecosystem types. This is a more subjective process, and results from this aggregation method will be less robust, but it may be more easily adoptable.

Table 2. Potential ecological and non-ecological characteristics for a multi-dimensional hierarchy

Category	Possible level of details
Ecological characteristic examples	
Climate	-tropical, subtropical, temperate, sub-arctic, arctic / cold, moderately cold, warm / arid, semi-arid, moist, wet etc. -use of Köppen climate classes or similar classifications -sub-classes: e.g., specific temperature and precipitation ranges
Terrain: Elevation, land forms	-upland/low-land, sub-alpine, alpine -mountains, plains, hills, foothills, coastal plains -Details (aspect, slope)
Soils/parent materials etc.	-E.g., Canadian System of Soil Classification soil orders: brunisols, chernozem, crysols, gleysols, luvisols, organic,[4] podzols, regosols, solonetz, vertizols (Use of soils links to/complements information on other aspects such as vegetation, land cover, wetlands etc.)
Land cover	-aquatic/terrestrial (sub-classes: saturated, seasonally or permanently flooded, aquatic-associated terrestrial e.g. riparian) -forest, grassland, cropland, built up etc.; and associated sub-level land covers. -Built-up (sub-classes: pervious/impervious)
Flora/fauna type/vegetation	-Hierarchy could capture from most basic to specific species (e.g. forest, coniferous, coastal evergreen, coastal western hemlock).
Non-ecological characteristic examples	
Land use type	-Modifier/sub-code rather than classification code? -May want to break out some of the "built-up areas" – e.g. mining and quarrying, recreational facilities (e.g. public beaches, urban parks), residential by type (continuous and dense, continuous moderate density, discontinuous moderate density, isolated residential.
Proximity to cities or population within	-Proximity could help link to services, (as a modifier rather than classification variable?) -Population could be ranges
Anthropogenic connection	-ID basic natural-semi-natural vs. altered/intensively managed landscapes that are more affected by human activity and interaction (e.g. natural grasslands vs. altered/deforested areas).
Ownership/tenure	-Could be a modifier/sub-type code – it does not define the ecosystem or services
Management	-Protected vs. non-protected etc. (modifier/sub-type code)

The SEEA EEA and the *Technical Recommendations* do not currently detail such a classification structure—instead, the documents identify examples of ecosystem types that are based on biomes (e.g.

[4] Note: Organic soils include peat, bog or fen soils, i.e. organic wetlands.

forest, wetland, grassland) and indicate that other projects have used similarly easily-understood terms for ecosystems. The above terms are not, however, mutually exclusive. The *Technical Recommendations* also present the SEEA CF Land cover classes as proxy ecosystem types and identified possible subdivisions for use when specific detail on ecological and use characteristics is not available (Table 3.1., p. 40). Some further comments on the land cover classes and example ecosystem types used in this table are discussed below and listed below in Appendix C (Table 3).

There are differences in the levels of detail proposed for the different land cover classes. The link to ecosystem service and condition should be identified otherwise it is not necessarily clear why some of the land cover classes are needed and greater aggregation may be suitable. Inclusion of detail should be based on actual needs since an increase in the land cover details often entails a decrease in the accuracy of each class.

For example, the 'Artificial areas' example ecosystem types (e.g. residential/housing, urban parks, industrial uses (e.g. factories), road infrastructure and waste deposit sites) are vastly more detailed than the ecosystem types for 'Tree-covered areas/forests' (e.g., coniferous, deciduous, plantation). We recognize the linkage between the ecosystem services provided by urban parks and their potentially higher values, and ideally would be able to delineate these types. On the other hand, information is available to define more specific ecosystem types for tree-covered areas/forests. For example, e.g., boreal forest / taiga, coastal rainforest, eastern woodlands/Carolinean forest, temperate/sub-tropical, by species type, etc., which might also be relevant in determining services.

Clarification and further development of these land cover-based subdivisions may be required since the detailed ecosystem type examples listed in Table 3.1 of the *Technical Recommendations* are not mutually exclusive and exhaustive and the details may not be possible to distinguish using remote sensing or field surveys. For example, under herbaceous crops, groupings include irrigated rice, other irrigated crops and rainfed annual croplands. However, irrigation areas are dependent on climate conditions—some crops may be irrigated in a given year and not in a subsequent year. Also, it can also be difficult to distinguish between the grassland categories natural and improved pasture and the herbaceous cropland categories for forage crops (e.g., alfalfa hay).

There are issues with identifying wetlands given saturated soils exist under a number of different land covers. For example, the black spruce-lichen forests of northern Canada—important habitat areas for caribou—overlie vast areas of organic wetlands (peatlands), which provide important carbon sequestration and water regulation services. These forested bogs (peatland forests) and fens cover significant areas, including about 25% of the productive forest land of parts of the Boreal Shield ecozone (NRCan, 2018). Identifying these wetland areas based on alternate categories than land cover, such as soils (organic) (Table 2) or vegetation may allow for recognition of these characteristics and aggregation.

The land cover based classifications may also have potential areas of overlap or confusion. For example, tidal wetlands (e.g., marshes and mangrove swamps) appear to be grouped separately from the coastal and intertidal areas where they may exist (e.g., lagoons and estuaries). Despite the inclusion of a separate land cover classification for shrub-herbaceous wetlands (incl. e.g., marshes), a parallel category for forest wetlands (incl. e.g., swamps) does not exist. Different types of wetland each provide their own functions and services.

In addition, the ecosystem type examples for sparsely natural vegetated areas and terrestrial barren land are not exhaustive and overlap, in Canada at least. Much of Canada's northern tundra is colloquially considered to be barren land, though it is covered with low-growing vegetation/lichens/mosses. The link to ecosystem services may not be immediately apparent for some areas.

Finally, it is not clear how to deal with areas where a mix of land covers (e.g., forest/woodland and cropland) is present within a small area since mosaic areas are not identified in the land cover classification. At a very fine level this may not be an issue, but with data sets at 250 m or 1 km, guidance or inclusion of additional mosaic classes linked to services may be needed.

Urban issues

The *Technical Recommendations* indicate that urban areas are included in ecosystem accounts because of the need to be exhaustive and not because they include a lot of plants or animals or provide a lot of ecosystem services (p.34). However, given that urban areas are the physical location where most people exist to benefit from ecosystem services and some ecosystem services are provided locally (e.g., micro-climate regulation, air filtering, noise reduction, water regulation, recreation), it likely does make sense to further differentiate the agricultural and natural and semi-natural lands within urban areas (e.g., parks, lawns/yards, unpaved areas, urban forests, beaches, riparian areas, natural and artificial wetlands, urban and periurban agricultural areas etc.) that provide these services. For a similar reason, it may also be useful to identify ecosystem assets outside the urban boundary based on proximity to urban areas.

Measuring specific ecosystem types within urban areas requires that either the available datasets be fine grained or that the ecosystem type patches within the urban area be relatively large (e.g., significant areas of urban forests, urban parks, periurban agricultural). Small areas (e.g., street trees, lawns and yards in areas of high or moderately-high density) may be difficult to delineate.

Within core-built-up areas it may be useful to continue to indicate these smaller areas as subsets of urban ecosystems, rather than aggregating with similar ecosystem types that occur outside urban areas (e.g., forestry, agriculture), given the link to the above mentioned services and likely differences in ecosystem functioning and value of services. A potential basic land cover-based disaggregation of these urban areas might be pervious/impervious areas, given their differing impacts on the environment.

Statistics Canada has developed preliminary ecosystem accounts for large urban areas—viewed as the ecosystem accounting areas—and work is progressing for smaller urban areas. This work integrates multiple data sources to identify the built-up areas (settled/roads), arable agricultural areas, and natural and semi-natural areas (forests, natural land for pasture and other) as described earlier in this document. However, more research and development is required to create this account as a single non-overlapping account for Canada. Canada's existing ecological classification does not lend itself to the definition of urban ecosystem types—newer and more detailed data sets will need to be included to identify these areas. This may become more feasible given the growing availability of detailed resolution data sets.

Conclusions and next steps

This review of select issues identified in the *SEEA EEA Revision 2020: Revision Issues Note* has highlighted a few topics that deserve additional consideration.

Firstly, the issue of scale should be considered more explicitly. The scale at which ecosystem types are defined should be flexible to allow for different policy needs, data availability and accuracy, and identification of links to services. For example, in Canada, ecosystems located in close proximity to major populations might be more carefully delineated than ecosystems in the far North.

Identification of a limited number of easily understood and mutually-exclusive ecosystem types is complicated by the fact that some of the characteristics of key interest in measuring ecosystem services coexist within a given area. For this reason it may be necessary to have more potential classification groupings than might otherwise be preferable, knowing that within a given country only a subset of the ecosystem types will be used.

The use of SEEA CF land cover classifications as a proxy for ecosystem type may place more focus than needed on less productive ecosystem service areas and downplay the importance of natural and semi-natural areas and ecosystem types such as wetlands that are difficult to distinguish using two-dimensional classes. New classes should merge the land cover-based classes with information on climate, landform and elevation, soils, and degree of human influence and land use characteristics to create classes that can be more directly linked to ecosystem services. The use of a multi-dimensional hierarchy would underlie this classification structure.

This paper does not provide a recommended shortlist of potential ecosystem type groupings that could be included in an internationally-relevant ecosystem type classification or a review of other existing classifications, but provides a preliminary breakdown for a potential multi-dimensional hierarchical classification structure (see Appendix D).

However the question of aggregation methods remains: one approach involves equally weighting characteristics, identifying a large number of ecosystem types, and aggregating through an iterative process to determine the resulting classes. A more subjective alternative is to allocate the identified areas to pre-determined ecosystem types based on expert decision or weighting of characteristics.

Another issue may be how to integrate administrative data (e.g., census data, business registers, cadastral data etc.) into this structure to support the delineation of ecosystem assets and/or to support definition of other characteristics (e.g., anthropogenic connection, agricultural extent etc.). It may also be useful to consider the extent to which non-ecological characteristics such as ownership and management should be used in delineating areas or whether they should simply be identified in the database, since these characteristics may have little impact on actual ecosystem functions and services, and may be more relevant in terms of analysis and reporting.

Finally, we note some overlap in the instructions in the *Technical Recommendations* regarding the inclusion of ecological characteristics to both delineate the ecosystem assets and also describe ecosystem condition. Specifically, the recommendations indicate that the delineation of ecosystem assets will “involve the use of a range of ecological and non-ecological criteria, including vegetation type, soil type, hydrology and land management and use,” and that these characteristics “can be used to classify ecosystem assets to various ecosystem types’ (UN, 2017, p. 14). The instructions on ecosystem condition also discuss including these basic, often static, characteristics as part of ecosystem condition (e.g., p.16 & p. 54) but note that these characteristics are not key indicators of changing condition.

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Appendix A – Some descriptive biophysical characteristics of Canada's ecozones

Ecozone	Landforms	Surface materials/soils	Climate/oceanographic characteristics	Vegetation/ productivity	Wildlife (mammals/birds)	Human activities	Main communities
Terrestrial ecozones							
Arctic Cordillera	Mountains	Ice, snow, colluvium, rock/Cryosols	Extremely cold, dry; continuous permafrost	Mainly unvegetated; some shrub–herb tundra	Polar Bear (along coast), Arctic Hare; Northern Fulmar, Common Ringed Plover, Snow Bunting	Hunting, tourism	Pond Inlet, Clyde River, Broughton Island
Northern Arctic	Plains, hills	Moraine, rock, marine/ Cryosols	Very cold, dry; continuous permafrost	Herb–lichen tundra	Peary Caribou, Muskox, Wolf, Arctic Hare; Red-throated Loon, Brant, ptarmigan, Greater Snow Goose	Hunting, tourism/recreation, some mining	Iqaluit, Cambridge Bay, Holman, Arctic Bay, Taloyoak, Pangnirtung, Sachs Harbour, Cape Dorset, Resolute, Igloolik
Southern Arctic	Plains, hills	Moraine, rock, marine/ Cryosols	Cold, dry; continuous permafrost	Shrub–herb tundra	Barren-ground Caribou, Wolf, Grizzly Bear, Arctic Fox, Arctic Ground Squirrel, lemming; Arctic Loon, ptarmigan, Snowy Owl	Hunting, trapping, tourism/ recreation, mineral development	Tuktoyaktuk, Rankin Inlet, Arviat, Paulatuk, Pevungnituk
Taiga Plains	Plains, some foothills	Organic, moraine, lacustrine/Cryosols, Brunisols	Cold, semiarid to moist; discontinuous permafrost	Open to closed mixed evergreen–deciduous forest	Moose, Woodland Caribou, Wood Bison, Wolf, Black Bear, Red Squirrel; Northern Shrike, Spruce Grouse	Hunting, trapping, tourism/ recreation, oil and gas development, marginal agriculture in south	Inuvik, Fort Simpson, Wrigley, Norman Wells, Aklavik, Hay River, Fort McPherson
Taiga Shield	Plains, some hills	Canadian Shield rock, moraine/Cryosols, Brunisols	Cold, moist to semiarid; discontinuous permafrost	Open evergreen–deciduous trees; some lichen–shrub tundra	Moose, Barren-ground Caribou, Wolf, Snowshoe Hare, Red Squirrel; Red-necked Phalarope, Northern Shrike	Tourism/recreation, some mining, some hunting and trapping	Yellowknife, Goose Bay, Uranium City, Churchill Falls, Happy Valley, Kuujjuarapik
Taiga Cordillera	Mountains	Colluvium, moraine, rock/ Cryosols, Gleysols, Brunisols	Cold, semiarid; discontinuous permafrost	Shrub–herb–moss–lichen tundra	Dall's Sheep, Grant's Caribou, Black Bear, Grizzly Bear; Peregrine Falcon, ptarmigan	Trapping, hunting, mining, tourism/ recreation, oil and gas	Old Crow
Hudson Plains	Plains	Organic, marine/Cryosols	Cold to mild, semiarid; discontinuous permafrost	Wetland; some herb moss–lichen tundra, evergreen forest	Woodland Caribou, Moose, Black Bear, marten, Arctic Fox; Canada Goose	Hunting, trapping, recreation	Churchill, Moosonee, Attawapiskat
Boreal Plains	Plains, some foothills	Moraine, lacustrine organic/ Luvisols, Brunisols	Cold, moist	Mixed evergreen–deciduous forest	Woodland Caribou, Mule Deer, Moose, Black Bear, beaver, Muskrat; Boreal Owl, Blue Jay	Forestry, agriculture, tourism/ recreation, oil and gas development	La Ronge, The Pas, Flin Flon, Peace River, Fort Smith, Fort Vermilion, Hinton
Boreal Shield	Plains, some hills	Canadian Shield rock, moraine, lacustrine/Podzols, Brunisols	Cold, moist	Evergreen forest, mixed evergreen–deciduous forest	White-tailed Deer, Moose, Black Bear, Canada Lynx, marten, Red Squirrel; Boreal Owl, Blue Jay	Forestry, mining, tourism/recreation, hunting, trapping	Thunder Bay, St. John's, Sudbury, Sault Ste. Marie, Chicoutimi, North Bay, Sept-Iles, Gander, Thompson
Boreal Cordillera	Mountains, some hills	Colluvium, moraine, rock/ Brunisols, Podzols, Cryosols	Moderately cold, moist	Largely evergreen forest; some tundra, open woodland	Moose, Dall's Sheep, Grizzly Bear, Black Bear; ptarmigan, Spruce Grouse	Hunting, trapping, forestry, tourism/ recreation, mining	Whitehorse, Dawson, Faro, Teslin, Haines Junction, Mayo Landing
Pacific Maritime	Mountains, minor coastal plains	Colluvium, moraine, rock/ Podzols, Brunisols	Mild, temperate, very wet to cold alpine	Coastal evergreen forest	Black Bear, Grizzly Bear, Mountain Lion; Black Oystercatcher, Tufted Puffin	Forestry, fish processing, urban-ization, agriculture	Vancouver, Victoria, Prince Rupert, Nanaimo, Port Alberni, Chilliwack
Montane Cordillera	Mountains and interior plains	Moraine, colluvium, rock/ Luvisols, Brunisols	Moderately cold, moist to arid	Evergreen forest, alpine tundra, interior grassland	Woodland Caribou, Mule Deer, Moose, North American Elk, Mountain Goat; Blue Grouse, Steller's Jay	Forestry, agriculture, tourism/ recreation	Prince George, Kelowna, Kamloops, Williams Lake, Vernon, Penticton, Nelson, Trail, Cranbrook, Quesnel
Prairies	Plains, some hills	Moraine, lacustrine/Chernozems	Cold, semiarid	Grass; scattered deciduous forest ("aspen parkland")	Mule Deer, White-tailed Deer, Pronghorn, Coyote, Prairie Dog; Sage Grouse, Burrowing Owl	Agriculture, urban-ization, recreation, oil and gas development	Calgary, Winnipeg, Edmonton, Regina, Saskatoon, Lethbridge, Red Deer, Prince Albert, Brandon
Atlantic Maritime	Hills and coastal plains	Moraine, colluvium, marine/ Brunisols, Podzols, Luvisols	Cool, wet	Mixed deciduous–evergreen forest	White-tailed Deer, Moose, Black Bear, Coyote, Raccoon; Blue Jay, Eastern Bluebird	Forestry, agriculture, fish processing, tourism/recreation	Halifax, Saint John, Dartmouth, Charlottetown, Moncton, Sydney, Rimouski, Sherbrooke
Mixedwood Plains	Plains, some hills	Moraine, marine, rock/Luvisols, Brunisols	Cool to mild, moist	Mixed deciduous–evergreen forest	White-tailed Deer, Red Fox, Raccoon, Striped Skunk, beaver, Grey Squirrel; Great Blue Heron, Blue Jay	Agriculture, urban-ization, tourism/ recreation	Toronto, Montreal, Windsor, Hamilton, Quebec, Ottawa, London, Mississauga

Source: Wiken (1986); State of the Environment Directorate, Environment Canada; Marine Environment Quality Advisory Group, (1994); Ecological Stratification Working Group, (1996).

Source: Excerpted from *A Perspective on Canada's Ecosystems* (Wiken, 1996, p. 4)

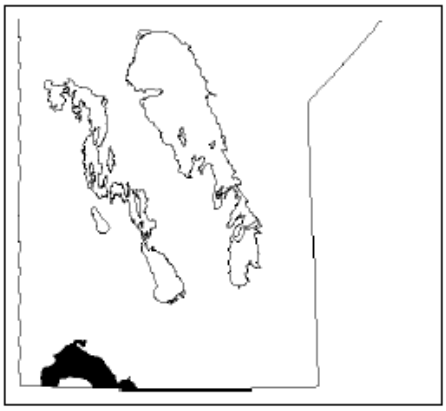
Appendix B – Sample ecodistrict description

Prairies Ecozone

Aspen Parkland Ecoregion

765. Killarney Ecodistrict (5163 km²)

The Killarney Ecodistrict forms an arch around Turtle Mountain, starting and terminating at the International Boundary.



Climate

This ecodistrict is in the driest subdivision of the Grassland Transition Ecoclimatic Region in southwestern Manitoba. The climate is marked by short, warm summers and long, cold winters. The mean annual temperature is about 2.8°C, the average growing season is 183 days, and the number of growing degree-days ranges from about 1400 to 1500.

The mean annual precipitation is approximately 500 mm of which about one-quarter falls as snow. Precipitation varies greatly from year to year and is highest from late spring through early summer. Average moisture deficit over the year is about 235 mm.

The ecodistrict has a cool, subhumid, Boreal soil climate.

There are no climate stations in the ecodistrict. Data from the Deloraine station, which is now closed, is presented. Data from Melita (763. Oak Lake Ecodistrict) and Baldur (764. Hilton Ecodistrict) has limited relevance.

Selected Climate Data[1] for Deloraine

	Year	June-Aug	May-Sept	July	Jan
Temperature °C	2.7	18.1	15.5	19.4	-17.6
Precip. mm (equiv.)	490.2	225.2	329.9	67.5	20.9
Rain/Snow (mm/cm)	375.9/114.1	225.2/0.2	328.1/2.0	67.5/0.0	0.1/20.7
Growing degree-days >5°C	1755.0	1204.1	1622.2	442.3	0.0

[1] Canadian Climate Normals, 1951-1980. Atmospheric Environment Service, Environment Canada.

Physiography and Drainage

The Killarney Ecodistrict is a dissected, level to very gently rolling morainal plain lying north of Turtle Mountain in southwestern Manitoba. Elevations range from about 580 masl along the border with the Turtle Mountain Ecodistrict to about 460 masl along its northeastern edge. Its mean elevation is about 470 masl.

The ecodistrict is characterized by low relief of less than 30 m and slopes that are relatively long, generally more than 150 m, usually with gradients between 5 and 10 percent. Whitewater Lake is contained within a large imperfectly to poorly drained, level, glacial lake basin that is variably saline. Intermittent creeks issue from deeply incised channels and gullies along the southern edge of the ecodistrict at the foot of Turtle Mountain, carrying runoff into Whitewater Lake and the Pembina River.

The extreme western corner of the ecodistrict is part of the Melita drainage division, and the western and central sections are part of the Hartney drainage division, both of which are part of the Souris River watershed. The eastern section is part of the Killarney division of the Red River watershed. Both the Souris River and Red River watersheds are part of the Nelson River system, which drains into Hudson Bay.

Soils

Well drained Black Chernozemic soils developed on very strongly calcareous, loam to clay loam glacial till derived from local bedrock shale, and limestone and granitic rock are predominant in the ecodistrict.

A significant area of imperfectly drained, variably saline, carbonated Gleyed Rego Black and poorly structured Black Solonetzic soils occurs in the Whitewater Lake basin. This is as a result of discharging hydrological conditions. The occurrence of salinity in the basin is variable because of the presence of thin, discontinuous, fine-textured lenses in the subsoils that act as barriers to the upward movement of salt-laden groundwater.

Local areas of imperfectly drained, variably saline carbonated Gleyed Rego Black soils also ring poorly drained Gleysolic soils in depressions. Cultivated soils on well drained sites have not been as seriously affected by wind and water erosion as similar soils on the rougher, hummocky terrain in adjacent ecodistricts.

Vegetation

As is usual for the Prairies Ecoregion, the natural vegetation in the Killarney Ecodistrict has all but disappeared through the spread of arable agriculture. The native vegetation consisted largely of a mixture of tall-grass and short-grass prairie. Aspen groves were only present in the eastern and northeastern part. Tree cover was, and still is, present on sheltered sites such as slopes of deep ravines where more favourable conditions exist due to the additional moisture provided by snow trapped during the winter.

Water

Variable annual rainfall is the principal source of water where some of it is retained in numerous dugouts. Surface water is also stored behind numerous small headwater retention dams along the channels and gullies which dissect this plain. Significant supplies of variable quality groundwater for domestic and livestock use are found in sandy and gravelly aquifers associated with glacial till and inter-till deposits. The dominantly shale bedrock underlying the till yields very little water.

Land Use

The major communities in this ecodistrict are Deloraine, Boissevain and Killarney.

Most of the land is cultivated for the production of spring wheat, other cereal grains, oil seeds and hay crops. Much of the saline and Solonetzic soils in the Whitewater Lake basin are used for pasture and hay production. Current continuous cropping practices, reduced summerfallow and retention of crop residues as surface cover has greatly reduced the risk of wind and water erosion.

Whitewater Lake and surrounding wetland is an important breeding habitat, staging and rest area for migratory waterfowl.

Source: Excerpted from *Terrestrial Ecozones, Ecoregions, and Ecodistricts of Manitoba: An Ecological Stratification of Manitoba's Natural Landscapes* (Smith et al.,1998).

Appendix C – Comments on proxy ecosystem type classes

Table 3. Comments on proxy ecosystem type classes identified in SEEA EEA Technical recommendations (Table 3.1, p.40) based on SEEA CF (Table 5.11/5.12 p. 176 & 178 and p. 289-301)

Land cover class (SEEA-CF)	Possible ecosystem types in Table 3.1 Technical Recommendations	Link to land use classification (SEEA CF)	Link to land use (detailed)	Link to ownership	Link to ecosystem service or condition? (I.e. why do we need this level of classification)	Comment / Progress / Data availability in Canada
Artificial areas (including urban and associated areas	-Residential / housing -Urban parks -Industrial uses (e.g., factories) -Road infrastructure -Waste deposit sites	-Use of built-up and related areas -Agriculture	-mining and quarrying, transport (roads, rail, airports, maritime) recreational facilities (includes beaches, cultural sites, cemeteries, game fields, green areas, urban parks, camping sites, marinas etc.), residential (includes gardens, small green areas and small playgrounds) -Agriculture under protected cover	Public, private Or more detail?	Recreation, water regulation, local climate moderation etc.	Proposed detailed ET types in Table 3.1 more relevant for land use than land cover. Canada - have produced data for built-up area, and for the areas around metropolitan areas data on settled area and roads. Currently do not have detailed data at national scale allowing breakdown into the ET types suggested.
Herbaceous crops	-Irrigated rice	-Agriculture	Land under temporary crops,	Public, private	Goods provision	SEEA CF includes hay crops under herbaceous crops (rather than as

	-Other irrigated crops -Rainfed annual cropland		Land with temporary fallow Land with temporary meadows and pasture	Or more detail?		grasslands). Data from the Census of Agriculture is aggregated and not spatially explicit. Irrigated area dependent on climate conditions – may be irrigated one year and not the next. Land cover/land use data set? – Issues with overlap crops/grassland/pasture (e.g., irrigated hay/alfalfa production, improved pasture)
Woody crops	-Fruit tree plantation -Coffee and tea plantation -Oil palm plantation -Rubber plantation	-Agriculture	-Land with permanent crops	Public, private Or more detail?	?	Data from the Census of Agriculture is aggregated and not spatially explicit. Maple data reported in # of taps not area. Land cover/land use data set – issues with overlap
Multiple or layered crops	Two layers of different crops (e.g., wheat and olive trees); One layer of natural vegetation (mainly trees) that covers one layer of cultivated crops (e.g., shade grown coffee)	-Agriculture	-Land with permanent crops	Public, private Or more detail?	Soil protection	N/A in Canada – minimal (e.g., some mushrooms production). Is there a benefit to splitting these out or should a basic level simply distinguish croplands.
Grassland	Natural grasslands Improved pastures Steppe	-Agriculture -Land not in use -Other uses of land -Land used for maintenance and	-Land under permanent meadows and pastures -by IUCN class?	Public, private Or more detail?	Carbon sequestration, erosion protection, habitat, etc.	Note terms Steppe (Prairie/Pampa) bringing in a climate aspect not present in main proxy land cover grouping.

	Savannah	restoration of environmental functions				Does savanna belong here or under tree-covered areas (i.e., it is a grassy open woodland?) Classification includes “natural herbaceous plants” in grasslands and grasses grown for hay as herbaceous crops. Improved pasture meanwhile includes sown pastures—maybe not “natural” ? Census of Agriculture, land cover/land use data although may be difficult to clearly distinguish between these and between grass crops.
Tree-covered areas (forests)	Deciduous forests Coniferous forests Plantation forest (Planted)	Forestry Land used for maintenance and restoration of environmental functions Land not in use Other uses of land		Public, private Or more detail?	Recreation, timber and non-forest timber product production, habitat, water etc.	Canadian Forest Service / Provincial data / NFI / AAFC land cover / land use/ other forestry? More detailed forest data (e.g., biogeoclimatic zones of BC, by species type available at different scales. Includes regularly/seasonally flooded.
Mangroves	Inland mangroves Nearshore mangroves			Public, private Or more detail?	Erosion protection, habitat (fish rearing)	Why is this a separate land cover category and not a vegetation class for coastal waterbodies and intertidal?
Shrub-covered areas	Natural dryland shrubland Degraded dryland shrubland	Land not in use Other uses of land Agriculture Forestry Land used for maintenance and		Public, private Or more detail?	?	AAFC 30m for south of Canada, 250 m MODIS for north.

		restoration of environmental functions				
Shrubs, and/or herbaceous vegetation, aquatic or regularly flooded	Wetland shrubland	Land not in use Other uses of land Agriculture Forestry Land used for maintenance and restoration of environmental function		Public, private Or more detail?	Wetland services – e.g., water filtration, regulation, erosion protection, habitat, fisheries.	Tidal marshes here or in intertidal? Wetland often exists under other land covers, and measured at different times of year resulting in different areas. (Perhaps wetland should not be captured under land cover but as a separate category.) Cranberry production? AAFC 30m for south of Canada
Sparsely natural vegetated areas	Periglacial vegetation	Land not in use Other uses of land Land used for maintenance and restoration of environmental functions		Public, private Or more detail?	?	-Is this “Tundra” (i.e., low growing lichens, mosses, shrubs, treeless permafrost? Or are they in the shrub area?) -Wetland here identified? -MODIS 250 m for Northern Canada
Terrestrial barren land	Sandy dunes	Land not in use Other uses of land Land used for maintenance and restoration of environmental functions		Public, private Or more detail?	?	-Colloquially tundra frequently called barrenland. When we report on “barren land” I think we are usually talking about up north so “sandy dune” doesn’t seem to be the best descriptor. Include deserts, dry salt flat, beach, sand dune, exposed rock, strip mines, quarries, gravel pits. - MODIS 250 m
Permanent snow and glaciers		Land not in use Other uses of land Land used for maintenance and restoration of		Public, private Or more detail?	Water regulation	MODIS 250 m –

		environmental functions				
Inland water bodies	Lakes Rivers	Used for aquaculture or holding facilities Used for maintenance and restoration of environmental functions Other uses Not in use		Public, private Or more detail?		-Includes open wetlands? Associated terrestrial areas (i.e. riparian areas and riparian wetlands) not identified here and maybe should be somehow given significant benefits. For North of Canada MODIS 250 m. For South 30m.
Coastal water bodies and intertidal areas	Coral reefs Seagrass meadows	Used for aquaculture or holding facilities Used for maintenance and restoration of environmental functions Other uses Not in use		Public, private Or more detail?	-habitat, fish	-tidal marshes/mangroves not included here, though these are in intertidal and estuaries. Eelgrass change data: lack of systematic and region-wide or provincial eelgrass monitoring in Canada. -Atlantic Canada – some data from specific sites. BC: Community mapping: BC Eelgrass inventory (http://cmnmaps.ca/EELGRASS)
Sea and marine areas		Used for aquaculture or holding facilities Used for maintenance and restoration of environmental functions Other uses Not in use		Public, private Or more detail?		**?**

Appendix D – Breakout of Table 2. Multi-dimensional hierarchy

Goal: database structure suitable to develop exhaustive non-overlapping hierarchical classification system that incorporates multiple ecological and non-ecological characteristics, that can be linked to ecosystem services and that is flexible/adaptable for international use. (Requires development)

Non-ecological:

Use categories: Agriculture (Cropping/Range-forage), Forestry, Built-up (Residential [low-density to high-density], Recreational, Mining and quarrying, Transport, Other, Maintenance/restoration of environmental function, Use for aquaculture, Other uses, Not in use.

Proximity to urban/degree of human influence: Population size classes or distance ranges (urban, periurban, rural, remote) etc.

Management type: (e.g., Protected etc.)

Ecological:

Climate: Tropical, sub-tropical, temperate, sub-arctic, arctic; Wet, moist, dry etc. Cold, warm, hot etc.

Terrain: Alpine, low-land, plain, mountain etc.

Soils: Soil types: organic, others (mineral types) etc.

Flora/Fauna: e.g., by type, species.

Land cover:

Aquatic:

Sea and marine waters

Inland water bodies

Context-dependent sub-class: Rivers, lakes, shallow water (i.e., open water wetland)

Coastal and intertidal

Context-dependent sub-class: Estuaries, Other

Context-dependent sub-class: Tidal wetlands (mangrove, freshwater, salt),

Terrestrial:

Context-dependent sub-class: Saturated/flooded/seasonally-flooded (or other wetland identifier) v.s. non-saturated flooded

Snow and glaciers

Sparsely vegetated and barren lands (e.g., dunes, sand shore, rock, sand desert, alpine, tundra)

Treed/Forest/Woodland

Context-dependent sub-class: Coniferous, Deciduous, Mixed

Context-dependent sub-class: Natural-semi-natural / Plantation / Rows

Shrubland

Context-dependent sub-class: Riparian, others

Grassland

Context-dependent sub-class: Riparian, others

Cropland

Context-dependent sub-class: Herbaceous, Shrub/wood, Mixed.

Context-dependent sub-class: Dryland, irrigated

Built-up /artificial

Context-dependent sub-classes (pervious/impervious)

Mosaics – define types ?