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Research Article

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# A Hierarchical Ecosystem Approach to Evaluate Global Warming Impacts in Three Global Ecoregions

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## Abstract
Global warming has substantial effects on terrestrial ecosystems in the different ecoregions. A hierarchical ecosystem approach was conducted to analyze global warming influences with global warming impacts on the three distinct global ecoregions. The ecosystem classification of land (ECL) has been developed and integrated into a hierarchical system. Recently, the hierarchical ecosystem classifications in the 300 Dry Domain of the United States, 100 Polar Domain of Canada, and 500 Plateau Domain of China were demonstrated and explored in studying the environmental system changes and global warming impacts. This article presents the distinctive dissimilarity in each ecoregion and demonstrates the ecosystem responses linked to the hierarchical ecosystem structure and ecological function level.

1) In the Dry Domain, the warmer and wetter climate of Utah gave rise to Rocky Mountain subalpine conifer forests and Great Basin pinyon and juniper woodlands suitable for growth, which corresponds to Utah's Climate life zone and is affiliated with the middle levels of ECL, scale ranging from U7 up to U4. Conversely, in a warmer and drier climate in Utah, annual plant species and invaded species shifted and expanded at the lower levels of ECL, scale ranging from U10 up to U9.

2) In the Polar Domain, a warmer and wetter winter of the Yukon climate influences the *Spruce* treeline moving northward and to higher elevations, as well as for the Arctic tundra and alpine tundra. Arboreal species grow fast to reach fructification. These typically appeared in the middle levels of ECL with ranging from Y8 up to Y5, and changed the carbon budget to a carbon sink, with a scale ranging from Y4 up to Y2. With a warmer and drier summer, shrubification in Yukon occurs rapidly, in a range from Y6 to Y5. *Potentilla shrub and Salix* shrub expand to the Arctic tundra region.

3) In the Plateau Domain, the annual air temperature Increased by 0.5°C/10 y over the last 45 years, and the temperature fluctuations have significantly affected the essential changes in the global energy balance and carbon budget in the upper levels of ECL, scale ranging from Q4 up to Q1. However, the precipitation showed no noticeable difference. The alpine tundra vegetation was simulated by the Vegetation Dynamic Simulation Model (VDSM) integrated with scenarios of a global temperature increase of 1 to 3°C. This illustrated the vegetation biomass changes in the lower levels to middle levels of ECL with ranging from Q8 up to Q6, and the vegetation distribution dynamics appeared in upper levels of ECL with ranging from Q4 up to Q1.

## Introduction
Desert shrub/grassland, Arctic tundra, and alpine tundra are the most vulnerable ecosystems in the 300 Dry Domain [1, 2], 100 Polar Domain [3, 4], and 500 Plateau Domain [5, 6], respectively. The dissimilarities in the different global ecoregions had presented independent ecosystem properties and identities. For example, because the habitats in the Dry Domain do not substitute for the habitats in the Polar Domain, a polar bear who adapted to the North Pole can not survive in a desert environment. Similarly, we can not bring a panda from a warm temperate forest mountain to the higher plateau ecoregion. The unique habitat becomes an authentic environment for living life. Therefore, it is necessary to scope our Earth from the broad ecoregion to the lower level of the ecological site and discover the ecological organisms and relationships between the different ecosystems. An initial definition is given in this paper: Ecosystem Classification of Land is a systematic hierarchical method to classify the level of ecosystem organization and regionalization on the Earth's surface.

In 2002, the global ecoregions were identified, and less emphasized the most various and distinct features. Moreover, the Global 200 made almost every nation in a global conservation strategy from the global scale to the national level with a worldwide perspective [7, 8]. Furthermore, the ecosystem responses to climate change have been assessed through varying dimensions, such as the temporal speed of climate change [9], the vulnerability under climate changes [10], or the novelty of future climatic conditions [11]. These studies identified those locations where climate change had the most significant and raised awareness of potential impacts. However, the potential and possible interactions between climatic changes and other major ecological processes have not been adequately focused on [12]. The World Wildlife Fund has described terrestrial ecoregions to classify global biodiversity [8]. IUCN Global ecosystem Typology 2.0 [13] described the biomes and ecosystem functional group and composition, which were integrated into the hierarchical structure of the classification in the top three levels and the lower three levels of the classifications. These included the critical ecoregions, vulnerable ecoregions, and intact ecoregions. In addition, the impacts of future climate change in alpine tundra and Arctic tundra ecoregions have been studied and simulated [14, 15, 16, 17]. Using a dynamic global vegetation model with current and future climate scenarios, ecologists have investigated the impacts on the ecological indicators, including net primary productivity (NPP), carbon storage, runoff, wildfire risk, and habitat transformation at the ecoregional scale. The analysis was accomplished for the terrestrial ecoregions as a whole or specific subset. The dynamics of the climate change metrics and the ecological indicators have significant implications for biodiversity conservation in changing climates [16, 17, 18].

Over a longer timescale, the ecological disruption produced by climate change is generally slower than that caused by other factors, such as habitat rapid destruction in land use, pollution by industrial nitrogen deposition, and the invasion of ecosystems by non-native plant and animal species. However, global temperatures are predicted to rise by up to 4 °C by 2100, are associated with alterations in precipitation patterns and extreme weather, and are unprecedented challenges to ecology and ecosystem study [19]. Initially, global warming was detected and began in northern Siberia and northeastern North America in the 1960s. Since then, the permafrost temperature has risen and caused the intensification of the thermokarst processes and disturbances of soil cover. As a result, the tundra transitioned from a carbon reservoir to a carbon source [20, 21]. A poleward expansion of the subtropical dry zone was diagnosed in the climate simulations of the IPCC AR4 project. The expansion of the Hadley cell is caused by an increase in the subtropical static stability, resulting in poleward the baroclinic instability zone and the outer boundary of the tropical atmospheric circulation [22].

Constant climate change produced natural disturbances and existed in a mixture of different succession stages, such as habitat disintegration and disruption of the ecosystem-type boundaries. In the meantime, suitable habitat loss, the ecological boundaries moving to the northwest, and higher elevation correspond to the different ecoregions and the climate domain features. This journal paper highlights the dissimilarities of global warming impacts in the three ecoregions of 300 Dry Domain, 100 Polar Domain, and 500 Plateau Domain. We try to discuss the characteristics of regional biological dissimilarity, the sensitivity in response to global warming, and the direction of ecosystem dynamics.

## Ecosystem Classification Method and Climate Features

Based on the studies of the Ecosystem Classification of Land (ECL), we used the following three steps to accomplish the ecosystem classifications for Western Utah in the U.S.[2, 23], Yukon Territory of Canada [6], and North-Eastern Qinghai Province of China [2].

1. Using Bailey's top-level Domain in a global framework with regional validation. For example, 500 Plateau Domain was identified and added to the top level of the Qinghai-Tibetan Plateau of China
2. Domain→Division→Province→Section Subsection or specified regional ecological or bioclimatic regimes, e.g., Canada's Bioclimatic framework: Ecozone→Ecoprovince →Ecoregion →Ecodistrict
3. Generate and develop the lower level of ECLs, including Ecological sites or Vegetation stands based on the ECL model developed in 2021 [2, 5]
4. Label all levels from top to bottom, e.g. Utah-U, Yukon-Y, Qinghai-Q, with level of 1,2,3,...10
5.

The examples of the nested ecosystem classifications are listed in Table 1, Table 2, and Table 3 for three ecoregions.

**Table 1: Western Utah's ECL in 300 Dry Domain, U.S.**

| Level | Utah's Nested ECL | Classification Name | Scale |
|---|---|---|---|
| U1 | Domain | 300 Dry Domain | Bailey's Domain |
| U2 | Division | 340 Dry Temperate | Bailey's Division |
| U3 | Provision | 342 Intermountain Semi-Desert | Bailey's Provision |
| U4 | Section | Central Great Basin | ECOMAPs Section |
| U5 | Subsection | Erosional Landscape | ECOMAP's Subsection |
| U6 | Landtype Association | Hard Sedimentary Erosional Landscape | ECOMAP's Landtype Association |
| U7 | Landtype | Eolian Sediments | EOCMAP's Landtype |
| U8 | Landtype Phases | Moderately Hard Sedimentary | ECOMAP's Landtype Phase |
| U9 | Ecological Site | Desert Loam | Ecological Site |
| U10 | Vegetation Stand | Foot slope Desert Loam | Stand |

**Table 2: Tukon Territory's ECL in 100 Polar Domain, Canada**

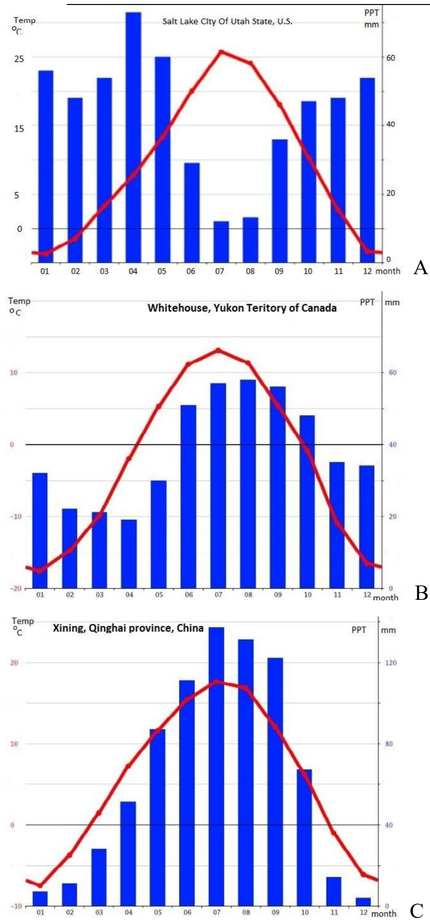
| Level | Yukon's Nested ECL | Classification Name | Equivalent Scale |
|---|---|---|---|
| Y1 | 100 Domain | Domain | Bailey's Top Level |
| Y2 | 12 Ecozone | Boreal Cordillera | Canada's Top level |
| Y3 | 12.2 Ecoprovince | Northern Bareal Cordilera | Bioclimatic Zone |
| Y4 | 12.2.176 Ecoregion | Yukon Plateau-North | Bioclimatic Subzone |
| Y5 | 12.2.176.0898 Ecodistric | Elsa | Ecodistric |
| Y6 | Broad Ecosystem | H. Wetland | Bioclimatic/slope position |
| Y7 | Broad Ecosystem Phase | Shrub and Carex Grasses | Bioclimatic/Plants |
| Y8 | Ecological site/Ecosite | Lodgepole Pine SpruceGrass-Lichen | Bioclimatic/Objective |

## The Main Features of Climate Change in Western Utah of 300 Dry Domain

The essential feature in 300 Dry Domain is that annual water losses through evaporation in an area exceed annual water gains from precipitation (Picture 1 A) [1].

**Table 3: North-Eastern Qinghai province in 500 Plateau Domain, China**

| Level | Qinghai's nested ECL | Classification Name | Equivalent to |
|---|---|---|---|
| Q1 | Domain | 500 Plateau Domain | Bailey's Top Level Domain |
| Q2 | Division | HII Plateau Temperate Division | Beiley's Division |
| Q3 | Province | HIIC Plateau Temperate Semi-Arid Province | Bailey's Province |
| Q4 | Section | HIIC1: Plateau & Mountains Semi-Arid Section (E. of Qinghai, Qilian Mountains) | ECOMAP's Section |
| Q5 | Subsection | QiLian Mountain East Alpine Shrub and Alpine Tundra Subsection | ECOMAP's Subsection |
| Q6 | Zone | QiLian Mountain East Alpine Shrub and Alpine Tundra Zone | Zone |
| Q7 | Subzone | Da-Tong River-Black River Alpine Shrub, Alpine Tundra Subzone | Subzone |
| Q8 | Ecological Site | Haibai Alpine Tundra Ecological Sites | Objectively Defined ES |




The least amount of rainfall occurs in the warmest month, July of the year with the average being 12 mm. In April,
the precipitation reached its peach, with an average of 73 mm.

The driest month is April, with 19 mm of rainfall. Highest precipitation falls in August, with an average of 58 mm.

The driest month is December, with 4 mm of rainfall. Highest precipitation falls in July, with an average of 137 mm.

**Picture 1:** Ecological climate features A. 300 Dry Domain, B. 100 Polar Domain, C. 500 Plateau Domains Data sources: https://en.climate-data.org/

According to Reichler's study [24], in Northern Utah, precipitation will increase by ~10% in winter and decrease by ~10% in summer. Temperatures will rise uniformly by ~3°F in winter and ~4°F in summer. Moreover, Utah's Salt Lake City experienced the warmest July 2021 on record (107 °F=41.7 °C), and the Utah state is in an extended drought. As a result, climate change may be amplified, including heat and flooding from extreme climate events. In the next 20-40 years, Utah's climate is projected to be hotter and drier in summer in the central and southern region, and warmer in summer and wetter in winter in the northern region.

(https://www.inscc.utah.edu/~reichler/talks/papers/Reichler_Logan_0904.pdf )

## The Main Features of Climate Change in Yukon Territory of 100 Polar Domain

Canada –100 Polar Domain: Characterized by low temperature, severe winters, and a small amount of precipitation mainly falls in summer (Picture 1 B). Since the Arctic sea ice in Yukon Territory is melting, the minimum annual sea ice area and overall volume have been reducing. Sea ice melt portion has performed to be accelerating in the past decade. The sea ice volume is lost by approximately 300 km$^3$ per year. The remaining sea ice is thinner and younger [25, 26, 27, 28 a/b, 29]. Over the past 50 years, Yukon's annual mean average temperature has increased by 2°C. The winters are warming more than other seasons, with an average increase of 4°C. Yukon's precipitation has risen by ~ 6%. The primary precipitation increase is during the summer season.

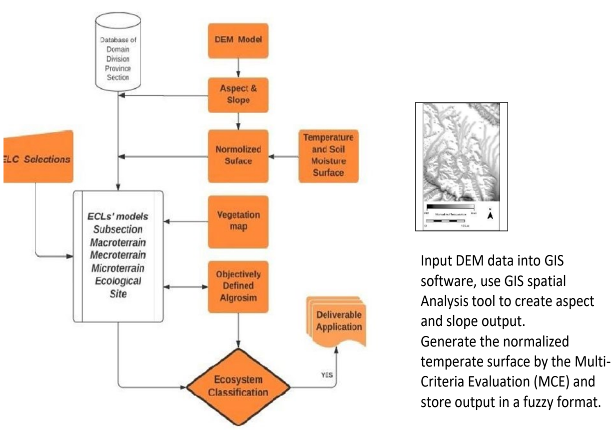
Arctic sea ice in the Yukon Territory of Canada is melting, reducing the minimum annual sea ice area and overall volume. As a result, the remaining sea ice has become younger and thinner. Moreover, winters have been warming more over the past 50 years than in other seasons. Accordingly, Yukon's annual average temperature has increased by 2°C, higher than the global rate. Furthermore, wetlands become more essential ecosystems that maintain water flows and provide fish and wildlife habitat. And the treeline is moving northward and to high elevations. National Snow and Data Center

(https://nsidc.org/arcticseaicenews/) provides sea ice extent change from 1979 to 2022, UK Polar Data Center provides Arctic sea ice volume from 1979 to 2020 (https://www.bas.ac.uk/data/uk-pdc/), and Environment and Climate change Canada provides Yukon projected annual temperature and annual precipitation anomalies (A2, A1B, B1) [25, 27, 29]

### The Main Features of Climate Change in 500 Plateau Domain

China -- 500 Plateau Domain: It is a unique empty entity, and Zhang (2021) identified it and added it to Bailey's ECL framework, which is comparable with Domain Arctic and Domain Tropic region [2]. The climate is colder and drier in winter and hotter and wetter in the summer in 500 Plateau Domain (Picture 1 C). In this region, the air temperature has increased slowly by 0.5 °C/10y over the last 45 years. The significant increase in air temperature took place during 1980–2005. The precipitation showed no noticeable change [14]. Li and Yang et al. (2010) analyzed the extreme climate events from 66 meteorological stations data and showed that warm and wet events increase, but cold and dry events decrease over the plateau region [30], with Climate trends of Precipitation, Evaporation, Runoff and Surface soil water content.

By integrating cellular automata and a Geographic Information System [15, 31], we found that the temperature changes across the study area depend on not only elevation changes but also aspects and soil water conditions. Therefore, the normalized temperature surface created by the Multi-Criteria Evaluation (MCE) was highly representative of the potential temperature distribution in a normalized fuzzy format and used in simulating the process (Picture 2) [2, 5, 6]. By integrating the normalized temperature into ECL's Model (Picture 2), the simulation of global warming's impacts on different ecosystems were carried out and evaluated.

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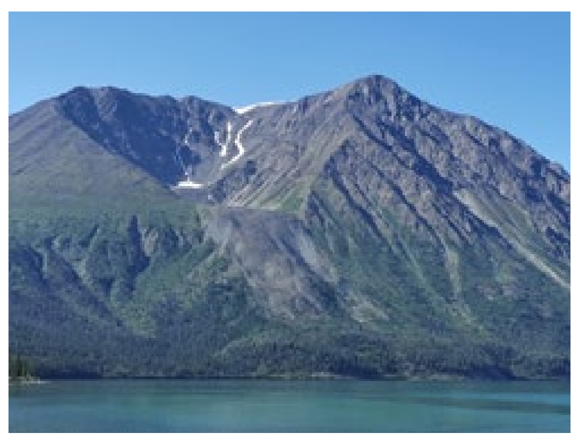
**Picture 2:** Objectively defined ECL and Global Warming Modeling

### Results and Discussions

Suppose the ecosystem approach leads to a universal conclusion and a closer precise 95% conclusion about evaluating Global Warming Impacts in three Global Ecoregions. This kind of expectation could be disappointed. The following paragraphs will try to demonstrate how the different ecoregions may have the different global warming responses, and understand the dissimilarity of global warming impacts. The current ecosystem's start points are different based on the Domain regime, and the ecosystem's succession direction and status are also different. In other words, the relevant phenomena relate to different climate changes and the levels of ECL.

The table 4 presented 300 Domain ecosystem responses to climate changes in the different ecosystems. A warmer and wetter climate did not appear in the Southern Utah state and could only happen in the Northern Utah mountain regions, which caused Rocky Mountain subalpine conifer forests and Great Basin pinyon and juniper woodlands to be suitable for growing. They are matched to the Utah region climate life zone in the middle levels of ECL (U7 up to U2). A warmer and drier climate is a typical climate regime in the middle western Utah state area. Great Basin alpine tundra decline substantially or disappear in the high mountain area at a level of the ecological site (U9). Semi-desert grassland and Sagebrush (*Artemisia tridentata*) are the typical dry domain vegetation types and expand northward and occupy an area nearly four times that of the present or widely expended. Great Basin shrub/grassland are distributed in the climate by extremes: hot, dry summers and cold, snowy winters; daily temperature over 90 °F (32 °C) followed by nights near 40 °F (4 °C). The desertification will be enhanced, and grassland will decrease by 40% and become a fragmented ecosystem. These changes will link the middle level of ECLs and above (U6 up to U3). Invasive species and annual species shift northward with increased risk in Idaho, Montana, and Wyoming. They are responded to lower levels of ECL (U10 to U9). The Great Salt Lake has increased evaporation without offsetting increases in rainfall, causing the lake to shrink and its salinity level to increase, impacting migratory bird populations in response to U6 up to U3.



**Picture 3:** Withdrawal of the cirque glacier above *Spruce* Forest at Kluane National Park and Reserve of Yukon Territory, CA (Taken on August 1, 2021, Elevation 760 m)

**Table 4: 300 Domain's ecosystem responses to climate changes at the different ecosystem levels [32, 33, 34, 35, 36, 37]**

| Habitat or Vegetation Type or Species | Climate Impacts | | Level of ECL |
|---|---|---|---|
| | Warmer in Summer and Wetter in Winter | Both Warmer and Drier in Summer | |
| Rocky Mountain subalpine conifer forests | Suitable growing | | Climate life zone, Middle level of ECL, e.g. U7 up to U4 |
| Great Basin alpine tundra | | Decline substantially or disappear | Ecological Site e.g. U9 |
| Great Basin pinyon and juniper woodlands | Suitable growing | Move northward and upper slope | Climate life zone, Middle level of ECL e.g. U7 up to U4 |
| Semi-desert grassland | | Expand northward and occupy an area nearly four times that of the present | Climate life zone, Middle level of ECL e.g. U6 up to U3 |
| Great Basin shrub/grassland | | Decrease by 40% and become fragmented | Climate life zone, Middle level of ECL e.g. U6 up to U3 |
| Sagebrush (Artemisia tridentata), | | Shift northwards, expend range widely | Climate life zone, Middle level of ECL e.g. U6 up to U3 |
| Invasive species, such as buffelgrass (Pennisetum ciliare), Lehmann lovegrass (Eragrostis lehmanniana), spotted knapweed (Centaurea biebersteinii), and leafy spurge (Euphorbia esula), | | Expand under future climate regimes | Ecological site, Stand e.g. U9, U10 |
| The invasive annual grass cheatgrass (Bromus tectorum) | | Shift northward with increased risk in Idaho, Montana, and Wyoming | Lower and middle level of ECL e.g. U9 up to U2 |
| Great Salt Lake | | Increase the evaporation without offsetting increases in rainfall, causes the lake shrinking, and salinity level increase, impacts on migratory bird populations | Upper level of ECL e.g. U6 up to U3 |

Table 5 presented 100 Domain ecosystem responses to climate changes at different levels. A warmer and wetter in winter influences the *Spruce* treeline moving northward and to higher elevations (Picture 3), same influence for Arctic tundra and alpine tundra. Arboreal species grow fast to reach fructification. These typical middle levels of ECL (Y8 up to Y5) will occur in the Polar Domain and will change the carbon budget. With a warmer and drier summer in the Polar Domain, Shrubification is happening rapidly. Potentila and Salix shrubs expand to the Arctic tundra region from Y6 to Y5. Spruce bark beetle outbreaks, insect outbreaks, forest fires, and no-native species invasions are increased by a higher frequency [25, 26, 27, 28].

**Table 5: 100 Domain's ecosystem responses to climate changes at different levels [40, 41]**

| Habitat or Vegetation type or Species | Climate Impacts | | Level of ECL |
|---|---|---|---|
| | Both Warmer and Wetter in Winter | Both Warmer and Drier in Summer | |
| Spruce Treeline | Moving northward and to higher elevations | | Ecological site to middle level of ECL e.g. Y8 up to Y5 |
| Shrub | | Shrubification is happening rapidly | Middle level of ECL e.g. Y6 up to Y5 |
| Tundra | Moving northward and to higher elevations | | Lower and Middle level of ECL<br>e.g. Y8 up to Y6 |
| Spruce bark beetle outbreak | | Intensified by warmer conditions and drought stress, killed half of the mature spruce forest in southwest Yukon. | Ecological site to middle level of ECL e.g. Y8 up to Y5 |
| Insect outbreaks | Variability in precipitation, warming temperatures | | Ecological site to Middle level of ECL e.g. Y8 up to Y5 |
| Forest fire | | Severity | Ecological site to Middle level of ECL e.g. Y8 up to Y5 |
| Non-native species | | Facilitate invasion | Ecological site Middle level of ECL e.g. Y8 up to Y7 |
| Arboreal species | 15–30 years fast to reach fruitification | | Middle level of ECL e.g. Y8 up to Y5 |
| Wetland | Expand and maintain water flows and flood, protection of habitats. Functioning as a net caron sink. Support the food chain. | | Upper levels of ECL e.g. Y6 up to Y4 |
| Carbon Budget | Carbon sink | Carbon source | Ecoregion e.g. Y4 up to Y2 |

The Yukon forest carries the title of a Taiga characteristic. Permafrost is widespread in the region, and the *Picea* forest is a component of the climatic climax.. *Picea* and *Populus* are suitable for growing in warmer climates. The latitude-driven botanical and phytosociological differences within flat regions occur in more than one ecoclimatic zone [38]. A latitudinal gradient was significant evidence among the geographic method to present locations. Forests with closed and semi-closed canopies occurred primarily south of 64˚ N latitude at low elevations [39]. Wetlands are expanded and maintain water flows and floods and protection of habitats. They function as a net carbon sink. Support the food chain. They are the response to upper levels of ECL, which maintain continental ecosystem stability.

Table 6 presents 500 Plateau Domain's ecosystem responses to climate changes at different levels. The Qinghai-Tibetann Plateau is situated in southwestern China and is the highest landmass in the world. At the level of Division, there are two different types, such as 510 Plateau sub-polar Division and 520 Plateau Temperate Division [2]. At the Province level, eight Provinces represent varieties of the next level of classification. Table 6 provides an example of the North-Eastern Qinghai region within 500 Plateau Domain, China. Under a warmer and wetter climate, *Potentilla* shrubs expand to a higher elevation or flat river valley, increasing the bird population. In addition, *Spruce* Forest grow and expand. These responses are linked from the ECL's lower to the middle level (Q8 up to Q6).

*Kobresia* tundra illustrated the vegetation biomass changes in the lower levels to middle levels of ECL (Q8 up to Q6), and the vegetation distribution dynamics appeared in the upper levels of ECL (Q4 up to Q1) [31]. Aspen is a common forest species that grows on drier and exposed slopes, and expands in the lower level of ECL (Q8 to Q7). QingHai Lake water volume increases with warmer and wetter climates, and the fish population grows with a warmer climate. Rodents are migrating to high elevations and the degraded grassland at the ecological site level [50]. The carbon budget is affected and changed at the upper level of ECL, which is still a question that needs to be answered.

**Table 6: 500 Plateau Domain's ecosystem responses to climate changes at the different ecosystem levels [42, 43, 44, 45, 50]**

| Habitat or Vegetation Type | Climate Impacts | | Level of ECL |
|---|---|---|---|
| | Warmer | Both Warmer and Wetter in Summer | |
| Kobresia Humlis Tundra | Alpine grasses are rapidly increasing in biomass, and forbs decrease. Effects on net ecosystem $CO_2$ fluxes, nutrient cycling, and forage availability in the alpine ecosystem | | Ecological site to middle level of ECL e.g. Q8 up to Q6 |
| Potentilla Fruticosa shrub | Species richness reduced in the plant community | Shrub expend to higher elevation and river side valley | Ecological site to middle level of ECL e.g. Q8 up to Q6 |
| Spruce Forest | | Growing and expending | Ecological site to middle level of ECL e.g. Q8 up to Q6 |
| Aspen | Growing and expending In exposed slope | | Ecological site e.g. Q8, Q7 |
| Birds | Changing migration | Increasing populations | Ecoregion e.g. Q8 up to Q2 |
| Qinghai Lake and Fishes | Increasing Fish populations | Increasing lake water volume | Middle level of ECL e.g. Q5 up to Q4 |
| Rodents | Migrating to high elevation or degraded grassland | Rodent community succession | Ecological Site e.g. Q8 |
| Carbon budget | Carbon source | Carbon sink | Ecoregion e.g. Q4 up to Q1 |

Chemists always mandated global warning as simple carbon sink and release in an ecosystem. Therefore, they tried to depict the carbon balance between the atmosphere and the biosphere. Here, Cleland et al. (2007) discussed some advances in the research that have enabled scaling between species responses to recent climatic changes and shifts in the ecosystem productivity, with implications for global carbon cycling[45, 46]. However, we acknowledge that was just half of the meaning of global warming's impacts on the ecosystems. Whether or not we can adopt global warming limited to less than 2°C by 2100 [47], different ecosystem dissimilarities demonstrated more deep adoptionism and survival path in a suitable environment before biological life reduced in population and extinct on Earth. Based on Köppen– Trewartha climate classification (KTC), Bailey generated the United State's Ecoregion framework and worldwide top levels' ecosystem classification [1, 10]. Our studies by implementing nested ecosystem classification in three continental ecoregions down to the lower level of ecological sites or stands provided a helpful tool and further understanding of the dissimilarities of how ecosystems respond to global warming and climate changes. Thus, customizing the global warming policy and management strategy is becoming critical in ecosystem study and implementation.

Compared to three continental ecoregions, there are common phenomena related to species shifting and boundary changes. However, we hardly compare them because they were different ecological processes and largely depended on their biological features in different Domains. Similarly, the coniferous forest had high resilience in 500 Plateau Domain, whereas the steppe and tundra had poor resilience [41, 45]. Nevertheless, similar coniferous forests in the Utah Dry Domain and Yukon Polar Domain had different magnitudes, and directions of such changes varied regionally [35, 36, 37, 38, 39]. For example, based on 2020 Yukon environment report [28 a, b], wetlands become more essential ecosystems that maintain water flows and provide fish and wildlife habitat in the Polar Domain.

Adapting to the ECL approach to protect the ecosystem structure, function, and biodiversity is a more critical management strategy under global warming influences. Furthermore, we should understand more details about different ecosystem responses regarding the hierarchy, plant shifting and animal moving, migrating birds, insect outbreaks, forest fires, heat waving, flooding, and changing ecosystem service output. Our research findings revealed that climate-induced resistance dynamics within a community's species are responsible for declining species [9, 19]. For example, temperature increase in the Tibetan Plateau favors the growth and development of herb grasses in the community, which may displace some forbs and sedges [42] because different species groups have different response patterns to global changes. In the meantime, the effects of shifting species' geographical range gradually changed vegetation succession, community structure [40], and species boundaries. Thuiler (2007) [19] recognized that "each 1°C of temperature change moves ecological zones on Earth by about 160 km". For example, if the climate warms by 4°C over the next century, species in the Northern Hemisphere may have to move northward by 4 X 160, equal to 500 km (or 500 m higher in elevation), to survive in a suitable climatic regime [24].

The spatial distribution and area of each vegetation or habitat will determine the level of ECL that can be fitted to study the global warming impacts. Also, our ECL model revealed the distinct ecosystem classification related to the levels of ecosystem structure, which had functions or constraints on ecosystem dynamics. For example, the Tundra area is only 72,425 acres (293 km2) in Utah state and is distributed in the alpine, subalpine, and high Mountains area [36]. Therefore, our ECL model had the subset models (Figure 2) at the level of the ecological sites to study the effects of global warming. However, the Pinyon-Juniper area has 10,567,696 acres (42765.95 km2), and 75% of them are distributed in semi-desert, and our ECL model classified and linked the level of climate life zone or middle level of ECL [36] (Table 4).

Thus, we understand that the nested hierarchical ecosystem will help us solve the environmental problem concerning the scale and level of organism structure. Under the limitation of resources, it is better to use similar habitats and ecoregion for reference [46] in terms of conducting research and making the policy decision.

It is possible to recognize the abstract responses, such as boundary changing, species moving, change abundant, and biomass [47, 48, 49]. When we look at these global warming impacts in the Dry, Polar, and Plateau Domain, the ecosystem responses are different depending on regional flora, population, community, ecosystem level, and ecosystem classification. It is recommended that we should compare the ecosystem to a near ecoregion for similarity. In other words, it is recommended that we could consider the dissimilarities of the different global ecosystems for making policy decisions as to adapt to the global environment changes.

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