
THE HIGHEST VASCULAR PLANTS ON EARTH
By Mattias Stich

GOAL OF THE PAPER:

- A taxonomic investigation that allows us to have a better understanding of the Himalayan flora, while also gives insight into the factors that limit plant growth at high elevations.

BACKGROUND:

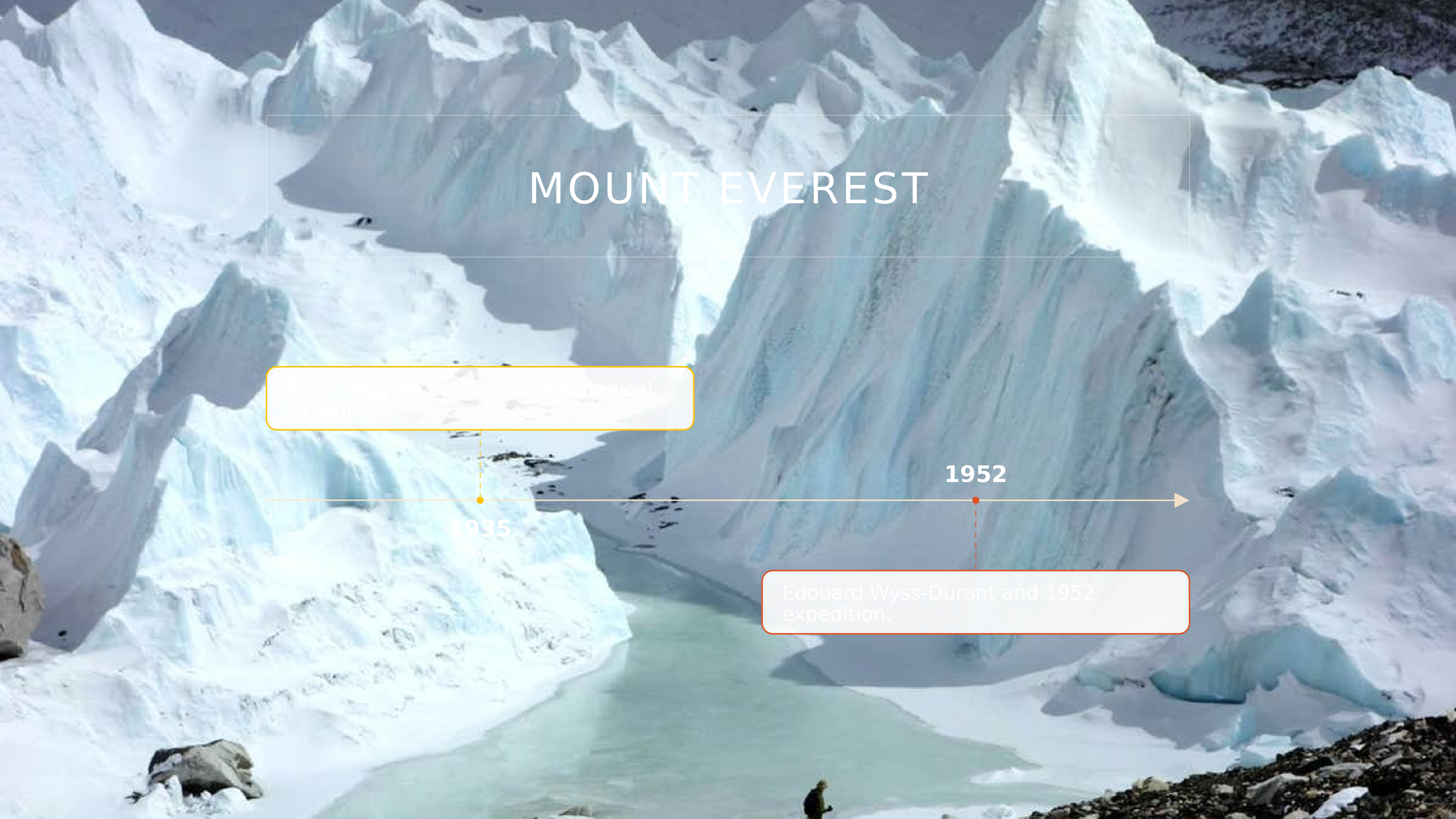
Mountain-loving scientists have been the primary source of high-elevation biological knowledge.

The extreme conditions present at these elevations prevent anyone but the most passionate biologists.

5 specimens were altogether were collected from both the north and south side of Mount Everest. One of the species was identified right after the expedition, while the other four were identified over 50 years later.

STUDIES:

- De Saussure, 1787, and the first scientific record of a high elevation plant.
- Humboldt, Bonpland, and their partial ascent up Mount Chimborazo.
- Heer, Piz Linard, and his meticulous cataloging.
- Whymper, the Matterhorn, and the “atoms of life”.
- Ball and Carrret’s encouraging words.



MOUNT EVEREST

Eric E. Shipton and his 1935 botanical expedition.

1935

1952

Edouard Wyss-Durant and 1952 expedition.

SITES FOR SAMPLING:

A total of five species were found around 6400 meter.



TAXONOMIC ANALYSIS:

DISCUSSION:

High-elevation vascular plants:

Asteraceae, Brassicaceae, Caryophyllaceae, Saxifragaceae, and Primulaceae.

Habitat conditions of highest plant occurrences:

Rock crevices, scree and moraine.

Distribution and phylogeny of the highest vascular plants:

These five taxa are similar in that they are mostly cushion plants and have distribution reminiscent of Eurasian mountain plants.

Table 1 Complete list of vascular plants ever recorded to date (above 6100 m a.s.l.)

Species[a]	Family[b]	Highest recorded elevation (m)	Mountain	Reference	Year of first description[c]
Androsace khumbuensis Dentant	Primulaceae	6350	Mount Everest (Nepal, Eastern Himalayas)	this study	2018
Arenaria bryophylla Fernald	Caryophyllaceae	6335	Mount Everest (Nepal, Eastern Himalayas)	this study	1919
Desideria himalayensis (Cambess.) Al-Shehbaz	Brassicaceae	6300	Kamet (Garhwal, Western Himalayas)	Miehe (1991)	1844
Draba alshehbazii Klimeš & D.A.German	Brassicaceae	6150	Mount Shukule II (Ladakh, Western Himalayas)	Angel et al. (2016)	2008
Draba altaica (C.A.Mey.) Bunge	Brassicaceae	6150	Shukule Peaks (Ladakh, Western Himalayas)	Dvorský et al. (2015), Angel et al. (2016)	1841
Ladakiella klimesii (Al-Shehbaz) D.A. German & Al-Shehbaz	Brassicaceae	6150	Shukule Peaks (Ladakh, Western Himalayas)	Dvorský et al. (2015), Angel et al. (2016)	2002
Lepidostemon everestianus Al-Shehbaz	Brassicaceae	6400	Mount Everest (Nepal, Eastern Himalayas)	Al-Shehbaz (2000)	2000
Poa attenuata Trin.	Poaceae	6150	Mount Shukule II (Ladakh, Western Himalayas)	Angel et al. (2016)	1835
Saussurea glacialis Herder	Asteraceae	6150	Shukule Peaks (Ladakh, Western Himalayas)	Dvorský et al. (2015)	1867
Saussurea gnaphalodes (Royle ex Royle) Sch.Bip.	Asteraceae	6400	Mount Everest (Nepal, Eastern Himalayas)	Miehe (1991)	1846
Saussurea inversa Raab-Straube	Asteraceae	6150	Shukule Peaks (Ladakh, Western Himalayas)	Dvorský et al. (2015)	2011
Saxifraga lychnitis var. *everestianus* Dentant	Saxifragaceae	6350	Mount Everest (Nepal, Eastern Himalayas)	this study	2018
Stellaria decumbens Edgew.	Caryophyllaceae	6130	Makalu (Nepal, Eastern Himalayas)	Miehe (1991)	1846
Waldheimia tridactylites Kar. & Kir.	Asteraceae	6150	Shukule Peaks (Ladakh, Western Himalayas)	Dvorský et al. (2015), Angel et al. (2016)	1842

[a]Species names based on The Plant List (theplantlist.org)

CONCLUSION:

FURTHER INVESTIGATION.

IMPORTANCE OF MOUNTAINEERING
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ASSEMBLY OF THE ARCTIC FLORA: HIGHLY PARALLEL AND RECURRENT PATTERNS IN SEDGES.

By Mattias Stich

GOAL OF THE PAPER:

- A study of the origin of the Arctic species of Carex, and it’s biological limitations.

BACKGROUND:

Two different types of grasslands have existed in the Arctic:

There are around 2800 species present in the Arctic, of which Carex is the most diverse (species-wise).

These factors make Carex a perfect genus for researchers to learn more about the genera.

MATERIALS AND METHODS:

- Used a tree consisting of 2146 individuals of 996 Carex species and four outlying taxa.
- Careful selection of clades:
  - "Arctic" vs "non-Arctic"
  - Bootstrap assistance gives ambiguous pointers.
  - Using ALL species is not possible due to missing species from the tree.
- Principles used for choosing appropriate clades
- The naming of the clades

DISTRIBUTION DATA, ECOLOGICAL DATA, AND CALCULATIONS:

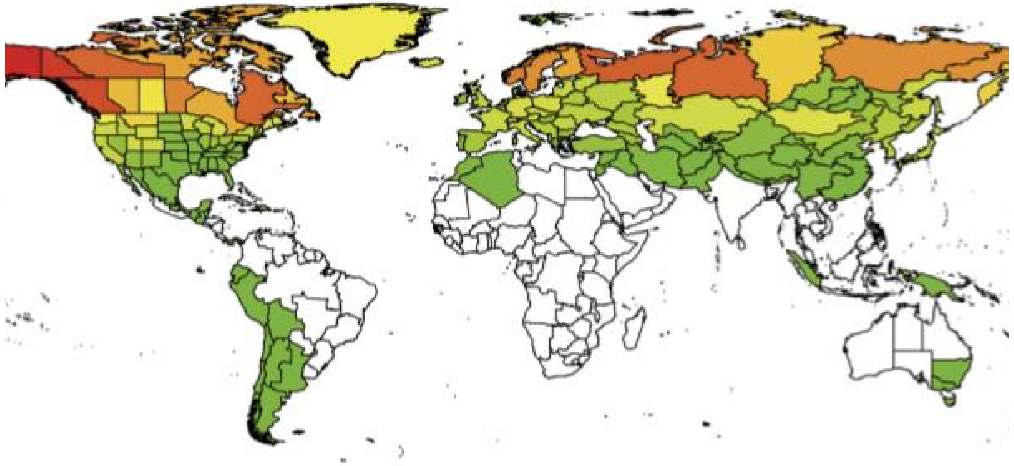
World Checklist of the specifically selected families of Cyperaceae to look at Carex distribution.

Focus of the ecological study was on altitudinal distribution, soil moisture, shade tolerance, and salt tolerance.

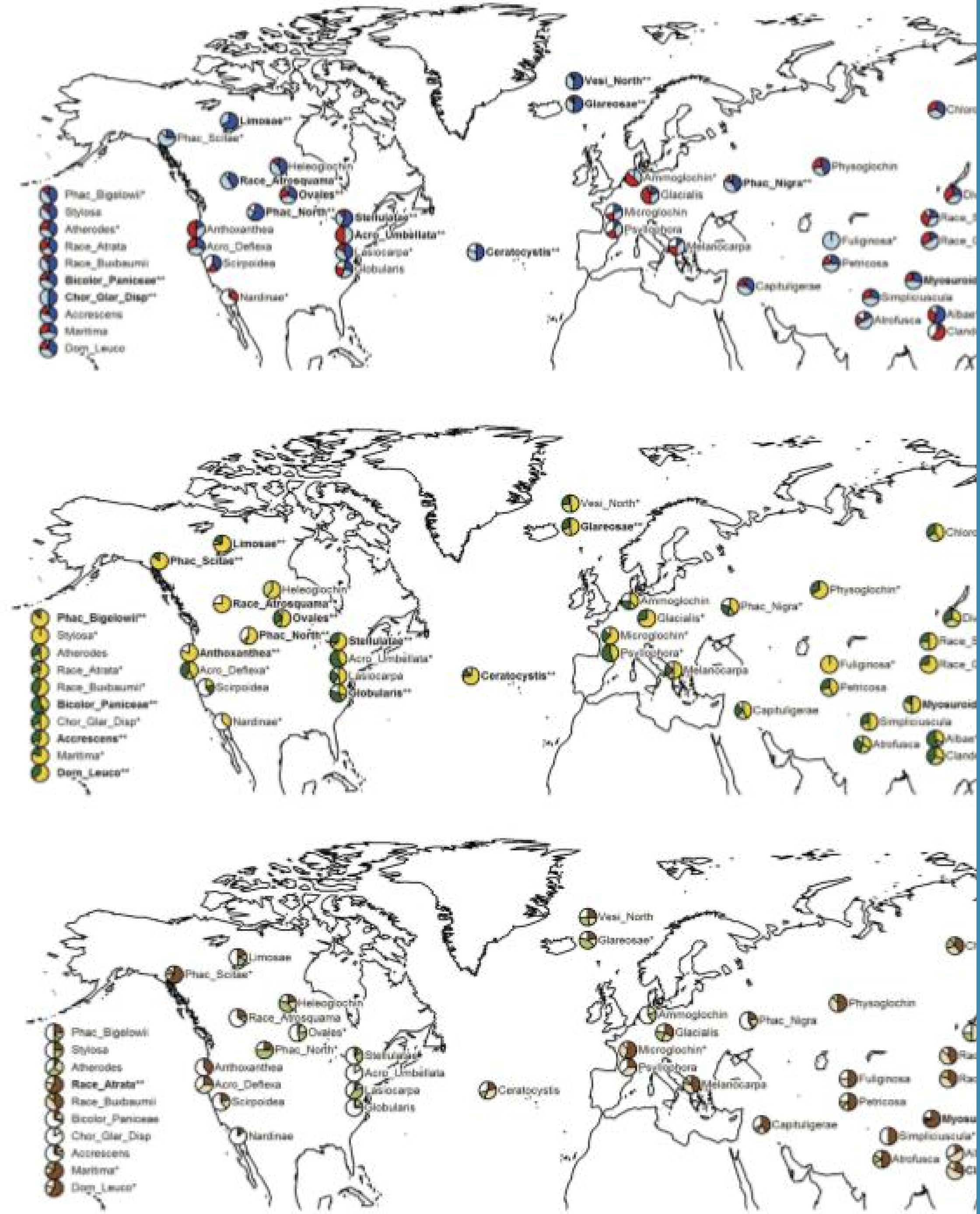
R was used for all calculations, the randomization was ran 1000 times, and the p-value was calculated in a bootstrap analysis.

DISTRIBUTION:

- Most of the Carex species were in and around Alaska.
- Carex marina Dewey subsp. pseudolagopina
- 46 clades: 15 in North America, 6 in Europe, 13 in Asia, 1 in the amphi-Atlantic region, 2 in the northern circumpolar region, and 10 that had no clear origin.
- Cases of possible high-mountain origin
- Lowland origins



ıp of the joint distribution of the 165 taxa of 136 *Carex* species reported to grow in the Arctic in the 369 TDWG level 3 areas (see te
are from green—one species to red—97 taxa in Alaska.



SOIL MOISTURE, SHADE AND TOLERANCE:

Soil moisture:

- Many Arctic species preferred wet soil conditions.
- Species of Carex were much rarer in dry soils.

Shade tolerance:

- Shade is rare in the Arctic, however, some examples are

Salt tolerance:

- Only five out of the 46 clades exhibited a tolerance to salt.

DISCUSSION:

The Arctic is one of the youngest ecosystems present on Earth.

Species diversity of Carex follows the same diversity pattern of other vascular plants in the Arctic. With more richness near oceans and less in continental areas.

48 independent lineages is surprising.

Carex had many evolutionary variations compared to other Arctic flora, but there are still numerous species that have evolved to deal with Arctic conditions.

Origin matters and dispersal is not universal.

Most Arctic species are from wetland clades.

COMPARISON:

Both papers involved looking at plants at extreme conditions.

Although, the main plant of the second paper is not present in the first paper’s environment.

Biol 330: Biogeography

Mattias Akira Stich

Biogeography presentation

Slide 1:

Hello, fellas, my name is Mattias Akira Stich, and my first paper was titled “The Highest Vascular Plants on Earth”.

Slide 2:

GOAL OF THE PAPER

Slide 3:

Not many people consider the importance of high-elevation plant collection. The collection of plants in these extreme conditions gives us a look at ecosystems which are at the exact opposite of the spectrum in comparison to the tropical rainforests near the equator. The main focus of this paper, as mentioned, is on the five specimens of plants that were collected on both the North and South side of Mount Everest. A good portion of this paper also contains accounts of the passionate biologists who have ventured into the harsh conditions of mountain ecosystems all over the world, and I have decided to keep these accounts in the presentation because of their contributions.

Slide 4:

For almost all of these scientist names, only the last name is given. A man named De Saussure in 1776 led an expedition up the highest mountain in the Alps, called Mont Blanc. While at an altitude of 3600 meters, De Saussure noted the presence of a plant called *Silene acaulis* which became the first time a high-elevation plant had ever been recorded. Humboldt and Bonpland became famous for their partial ascent up Mount Chimborazo, which is located in the Andes of Ecuador. They recorded every plant they observed on their journey up 5880 meters, until they were forced to turn back only 400 meters from the summit. They also observed that the upper limits of vascular plants was 4600 meters. Heer did pretty much the same thing, only he climbed the Piz Linard of the Swiss Alps. Between 1861 and 1864, Whymper made several attempts to reach the summit of the Matterhorn which is yet another part of the Alps. He was noted to have a huge interest in what he called “atoms of life in a world of desolation”. Ball was the first president of the Alpine Club of London, and published guidelines that encouraged mountain climbers to note plants that they saw at higher altitudes. Carret was a botanist who studied plants collected from La Maije, and who said, “mountaineering as a new means of extending the study of Natural History to mountain environments”.

Slide 5:

With a summit at 8848 meters, Mount Everest is a prime place for studying high-elevation organisms. Two significant botanical expeditions occurred in: 1935, led by Eric E. Shipton and 1952, led by a Edouard Wyss-Dunant. Shipton began in Tibet, went over the East Rongbuk Glacier, and eventually made it to the base of Mount Everest. Shipton was able to collect two plants, one at 6400 meters and one at 7100 meters, but was forced to turn back due to an unexpected snowstorm. The swiss expedition, led by Durant traveled over the Khumbu Glacier and made it to an altitude of 8600 meters, while also collecting three specimens at 6350 meters.

Slide 6:

A total of five species were collected around 6400 meters. One was almost immediately identified as *Saussurea gnaphalodes* and is credited with being "the highest vascular plant on earth". It is common throughout the northern India area at altitudes between 5000 and 6000 meters. This is a picture of a common *Saussurea sp.* The second sample from 1935 was identified in 2008 as a brand new species: *Lepidostemon everestianus.* The discovery of this plant changed the genus *Lepidostemon* from monotypic (a taxon that contains only one immediately subordinate taxon) to oligotypic (contains more than one but only a few subordinate taxa).

Albert Zimmerman was part of the 1952 expedition and collected the three species on the south (Nepalese) side of the mountain. Specifically, on a moraine and cliff on the side the Khumbu Glacier at an altitude between 6400 and 6335 meters.

Slide 7:

As I have mentioned, the first two specimens were identified as *Saussurea gnaphalodes* and *Lepidostemon everestianus*. The three from 1952 were just recently identified in 2017 *as Arenaria bryophylla, Saxifraga lychnitis*, and *Androsace khumbuensis*. The most notable features that helped identify *A. bryophylla* was the leaf margins which are glabrous, which is not normal for the genus. *S. lychnitis* differs from other *Saxifraga* species in its elliptical, brown leaves. *A. khumbuensis* differs from other species because of it's small, glabrous, homomorphic, white-teethed leaves.

Slide 8:

Five different families comprise the highest vascular species of plants: Asteraceae, Brassicacea, Caryophyllaceae, Saxifragaceae and Primulaceae. It is also worth mentioning that all these plants grow together in multiple-species patches wherever they can instead of just accidental occurrence. This table is a list of all vascular plants observed at an altitude above 6100 meters.

Saxifraga lychnitis and Androsace khumbuensis were both found in rock crevices on the mountain. A scientist named Miehe believes that the constant freezing and thawing and it's mobile effect on the soil is a huge limiting factor for plant colonization. However, the other three plants were found on scree (collection of rocks basically) and moraine (also a collection of rocks, but caused by glacier movement), which completely goes against Miehe's hypothesis. A scientist named Dvorsky concluded that the most important factor for a plant's survivability at high altitudes was root-zone temperatures, and not on soil properties.

The five families mentioned above are all abundant with cushion plants, which are compact, low growing plants that form a kind of woody mat on the ground. These families also make up 54% of flora in the Everest area, 49% in the Hindu Kush area, 46% in the Caucasus, and greater than 52% in the European Alps. Studies have shown that this convergent evolution appeared independently in the European Alps and in the Himalayas.

Slide 9:

New discoveries of plants above 6100 meters shows us the importance of further investigating high-elevation plant life. Studying these plants can and will bring new insight into not only the elusive species high above us but will also allow us to learn more about plants that are easier to investigate. The effect of climate change pushing both plants and animals upwards in order to "chase" their ideal environment, allows us to see the huge need for mountaineering scientists who are willing to study the changing conditions at higher altitudes.

Slide 10:

My second paper is titled, "Assembly of the Arctic flora: highly parallel and recurrent patterns in sedges".

Slide 11:

GOAL OF THE PAPER.

Slide 12:

In the Arctic, two different types of grasslands have existed: cryo-xerophilous (cold and dry adapted) Poaceae during the Pleistocene, and the currently dominating sedges and rushes. Of the 2800 species of Arctic flora, *Carex* is the most species-rich, and has a place among the most species-rich genera on Earth. It is a paraphyletic genera, but studies have showed that many species were not extremely genetically different from one another. *Carex* grow in abundance nearly everywhere with representatives in nearly all ecosystems, the only places where they do not grow in high numbers is tropical rain forests and deserts. The reason why *Carex* is such a great genus for studying biomes is: it's high number of Arctic species, the large phylogenetic tree available for the genus, and its presence in not only the extreme arctic but also in the areas south of the Arctic. Also, the relatively young age of the Arctic ecosystem (around 3 million years old), makes it a prime area for studying.

Slide 13: This is a long one.

Scientists used the diverse phylogenetic tree already available with a total of 2146 individuals of 996 species along with four outlying taxa. The use of this gigantic tree instead of a more simplified tree, that shows only one individual per species, has the added advantage of showing which clades may be "ignored" because of infraspecific sequence divergence. A disadvantage of this large tree is that some species dominate it because of their large numbers.

There were three different avenues of consideration when choosing appropriate clades to study in order to identify the origin for the Arctic *Carex*. The first consideration was determining which *Carex* species were "Arctic" or "non-Arctic", as I said earlier, this genus is abundant all over the world, so determining which ones are Arctic species is much more appropriate. The second consideration is with using a bootstrap method of ambiguous selection, which simplifies the selection. The third and final consideration is that scientists had to use a type of studying that did not include every clade of the tree for the upcoming calculations due to the large amount of missing species from the tree.

These first considerations narrowed down the selections considerably, but further, manual considerations were necessary to narrow down the selections further. One of the principles was that the clades had to have at least on Arctic and non-Arctic group of populations. If this situation was not available, sister-groups were identified by sectional affiliation and morphological similarities. Another principle was that clades in huge polytomies were counted separately so that the calculations were not inflated immensely. The end goal is to complete a comprehensive "list" that had both the number of lineages with Arctic species and specific clades that were suitable for further analysis based on their generally-considered origins and preferred environmental conditions.

The clades selected were study then named following very specific premises. If a clade is made of many closely-related *Carex* that already have a common name, the common name is used. If only part of the clade is made of closely-related, a new, specific name is added to it. And if the clade is already in existence and named, the name is kept.

Slide 14:

Scientists used a database that contains all known occurrences of species for the family Cyperaceae called World Checklist. Which included a total of 369 areas worldwide.

For the study on ecological data, four main environmental factors were used: altitudinal distribution, soil moisture, shade tolerance and salt tolerance. There are three main categories for the first three factors. For soil moisture they are, dry, moist, and wet. For shade tolerance, open conditions, forest occurrences, and shrub occurrences. And for altitudinal distribution there is alpine, mountainous and lowlands.

Calculations were all ran by the computer system R, which some of use have learned to use in Dr. Shipunov's biometry class, although this amount of data blows my mind. The goal of the calculations was to determine the ecological preferences of the different clades among the categories mentioned above, and they accomplished this by testing clades to see if many conglomerations of ecological preferences occur. When there was data present for all species present in a clade, the calculations were very straight forward. For the clades with missing or incomplete data, a randomization of the missing data was used. So, if altitudinal distribution, shade, and salt tolerance was available, but soil moisture data was missing, the program would insert a random value for the category. It may seem a little inaccurate to do it like this, but the randomization was ran 1000 times and used the calculated p-value to see if there were any significant differences in the data.

Slide 15:

Most of the *Carex* species were in and around Alaska. An interesting fact is that the further away you get from the oceans or some other large body of water, the less species you find. 28 of the 165 taxa were found only in the Arctic and nearby areas, and there was only that is almost completely restricted exclusively to the Arctic, Carex marina Dewey. The other clades had either a single or no species that were only in the Arctic. 46 clades were assessed to determine the location where the highest number of species were located. There were fifteen in North America, six in Europe, 13 in Asia, one in the Amphi-Atlantic region, two in the northern circumpolar region and ten that had no clear origin. As you can see in this table, the farther north you go, the more species are present.

Some cases of possible high-mountain origin are *C. atrata, C. atrofusca,* and *C. fuliginosa.* And some possible lowland clades are *Phaccocystis* and the *Lasiocarpa*.

Slide 16:

A preference for wet soil conditions was immediately apparent for almost all arctic clades, notable examples are *Limosae*, *Phacocystis* and Vesicarie. A small minority preferred dry soils, some examples are *Clandestinae*, *Ammoglochin*, and *Acrocystis*.

Shade is rare in the Arctic, however, some examples of shade lovers are the *Bicolores*-Paniceae, *Acrocystis-Umbellata*, and *Albae* clades

Only five out of the 46 clades exhibited any salt tolerance, with most salt-tolerant clades being located in the northern radiation. The clades were *Phacocystis, Atherodes, Glareosae, Divisae*, and *Racemosae-Gmelinii.*

Pie charts were used to show the proportion within the clades of the different levels present of the factors. The top table represents soil moisture. The color codes for the pie charts are, blue is wet, light blue is moist, red is dry, and white means there was not data available. The middle table is for light preference, and the color code is green for forest, yellow is for open, light green is for intermediate. The last table shows altitudinal distribution, and the color code is dark brown for alpine, light brown for mountains, green is for plains and white is for no data available once again.

Slide 17:

Because of the extremely fast rate that the Earth cooled during the Cenozoic, the Arctic is one of the youngest ecosystems available for studying. Studying the geographical and environmental conditions that affect *Carex* allowed scientists to not only discover interesting data on *Carex*, but also on other Arctic vascular plants, such as, the fact that more diversity of species was observed near oceanic areas and less diversity was observed farther inland. 48 independent lineages is astonishing because it is a very high number, and may give you the suspicion that EVERY lineage is able to have a representative in the Arctic. This not true however, not all widespread species of boreal *Carex* are able to survive in the Arctic. **READ YELLOW CHECKMARK**. The huge and seemingly random diversity of Arctic *Carex* flora may lead some people to believe that randomness determines which species become Arctic and that origin does not matter. Parallel geographical and ecological evolution of the Arctic flora shows that it definitely matters where the species starts, and that speciation is not random. There are many clades that have no representatives in the Arctic ecosystem, yet they are still distributed all throughout the Northern Hemisphere, which shows us that not all clades have the capacity to tolerate harsh Arctic conditions. This study of the Arctic species of *Carex* revealed that almost all of them were adapted from wetland clades. The existence of dry-adapted clades may be holdovers from the Pleistocene, when cryo-xerophilous plants were much more abundant. Because of their lower reliance on water, these dry-adapted plants may have a much lower rate of extinction in comparison to their water-loving brothers and sisters.

Slide 18:

These papers are semi-related because both are looking at ecosystems that we can all consider extremely harsh. The first paper mostly involved 5 specific species, none of which were related in anyway to the Cyperaceae family from the second paper, which supports the statement from the second paper that said not all clades of *Carex* are abundant in all areas of the world.