LIFE HISTORY TRAITS IN POA ANNUA L. POPULATIONS THROUGHOUT UTAH'S DIVERSE ENVIRONMENTS

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LIFE HISTORY TRAITS IN *POA ANNUA* L. POPULATIONS

THROUGHOUT UTAH'S DIVERSE ENVIRONMENTS

by

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ABSTRACT

Life History Traits in *Poa annua* L. Populations Throughout Utah's Diverse Environments

by

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To better understand the effects of environment and management on perenniality in annual bluegrass populations, we evaluated 60 populations of *P. annua*, collected from 15 golf courses ranging from moderate to highly maintained facilities, both young (<10 yrs.) and old (>50 yrs.), located throughout the state of Utah. These populations are of special interest because of the diverse environments present throughout the state of Utah, which include four climatic regions: desert, steppe, humid-continental, and undifferentiated highlands.

This study concluded that selective forces applied by intensive golf course management practices on *P. annua* populations may overwhelm selective forces applied by the climate. With gene flow readily occurring between golf course microenvironments, *P. annua* populations can be described as neither annual nor perennial but can be described as intermediate. Also, elevation may be considered a factor in determining life history traits of *P. annua* but elevation could be confounded with other environmental factors.

(55 pages)

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Alexander N. Stoy

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CHAPTER I

INTRODUCTION/ LITERATURE REVIEW

Poa annua L. (annual bluegrass) is a fascinating and complex species found growing almost anywhere in the world. Although *P. annua* is rarely intentionally planted, it is commonly found on golf course greens and fairways in temperate climates throughout the world. It is undesirable in the turf industry because it disrupts turfgrass uniformity, is a prolific seed producer, even at mowing heights of 3mm, dies out because of heat stress, and competes for space and nutrients (Hall and Carey, 1992). Yet *P. annua* can produce a high quality turf and tolerate extremely low mowing heights.

The annual type, *P. annua* var. *annua*, is associated with less intensely managed areas such as golf course roughs, home lawns and warm, dry climates (Heide, 2001: Xu & Mancino, 2001). *P. annua* var. *reptans*, the perennial type, is associated with golf course greens and fairways, and cooler climates of temperate regions (Johnson et al., 1993; Heide, 2001). *P. annua* var. *annua* reaches maturity quicker; has fewer leaves, nodes, tillers, adventitious roots; and produces a greater percentage of flowering tillers relative to the perennial form, var. *reptans* (Gibeault, 1971). Biological and morphological characteristics of *P. annua* are thought to be highly variable because of the variety of ecological pressures and turfgrass management programs, most notably on golf course turf.

Creeping bentgrass (*Agrostis palustris*) is the dominant turf planted on putting greens in northern, temperate climates. Because of *P. annua's* prolific seed production capabilities, toleration of compacted soils and low mowing heights, and variations and adaptability of the species, many golf course greens will eventually consist of a majority of *P. annua*.

P. annua, typically known as a cosmopolitan weed, is capable of rapidly "out-competing" creeping bentgrass on golf greens. Because of its negative attributes (Table 1-1) most turf managers, especially golf course superintendents, have gone to great lengths to eradicate or control *P. annua* in favor of creeping bentgrass. Some superintendents have been successful at reducing *P. annua* populations, but rarely is it eradicated, while some have chosen to manage it and have been very successful.

Most turf managers tend to overlook the positive attributes of *P. annua* (Table 1-1). Because of its ability to thrive at low mowing heights, its ability to grow in sun or shade, in compacted soils and with continuous moisture, is worldwide adaptable, is soft and easy to cut, has a beautiful and attractive color, and can re-seed itself naturally, *P. annua* can be a very desirable species.

Table 1-1. Attributes of *Poa annua* L.

Negative	Positive
Poor heat tolerance	Grows in sun or shade
Tolerates low mowing	Tolerates low mowing
Non-uniform putting surface	Provides a great putting surface
Turf discoloration	Beautiful and attractive color
Shallow rooting system	Grows in compacted soil
Prolific seed producer	Re-seeds itself naturally
High water demand	Grows with continuous moisture
Susceptible to ice damage, salinity,	Soft and easy to cut
diseases, annual bluegrass weevil	Worldwide adaptability
	Populations are not a monoculture

Peel (1982) stated different biotypes of *P. annua* exist and Lush (1989) has suggested biotypes have different niches in the environment. Johnson et al. (1993) showed *P. annua* is represented by a continuum of biotypes ranging from true annual to strictly perennial. The latter with a distinctive juvenile phase, requirement for vernalization for 10-12 weeks and a single spring-time reproductive period (Johnson et al., 1997a) would represent true var. *reptans* (McElroy et al., 2002).

Johnson et al. (1993) and Heide (2001) stated the perennial biotype, *var. reptans*, is more prevalent in alpine snow beds, golf course greens, and other areas of highly maintained turf. This type is considered the most desirable type of *P. annua* because it has a low flowering frequency, is primarily prostrate in growth, usually darker green in color, tolerates close mowing, provides an excellent putting surface, and better survives heat and drought stress (Frank, 2000; Xu & Mancino, 2001).

Taxonomy and Morphology

P. annua L. is a member of the *Poaceae* or grass family. It is an allotetraploid and thought to be derived from a cross between *Poa infirma* H.B.K. and *Poa supina* Schrad., both $2n = 2x = 14$ (Darmency & Gasquez, 1981; Heide, 2001; Johnson, 1995; Tutin, 1957). Defining characteristics of *P. annua* include a keel-shaped leaf blade, boat shaped leaf tip, and membranous ligule (Christians, 1998). In addition to the name *P. annua*, it is also known as annual meadow grass, winter grass, spear grass, and walk grass (Gibeault & Goetze, 1973; Johnson, 1995; Vargas & Turgeon, 2004). In 1753, Carl Linnaeus named this species of grass, giving the complete and accepted botanical name of *P. annua* L. (Christians, 1998; Gibeault & Goetze, 1973; Vargas & Turgeon, 2004). *P. annua*, known to have over 1600 strains (Huff, 2004), differs in respect to growth habits, life cycles, and morphological features. These variations reflect genetic modification or environmental adaptations, which are indicative of the massive variability this species exhibits (Vargas & Turgeon, 2004).

Many subspecies or botanical varieties have been identified (Gibeault, 1971; Johnson, 1995) and described based on color, shape, size, pubescence, and environmental adaptations. Gibeault & Goetze (1973) stated significant morphological variations exist and life length being the most understandable physiological characteristic between each biotype. However, classification into two or three botanical varieties is typical. Frank (2000), Johnson & White (1997a), and Lush (1989) noted the range of growth and flowering habits that exist in *P. annua* biotypes ranging from true annuals, winter annuals, biennials, and perennials. Timm (1965) identified two types of *P. annua* biotypes: 1) a vigorous perennial type, var. *reptans*, characterized by a darker green color, spreading habit, and numerous secondary tillers and 2) an erect annual type, var. *annua*, which is mostly upright, bunch-like in growth habit, and is a prolific seed producer. These two classifications are the most distinct types of *P. annua*, but Johnson & White (1997a) showed continuums of biotypes exist, all of which interbreed making further classifications difficult.

The plant, in particular var. *annua*, will often have inflorescences produced throughout the year (Christians, 1998; Johnson & White, 1997b; Vargas & Turgeon, 2004). The panicle-type inflorescence is made up of spikelets typically consisting of three to six florets. Tillers also occur in both the bunch type and stoloniferous biotypes. *P. annua* var. *reptans* usually produces more tillers per plant, therefore forming a denser turf stand (Vargas & Turgeon, 2004).

Germination usually occurs sometime in late summer and early fall, but can occur anytime of the year. The annual plants mature in the fall, over-winter, produce seed in the spring, and proceed to die. Law et al. (1977) described these types of plants as "opportunistic." Perennial type *Poas* produce a flush of seed in the spring and have strong vegetative growth the remainder of the growing season (Christians, 1998; Johnson, 1995).

Many have referred to selected *P. annua* populations as "biotypes" (Cattani, 2003; Gelernter & Stowell, 2001; Peel, 1982; Vargas & Turgeon, 2004). McElroy et al. (2002) and Sosebee and Wester (1995) defined a biotype as "a plant of a given population having the same genotype, thus have reproduced either vegetatively or by apomixis." Danneberger (1997) defined biotype in a much more simple way, as a "genotypic race or group of organisms." An ecotype, defined by Merriam-Webster's Dictionary (2003) is "a subdivision of an ecospecies that survives as a distinct group through environmental selection and isolation and that is comparable with a taxonomic subspecies." Ecotypes can be made up of numerous biotypes having selected a particular habitat because of environmental factors (McElroy et al., 2002; Sosebee & Wester, 1995). McElroy et al. (2002) claimed the term biotype could apply to a single population of var. *reptans*, but is not suitable when referring to var. *annua*.

In similar studies, Sosebee and Wester (1995), Lush (1989), Heide (2001), and McElroy et al. (2002) classified selected populations as ecotypes because the populations exhibited ecotypic variation (genetically based variation with a species related to habitat). Therefore, populations selected for this study will be referred to as ecotypes.

Turfgrass Ecology

Many "non-scientists" look at golf courses and see a one-dimensional, sterile plant community. In reality, all the ecological forces present on other grasslands are also present in golf turf communities, albeit mechanical or human imposed pressures.

The amount of genetic diversity within turfgrass populations can vary greatly (Danneberger, 1997). Golf course communities contain multiple species of turfgrasses such as Kentucky bluegrass (*P. pratensis*), creeping bentgrass, perennial ryegrass (*Lolium perenne*), and *P. annua*. In addition, numerous weeds such as dandelion (*Taraxacum officinale*) and moss (*Bryum sp.*) could be counted as part of the plant community. The end result is greater plant diversity, which often causes a patchy appearance (Danneberger, 1997).

Species within a community have their own niche (Table A-1). Danneberger (1997) describes a niche as "the entire range of resources and conditions in which a species can live and reproduce." Resources of a niche include varying levels of sunlight, water, oxygen, nutrients and space. Examples of conditions include pH, temperature, and mowing height (Danneberger, 1997).

The adaptation range of a single species can be quite large when all the conditions and resources are taken into account. This type of niche is considered the species' "fundamental niche" (Danneberger, 1997). A niche can severely be reduced or eradicated when a competing species is introduced. Danneberger (1997) termed this type of niche where an organism is capable of surviving competition, as the "realized niche." Species overlapping in their realized niches can coexist if there is enough differentiation in supplies for resources and conditions. One of the species will be driven from the habitat if differentiation does not exist (Danneberger, 1997).

Vargas and Turgeon (2004, p. vii) stated that 'the perception of *P. annua* as a weed reflects the assumption it is a weak and unreliable species, especially when subjected to severe, or even moderate, environmental stresses. But this is an oversimplification of what actually happens in cultured turfgrass communities.' They concluded that highly evolved *P. annua* biotypes can be very persistent and extremely competitive in mixed turfgrass stands (Vargas & Turgeon, 2004).

Vargas and Turgeon (2004, p. 3) further stated that "rapid evolutionary development from hybridization and subsequent selection pressure can lead to new *P. annua* biotypes that respond differently to environmental conditions." Thus, rapidly colonizing "annual" biotype populations which typically die from summer heat and drought stresses often produce an abundance of seed providing a bridge to the next generation. These populations, in time, evolve into a slower growing but intensely competitive "perennial" biotype which is less susceptible to these environmental stresses.

"Perennial" biotypes may result from selection pressures from competition, environmental and cultural stresses. Distinct populations might occur from genetic drift of different original sources in each environment (Cline, 2001). Huff (1998) stated a common method of obtaining a "perennial" biotype is to "wait until *P. annua* invades as a weed and slowly evolves under pressures from these stresses."

Turfgrass Microenvironments

Three distinct microenvironments exist on golf courses: putting greens, fairways, and roughs. These exist because the game of golf demands them. To maintain each area properly, varying management techniques are applied to the individual areas of play.

The most intensely managed environment is the putting green (Cline, 2001). A majority of the strokes are played on the putting green so traffic is concentrated here more than any other microenvironment. Putting greens are mowed 5 to 6 days per week and mowed as low as 2.5 mm. They are frequently irrigated and subjected to frequent, light applications of fertilizers while soil moisture levels are sometimes maintained above evapotranspiration rates (Cline, 2001). Foot and machinery traffic compact the underlying soil, creating an unfavorable environment for root growth. High surface temperatures (>46°C) are common during midsummer months (Beard, 1969), which can lead to high temperature kill. Because of these and other unique management practices, the grasses on putting greens are put under extreme stress, making them more susceptible to diseases (Cline, 2001).

The fairway environment is intermediate between the intensively managed green and the not so intensively managed rough environment. Fairways are usually maintained at a height between 6 and 13mm (Vargas & Turgeon, 2004), receive 1.36 to 1.81 kg of Nitrogen (N) m^{-1} y^{-1} and are well irrigated. Cline (2001) has claimed "soil temperatures are lower than putting greens due to greater buffering from the thicker layer of verdure covering the soil surface." Compaction is usually less severe in fairways because traffic is spread over a greater area while the frequency of equipment use is lower.

Cline (2001) stated that "the order of these environments relative to stress can vary depending on climate and intensity of management." These very different micro-environments exist in close proximity allowing gene flow between them (Till-Bottraud et al., 1990) but yield very different types/populations of *P. annua* (Lush, 1989).

***Poa annua* Management**

Primary Cultural Practices

Despite its dominance and persistence, *P. annua* is considered a weed by many turf growers with much time, money, and energy being placed into effective control methods. In years past, most research conducted on *P. annua* has been on how to control or eradicate this problematic species. Elimination seems impossible because every time a fine turf stand is damaged by ball marks, insects, or diseases, *P. annua* seed allows it to gain a strong foothold (Christians, 1998). The more a green is cultivated, the more open the ground is available for *P. annua* seed to germinate (Huff, 1999b). *P. annua* can be managed with proper cultural practices. Discussed below is some information for sustaining healthy *P. annua* turf stands.

Mowing

Putting Greens

Playing characteristics of each green will vary, but management practices may also have to be varied to cope with the presence of *P. annua* (Gange et al., 1999).

Huff (1999b) stated that "mowing is the strongest selective factor on a golf green and *P. annua* seems to become specifically adapted to the mowing height of the green on which it grows." *P. annua* is capable of mowing heights to less than 2.5 mm, making it an ideal putting surface (Vargas & Turgeon, 2004).

Generally, greens-type *Poas* do not grow vertically much above the height of the cut to which they are adapted (Huff, 1999b). With the capability of producing viable seed at low mowing heights and the plants ability to become very dense, especially in greens-type ecotypes, resistance to invasion by other turfgrasses and weeds is enhanced (Vargas & Turgeon, 2004). *P. annua* greens should be mowed at least 5 days per week to mitigate environmental stresses.

Fairways

According to Vargas and Turgeon (2004), fairways should be mowed at a height of 13mm or below at an interval of no less than 3 days per week, with 5 or 6 days preferred. To encourage *P. annua* populations, clippings should be recycled to allow for the return of nutrients, moisture, and seed to the soil profile. Christians (1998) maintains mowing any turf at an excessively low height results in severe stress, which can lead to a variety of problems, including *P. annua* encroachment. This is good, however, if one is to encourage *P. annua* growth on golf course fairways.

Fertilization

During an entire growing season, 1.81 to 2.7 kg of N m^{-1} is recommended to maintain a healthy turf (Christians, 1998; Dr. Paul Johnson, personal communication; Vargas & Turgeon, 2004). These quantities should be applied in small amounts using multiple applications, also known as spoon-feeding. This will help sustain plant health and maintain high putting speeds (Vargas & Turgeon, 2004), a condition of a putting surface as it relates to ball-roll distance. Huff (1999b) recommended using a liquid instead of granular fertilizer because even the smallest granules can leave "freckles" on a *P. annua* turf stand.

Fairways require the same amount of fertilizers as do greens, with the exceptions of whether clipping removal occurs or not. If clippings are returned, which is the case for the majority of golf course fairways; it is recommended to reduce N inputs by about 25% (Vargas & Turgeon, 2004). They also recommend the use of granular fertilizer because putting speed is not of importance.

Irrigation

Irrigation is a common practice on all golf courses and most athletic fields. It is used to replace water loss through transpiration in plants and evaporation from soil and plant surfaces, otherwise known as evapotranspiration (ET). Turf usually requires from 2.5 to 4 cm of water per week for standard summer conditions. Local conditions may readily result in situations where more or less may be required (Vargas & Turgeon, 2004). Two important aspects of irrigation applications are: 1) How often should water be applied and 2) When should water be applied?

Historically the proper method of watering plants was to apply water to moisten root zones thoroughly without applying water in excess and at rates that create surface runoff or standing water. In between irrigations, it was also recommended to allow the soil to dry, which would maximize atmospheric and soil gas exchanges. Incorporating the two would greatly benefit a more favorable soil environment for optimal plant root growth (Vargas & Turgeon, 2004).

The rule of thumb was to apply water to the soil profile deeply and infrequently, allowing the soil to dry in between irrigations and the plants to become moderately stressed. This method, however, is not appropriate for all conditions. For example, irrigating a compacted clay soil with poor infiltration rates would lead to serious surface runoff, therefore not fulfilling the purpose of the irrigation. Secondly, watering sand based root zones using the deep and infrequent method could lead to nutrient leaching as well as water being pushed beyond the root zone, rendering the excess irrigation useless. *P. annua*, known for its shallow root system, would not benefit from this method.

An alternative approach would be to irrigate using light and frequent applications of water. This method is aimed to meet moisture requirements of a shallow rooted turfgrass like *P. annua* by mitigating heat and drought stresses to which the turf would otherwise be subjected. Very high shoot densities can be sustained if a continuous supply of water is provided (Vargas & Turgeon, 2004).

The second question of "When to apply" water is a controversial topic. In order to prevent evaporative water losses it has been suggested water be applied either at night or in the early morning hours, when evaporation rates are at their lowest. Applying water in the evening hours should be avoided if at all possible because the turf canopy stays wet for an extended period of time, which may lead to disease development (Christians, 1998). A more suitable time would be to apply water in the early morning hours when evaporative losses are minimal and excessively wet conditions are avoided.

Vargas and Turgeon (2004) have suggested irrigating *P. annua* turf in the middle of the day, when heat and drought stresses are sometimes severe and of increasing concern as the day progresses. Benefits of this method include direct evaporative cooling, which helps shallow rooted turfgrasses survive heat and drought. This method also keeps the turf and soil drier, which alleviates associated problems that might occur if these areas were to be saturated.

Reducing Water Use

Water conservation, especially in semi-arid to arid climates, should be of utmost concern of all turf managers, home owners, businesses, and municipalities alike. In areas where water resources are extremely limited, like the Intermountain West, and even areas where water is abundant, efforts should be made to use this valuable resource efficiently and effectively.

Secondary Cultural Practices

Green et al. (2001) stated in order to mitigate stresses on *P. annua* putting greens associated with summer stress, it is of utmost importance to maintain good soil physical and hydraulic properties for adequate water infiltration, aeration, and salt leaching. Cultivation, the processes used to loosen the soil, reduces compaction and thatch, or groom the turf surface, is common on golf courses worldwide. Cultivation methods include vertical mowing, spiking, rolling, topdressing, plant growth regulator applications, and core aerification. For further information, please refer to Christians (1998) and Vargas and Turgeon (2004).

Temperature Effects

Optimum Temperatures

The optimum growth temperature frequently corresponds to the optimum temperature for photosynthesis, the process by which plants absorb CO_2 from the atmosphere and convert it to sugars used for energy and growth. Temperature also affects the rate of plant development. Higher temperatures speed annual plants like *P. annua* through their developmental phases while slowing perennial plants metabolic processes (Beard, 1969).

Beard (1969) noted the optimal temperature ranges for *P. annua* will fluctuate given the plant's age, development stage, physiological condition, duration of temperature level, plant organ involved, and variations in environmental factors. Ranges for *P. annua* shoot growth fall between 15 and 21°C while optimal ranges for root growth occur between 13 and 18°C.

Low Temperature Stress

P. annua is more susceptible to low temperature kill than other turfgrasses such as creeping bentgrass, Kentucky bluegrass, and perennial ryegrass (Cline, 2001). At what temperature kill occurs is of debate and is not due to one factor. As temperatures decrease, tissue growth slows and eventually will cease. Although, even at temperatures close to 0° C, respirations and photosynthesis have been found to occur (Beard, 1969).

Low temperature kill is caused by ice crystal formation within plant tissue, in particular, the protoplasm, and is directly related to the hydration level of the plant. As the hydration level increases, killing temperatures increase. Variation in low temperature tolerance is likely to vary over the course of the winter season. By late December maximum hardiness is usually achieved followed by a slight decrease the following months. By early spring, low temperature tolerance of *P. annua* is usually at its minimal level (Beard, 1969). This means low temperature kill is most likely to occur during the spring freeze/thaw cycle when crown tissues are at a higher hydration level.

Cold temperatures are important however to the biology of the plant. Vernalization requirements, or lack of them, are critical in determining the seasonal timing of flowering and life history of *P. annua* populations (Grime, 1979; Johnson & White, 1997a). Variation in these vernalization requirements explains a portion of the diversity within the species, ranging from annual to perennial (Johnson & White, 1997a). In addition, sensitivity to vernalization varies among turf areas on golf courses.

Cold treatments, however, do not influence flowering in var. *annua*. Johnson & White (1997a) found a cold treatment or vernalization period is required for flowering in var. *reptans*. With intermediate type plants, vernalization enhances flowering but is not required. This explains the large number of flowers produced in spring because var. *reptans* genotypes are responsive to vernalization (Johnson& White, 1997a).

High Temperature Stress

High temperature stress is common among turfgrasses during summer periods, especially the shallow rooted *P. annua*. High temperature stress causes an increase in maturation and death of the existing root system while also impeding initiation of any new root system (Beard, 1969). Reduced growth is a negative response first noticed. The root systems begin to appear brown, spindly, and weak due to die back. Cline (2001) says var. *annua* is less tolerant of high temperatures than is var. *reptans*.

Shoot growth, particularly the reduction in leaf width, leaf length, area, rate of new leaf appearance, and succulence is the next considerable effect of high temperature stress (Beard, 1969). This condition is noticed when the turfgrass begins to appear a bluish-grey color. *P. annua* can be killed at temperatures as low as 38°C, which is fairly low for death to occur, since mid-summer temperatures at the turf canopy often reach as high as 46°C (Beard, 1969).

Plants, using transpiration as a way to cool themselves, do so by using energy to evaporate water from the leaf surface, thereby cooling the plant as long as the stomata are open and actively transpiring (Beard, 1969). If stomata were to be closed, transpiration will cease and lethal high temperatures may arise.

Both high and low temperatures represent the major environmental limitations to distribution and growth of *P. annua*. In general, this lack of tolerance to extreme temperatures makes it a weak turf for some part of the year in various climates. Despite this general observation, strains of *P. annua* have been observed to perform well in irrigated turf areas subjected to the heat of the Mojave Desert and the cold of alpine valleys.

Climate Classification of Utah

While Utah is perceived to be a desert state, and statistically Utah is the second driest state in the nation, its climate, soils, and vegetation are as diverse as are its landforms. Climates, according to the *Atlas of Utah*, are "generalizations of all major weather conditions of an area over a long period of time usually a 30-year period."

Utah, famous for its champagne powder, experiences most of its precipitation during the winter months. Summer precipitation comes primarily from intense thunderstorms, sometimes depositing an inch of rain per hour. These storms, however, hardly give any relief from the summer droughts Utah experiences.

The Modified Koppen System (MKS) characterizes climate types according to vegetation, temperature, and precipitation patterns. The four major climate regions of Utah include: desert (arid), steppe (semiarid), humid continental, and undifferentiated highlands (Greer et al., 1981).

Deserts

Greer et al. (1981) estimate Utah's landmass is made up of about 33% of true desert, which generally receives less than 20cm of precipitation annually and has an evapo-transpiration (ET) rate from 76 to 127 cm. Utah has three distinct deserts: the Great Basin desert, the Colorado Plateau, and the Mojave Desert of the southwest region.

The Great Basin Desert is a region of hot summers and cold winters, with winter temperatures averaging below 0°C (Greer et al., 1981) while summer temperatures can reach above 38°C. Much of the region is dominated by extensive areas of salt flats, many of which are devoid of plant and wild life.

The Colorado Plateau Desert is located in south central and south eastern Utah, an area known as the Canyonlands. Temperature and precipitation conditions in the northern portion of the Colorado Plateau are comparable to the Great Basin. However, these two desert regions are unique and quite different due to contrasts in exposed geological formations, vegetation types and topography (Greer et al., 1981). The southern region maintains average winter temperatures above 0°C. Summer temperatures can escalate to 43°C, with night time lows dipping into the single digits in winter.

Utah's southwestern region consists of a minor extension of the Mojave Desert, as suggested by Joshua tree populations. Like the Colorado Plateau, this desert region also has winters averaging above freezing (Greer et al., 1981). The St. George area records the highest mean annual temperatures in Utah, with Zion National Park and St. George averaging 16.11° to 16.67°C, respectively (Greer et al., 1981). Summer temperatures can reach as high as 49°C.

Steppelands

The steppelands region is the most extensive climatic zone, making up 40% of Utah (Greer et al., 1981). This region is generally considered a narrow belt of land which lies between the deserts and mountainous regions. Greer et al. (1981) stated this region averages between 20 and 36 cm of precipitation per year, but still below the potential annual ET. Most of the steppelands regions experience winters averaging below freezing (Greer et al., 1981). Steppelands, a semi-arid climate, are sufficient for the growth of short and medium grasses such as wheatgrasses, *Poa* species, and fescues.

Humid Continental

The humid continental region generally receives about 51cm or more of precipitation, which usually exceeds the ET rate. This region, 3% of Utah's total landmass, is a narrow belt along the Wasatch Front from the Idaho border down to Nephi, UT (Greer et al., 1981). The majority of Utah's population resides in this region, which is home to the capitol, Salt Lake City.

Serving as the backdrop to this region, the Wasatch Mountain Range not only influences people to move there, but the mountains also influence the amount of precipitation that falls because they act as a barrier to moisture-laden winds approaching from the Pacific Ocean. As approaching air masses rise to clear the mountains, temperatures decrease, creating conditions that cause the air to give up its moisture (Greer et al., 1981).

Summers can be quite hot with temperatures exceeding 38°C while winters are capable of dipping below -18°C (Greer et al., 1981). Normally, valley floors do not experience extensive periods of snow pack, but there is always an occasional year the ground is covered from early November through early March.

Undifferentiated Highlands

Greer et al. (1981) claim Utah is approximately made up of about 24% undifferentiated highlands. Mid-latitude highland climates are generally considered as humid regions with severely cold winters and cool to cold summers. This is typical in areas such as Eden, Park City, Woodruff, and the Uinta basin.

Summer temperatures average at or below 22°C in the highlands region with winter temperatures frequently dipping below -18°C. Within this region there is a great variety of temperature and precipitation fluctuations ranging from the cool summers of valley floors to the alpine tundra of the high Uinta Mountains (Greer et al., 1981). It was in this region the second coldest temperature ever recorded in North America occurred. On February 1, 1985, the temperature dipped to -56.3°C at Peter Sinks in Logan Canyon, Utah.

One would expect the climatic diversity of Utah to have a large impact on the plants growing and evolving in each region. Although urban landscapes are modified with irrigation and other management practices, climatic factors may play a role in determining types of weeds or other plants growing there. This may especially be the case with a diverse plant such as *P. annua*.

Research Objectives

The purpose of this research was to study ecotypic variation within *P. annua* L. populations from maintained golf courses throughout Utah's diverse environments by examining differences in life history traits and relating these traits to micro- and macro-climate effects. The ecotypes represented distinct populations from 15 Utah golf courses.

- Examine life history traits of *P. annua* L. on golf courses in four climatic regions of Utah.
- Examine life history traits of *P. annua* L. between golf course greens and fairways.

CHAPTER II
METHODOLOGY

The *P. annua* populations used in this study are a mixture of ecotypes collected from fifteen Utah golf courses in four distinct climatic regions (desert, steppe, humid-continental and undifferentiated highlands) (Greer et al., 1981). The *P. annua* populations were used to determine whether or not varying micro- and macroclimatic conditions in the regions and golf courses have an effect on life history traits, the ability to optimize the allocation of finite resources between maintenance, growth, and reproduction (Law et al., 1977; Cline, 2001) of *P. annua* L. Golf courses were selected based on the following criteria: climatic location, degree of maintenance expectation, and age of facility (Table 2-1; Table A-2). Golf course collection sites ranged from medium to highly maintained facilities, both young (<10 yrs) and old (>50 yrs).

Table 2-1. Utah golf course collection sites.

Course	Region	Ownership	Constructed
Dixie Red Hills Golf Course	Desert	Public	1965
Green Spring Golf Course	Desert	Public	1989
Moab Golf Course	Desert	Public	1986
St. George Golf Club	Desert	Private	1935
Sunset View Golf Course	Desert	Public	1985
Wingpointe Golf Course	Desert	Public	1989
Country Club, The	Humid	Private	1889
Hidden Valley Country Club	Humid	Private	1960
Ogden Golf & Country Club	Humid	Private	1940
Thanksgiving Point Golf Course	Humid	Public	1997
Logan Golf & Country Club	Steppe	Private	1949
Logan River Golf Course	Steppe	Public	1992
Park City Golf Course	Highland	Public	1962
Park Meadows Country Club	Highland	Private	1983
Wolf Creek Golf Course	Highland	Public	1963

Collection

With the exception of two golf courses, Thanksgiving Point and Sunset View Golf Course, 10 populations (6.4 x 2.5 cm), each containing several plants, were collected from two distinct but adjacent environments of the golf course, putting green and fairway, (Appendix A-2) which are maintained and usually constructed, much differently. Two greens and two fairways were sampled for a total of 40 plants per course, 580 plants in all. A *P. annua* patch on a putting green or fairway was considered a population.

To accomplish a "relatively" randomized sample, populations were chosen by tossing a golf tee blindly onto various areas of a putting green and fairway and taking the sample from the closest *P. annua* patch nearest the point of the golf tee. This method was used to expedite the collection process due to the golf courses being in play and allow for a variety of *P. annua* populations. At each golf course collection site, questions were asked pertaining to maintenance practices associated with each golf course, course history, and annual rounds. Information from each location is listed in Tables A-3 and A-4.

Populations were kept in a sealed storage bag containing moist paper towels until planting at the Utah State University Research Greenhouse in Logan, UT, where one tiller from each population was propagated into 50-cell greenhouse plug flats (each plug was 4 cm dia., 5 cm deep). This resulted in 20 plants per putting green and fairway and 40 plants per golf course, with the exception of two golf courses. These plants were monitored for growth habits and seed head formation. The remaining plants from the collection sites were established in 10 x 10 cm pots until actively growing and placed in a cooler at 6°C to prevent inflorescence production.

Field Experiment

In May of 2003, plants were established in a common garden at the Utah State University Greenville Farm in North Logan, UT. Plants were spaced 35cm apart in rows of rows 40cm apart. The plants were evaluated for two consecutive years and dead plants were replaced for the second years study with clonally propagated material (i.e. same plant) or if not available, grown from seed. *P. annua* is primarily a self-pollinating species (Tutin, 1957) where exchange of pollen between plants is unlikely, especially in a controlled environment. Therefore, these genotypes would breed relatively true-to-type (Vargas & Turgeon, 2004). In 2004, 55% of the plants needed replacement.

The plants were trimmed prior to field planting. The plot was fertilized with Milorganite® (6-2-0) on a monthly basis at a rate of 1.36 kg of N m^{-1} y^{-1}. Irrigation was applied as needed to maintain healthy turf. Prior to planting in 2003, weeds were controlled with an initial application of glyphosate and thereafter by physical removal. In April of 2004, volunteer *P. annua* plants and other weeds were sprayed with glyphosate and tilled over. The plot was mulched to prevent weeds and retain moisture.

In both years, all plants were evaluated for vegetative (tiller production) and reproductive (days-to-flower, inflorescence production) growth characteristics and were given a rating of 1-5 (1 = perennial, 5 = annual) based on the characteristics in Table 2-2 (Johnson & White, 1997a). Ratings were taken in August and September of 2003 and June through September on a monthly basis in 2004. The ratings were averaged and significance was tested for life history traits by plotting assigned ratings for each population.

Table 2-2. Perenniality rating system based on vegetative and reproductive morphology.

Rating	Variety		Description
1	*reptans*		True perennial. Lots of vegetative growth (low and compact), no inflorescence production, over-winters
2	*reptans*		Lots of vegetative growth, over-winters, little inflorescence production, mainly in the spring
3	*reptans*		Equal ratio of vegetative and inflorescence production, growth habits range from low and compact to tall and sparse, over-winters
4	*annua*		Less vegetative growth compared to inflorescence production, dies after one growing season
5	*annua*		True annual. Mainly reproductive growth, prolific seed producer, dies after one growing season

Greenhouse Experiments

Throughout the fall and winter of 2003 the plant collections were examined for morphological variation, in particular, the ability to produce tillers and inflorescences. Tillers counts were calculated as the number of tillers from the basal portion of the plant between removal from the vernalization chamber and 90 days thereafter. Days-to-flower was calculated as the number of days between removal from the vernalization chamber and emergence of the first inflorescence from the plant. Plants were considered not flowering if emergence did not occur within 40 days. Days-to-flower were noted on a daily basis for a 40 day period. Inflorescence counts were calculated every 60 days for a 6-month period.

Greenhouse Experiment 1: Reproduction without cold treatment

Single tillers propagated from golf course green and fairway populations were planted in 50-cell greenhouse plug flats using a soil media mix composed of one part perlite, one part peat, and half-part vermiculite. The flats were randomly placed in a greenhouse and allowed to grow under normal light conditions. Light intensities at plant level, as measured with a Quantum Sensor, model QSO-SUN (Apogee Instruments, Inc.), ranged from 200 to 400 μmol m^{-2} s^{-1}. The greenhouse temperature was maintained at 21°C by artificial heating and cooling although infrequently temperatures rose above that level on warm days. Three weeks following planting and every 3 weeks thereafter the plants were rearranged in a randomized design to eliminate variation in the greenhouse growth environment.

The plants were monitored for vegetative growth (tiller production), days-to-flower, and inflorescence production. Tiller counts were taken on a monthly basis for 7 months. Days-to-flower (day 1 = day of planting) were noted when the inflorescence would push from the boot. Inflorescences were counted every 2 months for 6 months.

Greenhouse Experiment 2: Reproduction with cold treatments

Using the same soil media mix, single tillers (10 per replication, 3 replications) were propagated from plants in Experiment 1. All plants were grown in 50-cell greenhouse plug flats. The ten plants were split into two groups of five and randomly assorted. The plants were maintained until individual plants accrued three tillers and were actively growing. Tiller counts were made before the plants were placed into a cooler at 6°C for 10 and 12 weeks to meet vernalization requirements.

In each replication of this experiment, all plants were put into the vernalization chamber, removed after 10 and 12 weeks, and placed in the greenhouse for floral development. High pressure sodium lamps were used to provide light (200 to 400 μmol m^{-2} s^{-1}) for an 8-h day length. Each replication was monitored for 40 days following removal from the cooler for the following: 1) vegetative growth, 2) days-to-flower, and 3) inflorescence production.

Data Analysis

The *P. annua* populations, due to complexity, were analyzed using a split-split-split plot design, with the whole plot being the golf course treatments; the subplot the golf course holes; and the sub-subplot the turf type (putting green and fairway). Data were subjected to an analysis of variance and significance was determined at the 5% level. However, if significance was under the 10% level, some interpretation was considered. ANOVA tables are presented in Tables A-5 and A-6. The mean field ratings, days-to-flower, and number of inflorescence data were analyzed using PROC Mixed of SAS for Windows, version 9.0 (SAS Institute, Inc., 2002).

For the field experiment, plants which did not survive the first two weeks of establishment for both replications were not included in the analysis. This eliminated 44 individuals from the green populations and 36 from the fairway populations. In total, 500 plants were used in the evaluations.

CHAPTER III

RESULTS AND DISCUSSION

Golf courses differ from course to course, hole to hole, micro-environment to micro-environment. Golf course management practices differ slightly from course to course, but relatively speaking, is much the same. Differences between golf courses include mowing height and frequency, types of fertilizers, pesticides, equipment used, and frequency of water application. Soil compositions vary from tee to fairway to putting green because soil compositions are usually altered during construction and/or renovation. Locations of individual holes vary as well. In some cases, one golf course may have a hole located on a slope with rocky soil, a hole surrounded by wetlands, forests, and/or water features. All of these factors are important to the diversity of a golf course and the micro-environments within them.

Populations from putting green environments were generally more perennial while fairway populations were more annual. However, a vast majority of the populations sampled were classified and rated as an intermediate type plant. Comparisons between these golf course micro-environments, putting greens and fairways, were marginally significant.

Climatic Effects

Although differences in perenniality, as measured in the field experiments, among the *P. annua* collections of the different regions were not statistically significant ($p>0.24$), the trends we hypothesized did occur (Table 3-1; Fig. 3-1). The cooler, moister climates of the Undifferentiated Highlands and Humid Continental regions produced the most perennial type plants for the putting green (mean= 2.64) and fairway (mean= 2.85) populations. The hotter, arid Desert regions produced the most plants with annual characteristics with a mean of 2.94 for putting green populations and 3.23 for fairway populations.

In the greenhouse experiments, days-to-flower measurements were deemed insignificant among *P. annua* populations from the climatic regions (p>0.59) with no evident trends. The earliest day-to-flower was 7 days while the latest was 40 days which occurred in all climatic regions. Some populations however, did not flower. The number of inflorescences produced varied greatly within and among climatic regions.

Table 3-1. ANOVA for Experiment 1: Comparison of *P. annua* populations from golf course putting greens and fairways in four climatic regions.

Source	Num df	Den df †	F	p
Region	3	11.3	1.61	.2428
Turf Type	1	10.8	4.48	.0585
Region* Turf Type	3	10.5	.54	.6623

†Kenward-Rogers method used to obtain Denominator degrees of freedom

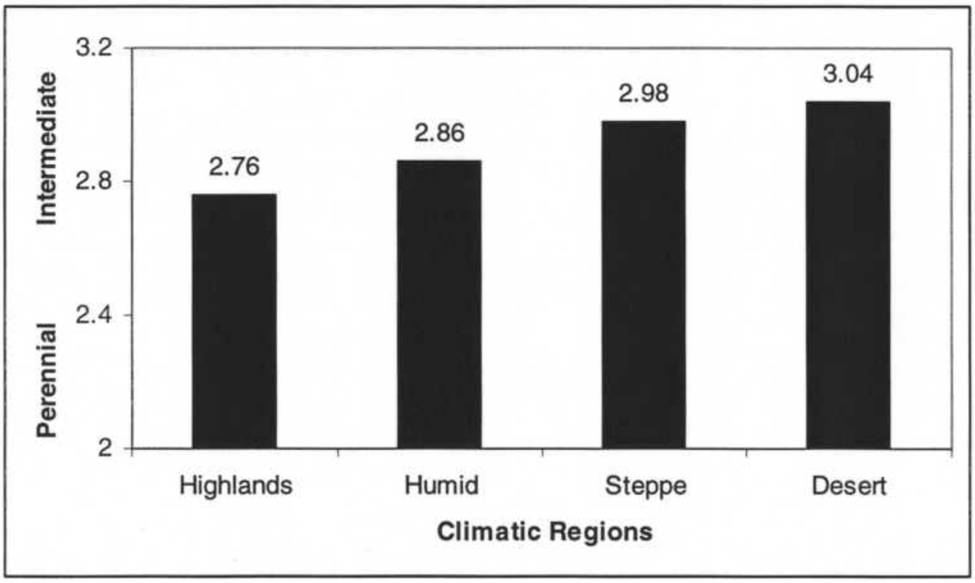

Figure 3-1. Mean perenniality ratings of *P. annua* populations from four Utah climatic regions.

The climatic regions are distinct due to many environmental factors, but one of those is elevation. When the populations are compared in relation to elevation alone, some significant effects appear. As elevation increases, perenniality increases (p=.0042; Fig. 3-2; Table A-7). For example, populations from Park City Golf Course at 2088 meters was determined to be the most perennial (mean=2.7), while populations from the St. George Golf Club at 838 meters was determined to be the most annual (mean= 3.3).

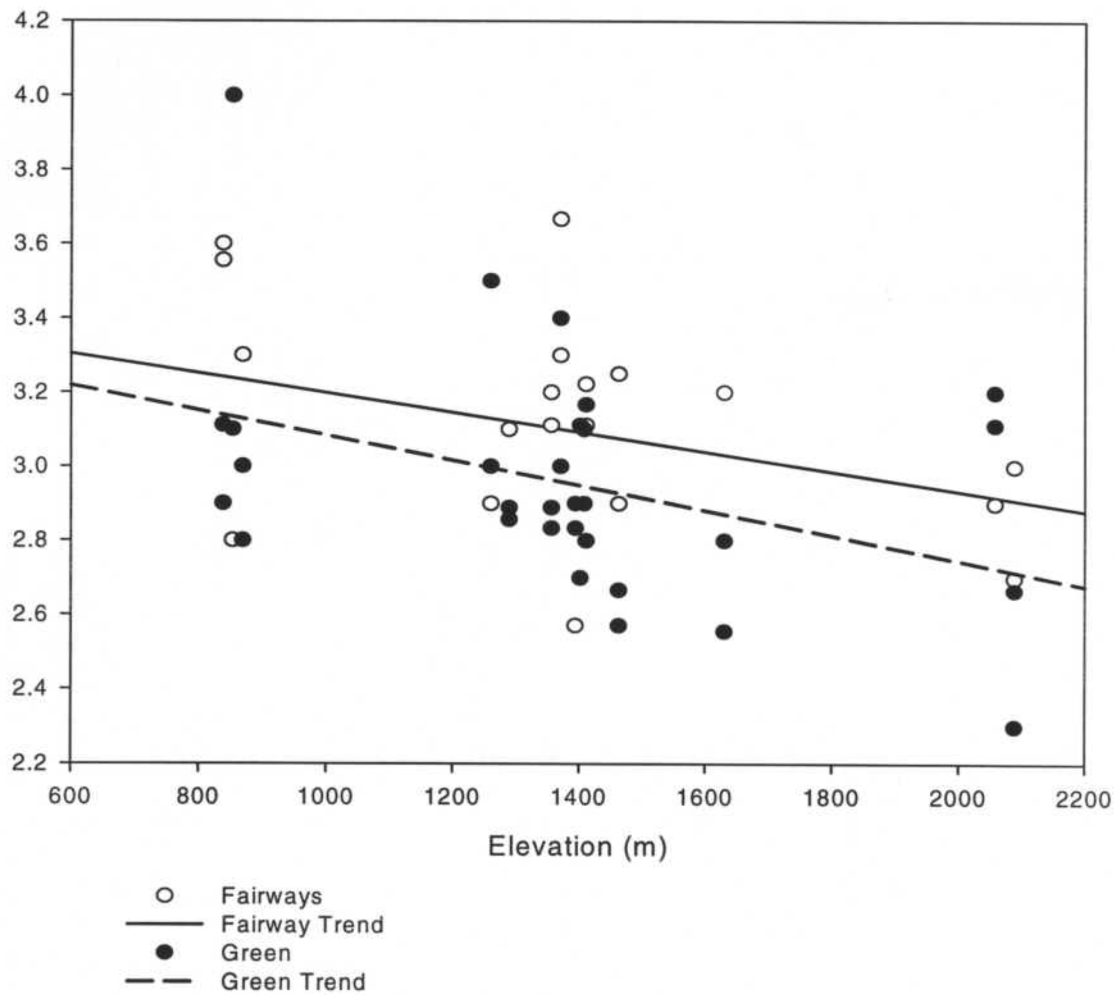

Figure 3-2. Relationship of putting green and fairway perenniality ratings of *P. annua* populations with elevation.

Ecological diversity in Utah is enormous and classification into four regions may not be realistic. The state is made up of arid deserts and canyonlands, semi-arid shrublands, irrigated valleys, salt flats, wetlands, woodlands, forested mountains, and glaciated peaks. The Modified Koppen System (MKS) characterizes climate types according to vegetation, temperature, and precipitation patterns (Greer et al., 1981). This system limits the make up of Utah's climatic regions to four broad and general categories. Thus, the alpine ecosystem of the high Uinta Mountains (3,657 meters) is classified into the same climatic region, the Undifferentiated Highlands, as the town of Eden, UT (1524 meters), even though they are two different ecological systems. Numerous ecological systems exist within these climatic regions; therefore a more detailed classification system is needed.

Poole et al. (in press) evaluated greens-type *P. annua* by designating 78 golf course sites in the Pacific Northwest into "six climatic regions by unweighted pair-group method using arithmetic averages (UPGMA) cluster analysis based on long-term data for temperature, rainfall, snowfall, and growing degree days from 26 weather stations in close proximity to the golf course collection sites." They found a high amount of diversity in their collection which was influenced by climatic factors. Categorizing climatic regions using this method has shown some promise and might warrant further investigation.

Prevailing environments exert strong pressure on *P. annua* populations which result in life history variation among the populations (Law et al., 1977). However, this study did not detect effects of, in this case, climatic regions. Golf courses are highly managed environments with similar mowing, irrigations, and other management practices which likely reduce possible climatic selection pressures. Although conditions the golf course turf plants experience from location to location may not have been as large as expected across Utah, there is variation in microenvironments within each golf course, specifically putting greens and fairways.

Turf Type Effects

Poa annua populations from putting greens and fairways showed marginally significant differences (p>0.06; Table 3-1) when compared within climatic regions (Fig. 3-3). However, when grouped into elevation categories, perenniality rating mean differences were significant (p>0.025; Table A-7). In the greenhouse experiments, plants from the putting green populations produced flowers 17.2 days after propagation compared to 19.4 days for the fairway populations, however these are not significantly different (p>0.66; Table A-5). Putting green populations averaged 5.33 inflorescences per plant while fairway populations averaged 3.91 inflorescence per plant, however these are not significantly different (p>0.59; Table A-6).

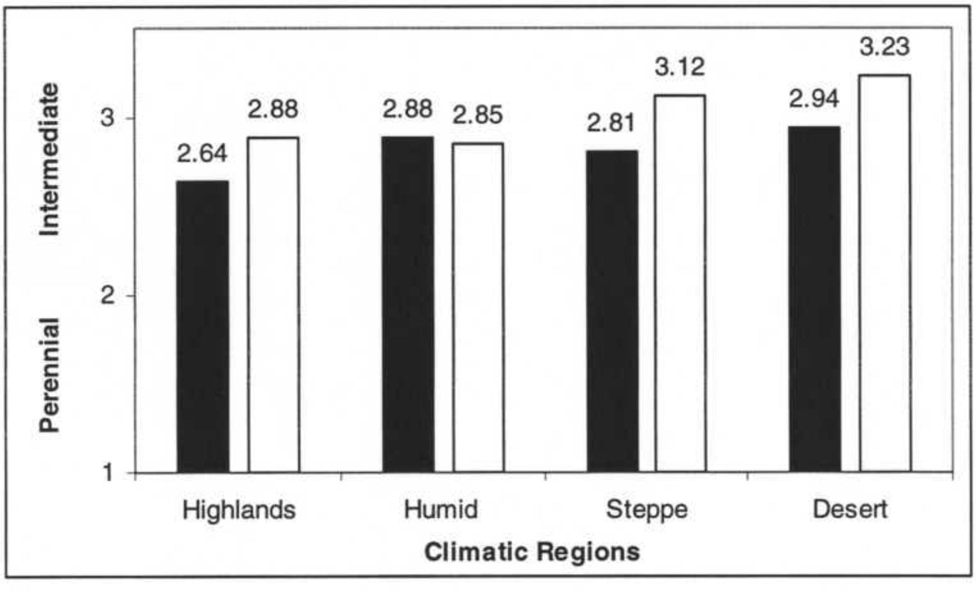

Figure 3-3. Mean perenniality rating comparisons between golf course putting greens and fairways and climatic regions.

Till-Bottraud et al. (1990) concluded green and rough populations differed significantly for all traits except growth characters at maturity. They also reported at maturity, reproductive characters were greater in rough populations while the number of vegetative tillers was greater in green populations. This study has shown marginal statistical difference in life history traits between green and fairway populations when grown in a common garden. The greenhouse experiment comparing days-to-flowering and inflorescence production of greens and fairways yielded no observed differences.

Golf course management practices create distinctly different microenvironments represented by the putting green, fairway, and rough areas. Cline (2001) stated a complexity of selection pressures resulting from different intensities of management are most likely at work in these environments including mowing height, nutrition, watering, compaction, and soil temperature. Cline (2001), Till-Bottraud et al. (1990), and Wu et al. (1987) claim a gradient of selection pressures exist among the three micro-environments. However, there is still some debate as to which micro-environment is the harshest or most stable.

Lush (1989) and Till-Bottraud et al. (1990) described putting green populations to be more perennial. Cline (2001) concluded putting green populations from a golf course in Minnesota to be annual. In this study, populations from the putting green and fairway environments could not be described as perennial or annual, but rather, intermediate in nature. A small collection of rough populations sampled for a related study shows them to be more annual like (Table A-8), indicating a gradient may exist between the three micro-environments of the golf course.

Golf Course Effects

Golf courses were evaluated and rated on a scale of 1-10 (10= high) according to maintenance practices, budget, and aesthetics. According to this study, there was no significant difference (Table A-9) between moderately and highly maintained golf courses for either a perennial or an annual plant. Most populations collected exhibited traits of the intermediate type plant (Table 3-2). Course age was not a significant factor ($p>.85$) (Table A-10) in determining life history traits of *P. annua*. The oldest course, 115 years of age, had plants more perennial than average (mean=2.82), but the youngest course in the collection at 7 years of age (mean=2.89) was similar.

Table 3-2. Regional and golf course mean perenniality ratings for *P. annua* populations.

Region	Golf Course	Greens Rating	Fairway Rating	Overall Rating
Undifferentiated Highlands		2.64	2.88	2.76
	Park City Golf Course	2.47	2.84	2.66
	Park Meadows Country Club	3.15	3.05	3.10
	Wolf Creek Golf Course	2.55	3.00	2.85
Humid Continental		2.88	2.85	2.86
	Country Club, The	2.88	2.76	2.82
	Hidden Valley Country Club	3.00	3.17	3.10
	Ogden Golf & Country Club	2.87	3.16	3.03
	Thanksgiving Point Golf Course	2.89	†	‡
Steppe		2.81	3.12	2.98
	Logan Golf & Country Club	2.62	3.00	2.81
	Logan River Golf Course	3.05	3.30	3.24
Desert		2.94	3.23	3.04
	Delta Golf Course	3.00	†	‡
	Dixie Red Hills Golf Course	3.31	2.95	3.09
	Green Spring Golf Course	2.88	3.30	3.11
	Moab Golf Course	3.28	2.94	3.11
	St. George Golf Club	3.00	3.58	3.29
	Wingpointe Golf Course	2.88	3.00	2.94

† No populations collected for examinations

‡ No population mean

Green Spring Golf Greens

Results of perenniality comparisons among two putting greens at Green Spring Golf Course are noticeably different when evaluated for days-to-flower and inflorescence production. Although these two putting greens are in close proximity, ~1 km, life history traits of collected plants differ significantly. The mean days-to-flower for Green #7 and Green #16 were 29.5 and 16.2, respectively. The mean inflorescence production for these greens was 1.25 and 19, respectively (Table 3-3). Green #16 lies on a hillside while green #7 lies in a valley bottom, possibly two differing micro-environments.

Table 3-3. Life history comparisons between two Green Spring Golf Course putting greens.

Green	Perenniality Rating	Days-to-flower† Rep 1	Rep 2	Rep 3	Inflorescence‡ Rep 1	Rep 2	Rep 3
#7	3	16.7	31.7	40	2.75	1	0
#16	2.8	11.56	16.8	20.3	12	29	16

† Days-to-flower calculated as the number of days between removal from the vernalization chamber and emergence of the first inflorescence from the plant.
‡ Inflorescence calculated as the total number of seedheads formed during a 40 day period.

Evolution of life history strategies has been observed within localized areas. Different ecotypes or populations may arise as close as one meter away (Cline, 2001). Bradshaw (1982) found 'species broken into vast arrays of small populations which are so small in diameter that they can match the size of extremely localized variations of the environment, variation even over a distance of a few meters. The Green Spring example shows life history strategies of collected populations may have evolved differently in response to varying environments which are in close proximity, a few hundred meters. The reasons for these differences however, are unknown.

Although variations occur randomly, similar ecological circumstances sometimes yield uncannily similar adaptations. Turesson (1922) concluded species with widespread distribution have variable genotypes when measured by morphological characteristics. He further stated plants growing under different climatic conditions exhibited phenotypic responses correlated with a particular habitat. This study concluded there were no correlations of habitat, micro or macro, and growth habits.

CHAPTER IV

SUMMARY AND CONCLUSIONS

Around the globe, *Poa annua* L. is an important turfgrass species on many golf course greens and fairways, but seldom is it planted purposely as a turfgrass (Huff, 1999a; Johnson et al., 1998; Vargas & Turgeon, 2004). Despite various efforts to eradicate the species, *P. annua*, in particular var. *reptans,* has become the most prevailing turfgrass species of many moderate and highly maintained golf courses (Huff, 1999b). Variation within the species has allowed for the evolution of life history differences. The annual type, var. *annua*, is associated with less intensely managed areas (Heide, 2001) and the perennial type, var. *reptans*, is usually associated with golf course greens and fairways, and cooler climates of temperate regions (Johnson & White, 1993; Heide, 2001). These two classifications are the most evident types of *P. annua*, but Johnson et al. (1997a) showed a continuum of ecotypes exist, all of which interbreed making further classifications complicated and difficult. *P. annua* is highly variable in terms of turf quality, but can grow well in environments favorable for its growth.

The objectives of this study were to:

1. Examine life history traits of *P. annua* L. populations on golf courses in four climatic regions in the state of Utah.
2. Examine life history traits of *P. annua* L. populations between golf course putting greens and fairways.

P. annua samples from golf courses in four climatic regions of Utah were planted in a common garden and in an environmentally controlled greenhouse. The collection was evaluated to determine whether or not varying micro- and macroclimatic conditions in regions and golf courses influence the evolution of different life history traits. Perenniality ratings, days-to-flower, and inflorescence production were evaluated and then related to the climatic origin of the samples to determine regional climatic effects on *P. annua* diversity. Also, plants grown from seed and tillers from the parent selections were subjected to various analyses.

Average life-history traits of *P. annua* populations were not determined to be different among the collections in this study--even when those plants had evolved in different climatic regions, microclimates, and management regimes. Some of these populations existed in close proximity and developed, in some cases, over a 115 year period. Populations from putting greens have typically been described as perennial (Lush, 1989; Till-Bottraud et al., 1990), but in some cases, populations from putting greens have been described as annual (Cline, 2001). This study indicates neither the putting green nor fairway populations are perennial or annual dominant, therefore being described as intermediate. Results of this study should be considered specific to the areas of collection.

A majority of the putting green and fairway populations monitored were characterized as intermediate, perennial plants with a variety of vegetative growth habits (dense and compact, tall and thin), but producing a prolific amount of inflorescence and seed. Statistical comparisons of life history traits between these microenvironments were marginally significant. Most fairway populations produced inflorescences the entire growing season while some green populations produced little to no inflorescences while having a dense and compact growth habit.

Three conclusions can be drawn from this study:

First, the selective forces applied by intensive golf course management practices on *P. annua* L. populations may overwhelm the selective forces applied by the climate.

Second, gene flow may readily occur between the putting green and fairway microenvironments through means of intensive golf course management practices, foot traffic, and natural occurrence. Therefore, *P. annua* populations can neither be described as annual or perennial dominant but can be described as primarily as intermediate.

Third, elevation may be considered a factor in determining life history traits of *P. annua* but elevation could be confounded with other environmental factors.

Knowing whether annual or perennial forms exist on a golf course, turf managers might be able to adjust management practices to reduce inputs such as water, fertilizers, time, and pesticides to favor the desirable forms that exist. Plant breeding programs might be able to develop greens-type *P. annua* with specific traits more rapidly for superior turfgrass quality. Our knowledge of *P. annua* biology and culture is far from complete. More studies are needed in order to understand what environmental or management factors are responsible, if any, for adaptation and genetic differentiation in *P. annua* at the micro-climatic level. Recommendations for future research are:

Larger sample sizes should be collected and be more indicative of the entire golf course. Sampling from numerous greens, fairways, tees, and rough areas is highly important.

Exact location of each plant should be noted, i.e. center of green, clean-up cut, apron, landing area, etc. and monitored for life history traits.

Plants for the field experiment should be grown from seed of collected plants in order to exclude other turfgrasses from the samples and allow for each plant to be evaluated from the same stage of growth and age.

Once plants are established and well grown, tillers and seed from each field plant should be propagated and kept for re-establishment.

Evaluations should be based according to climatic region maps categorized using the latest data for temperature, precipitation, elevation, and growing degree days.

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APPENDIX

Table A-1. Definitions of ecological terms.

Term	Definition
Biotype	Genotypic race or group of organisms
Community	Population of all the species (insects, animals, plants, humans) living in the habitat
Ecospecies	Biological group comprising of organisms fully fertile among themselves but only weakly fertile with members of allied groups
Ecosystem	Community and its environment with two major components; the living (biotic) and non-living (abiotic)
Ecotype	Subdivision of an ecospecies that maintains its identity through isolation and environmental selection
Environment	Aggregate of all the external conditions and influences affecting the life and development of an organism
Genotype	Genetic makeup of each individual
Habitat	Space where an individual lives
Population	Group of individuals of the same species occupying the habitat
Niche	Entire range of resources and conditions in which a species can live and reproduce

Source: Danneberger, 1997; Webster's Dictionary, 2003

Table A-2. Location of golf course and turf areas sampled.

Location	Address	Elevation (m)	Turf type	Sample site
Undifferentiated Highlands				
Park City Golf Course	Park City	2088	Green	# 4 & 12
			Fairway	# 4 & 12
Park Meadows Golf Course	Park City	2057	Green	# 5 & 17
			Fairway	# 5 & 17
Wolf Creek Golf Course	Eden	1630	Green	# 3 & 5
			Fairway	# 3 & 5
Steppe				
Logan Golf and Country Club	Logan	1463	Green	# 11 & 18
			Fairway	# 7 & 17
Logan River Golf Course	Logan	1371	Green	# 3 & PG†
			Fairway	# 10 & 16
Humid Continental				
Hidden Valley Golf Course	Sandy	1411	Green	# 8 & 13
			Fairway	# 14 & 17
Ogden Golf & Country Club	Ogden	1356	Green	# 8 & 10
			Fairway	# 10 & 14
Country Club, The	SLC‡	1394	Green	# 10 & 17
			Fairway	# 16 & 17
Thanksgiving Point GC	Lehi	1402	Green	# 12 & PG
Desert				
Dixie Red Hills	St. George	853	Green	# 5 & 9
			Fairway	# 5 & 9
Green Spring Golf Course	Washington	869	Green	# 7 & 16
			Fairway	# 7 & 16
Moab Golf Course	Moab	1260	Green	# 9 & 18
			Fairway	# 8 & 18
St. George Golf Club	St. George	838	Green	# 9 & 17
			Fairway	# 10 & 17
Sunset View Golf Course	Delta	1408	Green	# 1 & 8
Wingpointe Golf Course	SLC	1289	Green	# 9 & 18
			Fairway	# 9 & 18

‡SLC- Salt Lake City †PG- practice green

Table A-3. Summary of management practices on greens at the collection locations.

Course	Green Type†	Aerate	Hydroject Freq.	Mowing Regimen	Mower Type	Vert.	Spike	PGR	Topdress Freq.	Fertilizer Program
Logan G&CC	N	1x‡	1x	6-7 days, 3mm	Hand	Yes	No	Yes	4 week	Spoon, Some granular
Logan River	USGA	1x	1x	6-7 days, 3mm	Tri	Yes	No	Yes	2 week	118ml/M Gary's Grn, some granular
Ogden G&CC	N	1x	N	6-7 days, 3mm	Tri	Yes	Yes	Yes	4 week	Spoon, Some granular
Wolf Creek	N	1x	3x/ Yr	6-7 days, 3mm	Tri	Yes	Yes	Yes	3 week	Spoon, Some granular, 4lbs N/M/Yr
The Country Club	N	2x	2 weeks	6-7 days, 3mm	Hand	Yes	Yes	Yes	7-10 days	Spoon, Some granular, 4lbs N/M/Yr
Wingpointe	USGA	1x	N	6-7 days, 4mm	Tri	Yes	No	Yes	4 week	118ml/M Gary's Grn, some granular
Hidden Valley	N	1x	3-4 weeks	6-7 days, 3mm	Both	Yes	No	Yes	2 week	Spoon, 2lbs N granular
Thanksgiving Point	USGA	1x	3-4 weeks	6-7 days, 3mm	Hand	Yes	Yes	Yes	2 week	Spoon, Some granular, 4lbs N/M/Yr
Park City GC	N	1x	1x	6-7 days, 3mm	Tri	Yes	No	Yes	4 week	1.8kg N/M/Yr
Park Meadows	N	1x	3x/ Yr	6-7 days, 3mm	Both	Yes	Yes	Yes	2 week	Spoon, Some granular, 4lbs N/M/Yr
Moab GC	N	1x	N	6-7 days, 3mm	Tri	Yes	No	Yes	2 week	1.36kg N/yr, Fe!
Dixie Red Hills	N	2x	N	6-7 days, 3mm	Tri	Yes	No	Yes	4 week	1.36 N/yr
Green Spring	USGA	2x	3-4 weeks	6-7 days, 3mm	Tri	Yes	No	Yes	2 week	1.8kg N/M/Yr
Sunset View GC	N	1x	N	6-7 days, 3mm	Tri	Yes	No	Yes		1.8kg N/M/Yr
St. George CC	N	1x	3-4 weeks	6-7 days, 3mm	Both	Yes	Yes	Yes	3-4 weeks	Spoon, Some granular

†N- Native Soil
USGA- USGA Green Specifications

‡ 1x = 1 time per year

Tri- Triplex mower
Hand- Walk-behind mower

Table A-4. Summary of management practices on fairways at the collection locations.

Course	Fairways Sampled	Soil†	Aerate	Clippings Returned	Mowing Regimen	PGR Appl.	Topdress Frequency	Fertilizer Program
Logan G&CC	7, 17	N	AN	Yes	3 days @ 12.7mm	Yes	AN	1.35-1.8kg N/ Yr
Logan River GC	10, 16	N	1x ‡	Yes	4 days @ 12.7mm	No	Bi-annual	1.35-1.8kg N/ Yr
Ogden G&CC	10, 14	N	AN	Yes	5 days @ 12.7mm	Yes	AN	1.35-1.8kg N/ Yr
Wolf Creek GC	3, 5	N	1x	Yes	4 days @ 16mm	Yes	2-3 weeks	1.35-1.8kg N/ Yr
Country Club, The	16, 17	N	1x	Yes	5 days @ 12.7mm	Yes	2-3 weeks	1.35-1.8kg N/ Yr
Wingpointe GC	9, 18	Alk	AN	Yes	3 days @ 19mm	Yes	Spot	1.35-1.8kg N/ Yr
Hidden Valley CC	14, 17	N	1x	Yes	4 days @ 19mm	Yes	AN	1.35-1.8kg N/ Yr
Park City GC	4, 12	N	1x	Yes	5 days @ 12.7mm	No	AN	1.35-1.8kg N/ Yr
Park Meadows CC	5, 17	N	1x	Yes	6 days @ 12.7mm	Yes	AN	1.35-1.8kg N/ Yr
Moab GC	8, 18	N	AN	Yes	7 days @ 12.7mm	Yes	Spot	1.35-1.8kg N/ Yr
Dixie Red Hills GC	5, 9	RBS	AN	Yes	3 days @ 13mm	No	AN	1.1kg N/Yr
Green Spring GC	7, 16	RBS	1x	Yes	6 days @ 12.7mm	No	AN	1.6-1.8kg N/Yr
St. George CC	10, 17	N	1x	Yes	7 days @ 12.7mm	Yes	AN	1.35-1.8kg N/ Yr

†N- Native Soil AN- As Needed RBS- Red Blow Sand
Alk- Alkali Soil PGR- Plant Growth Regulator ‡ 1x = 1 time per year

Table A-5. ANOVA for Experiment 2: Analysis of region and turf-type effects on days-to-flowering of *Poa annua* populations.

Source	Num df	Den df †	F	p
Region	3	11.5	1.23	.3441
Turf Type	1	37.4	.20	.6561
Region* Turf Type	3	37.6	.35	.7891

†Kenward-Rogers method used to obtain Denominator degrees of freedom

Table A-6. ANOVA for Experiment 3: Analysis of region and turf-type effects on inflorescence production of *Poa annua* populations.

Source	Num df	Den df †	F	p
Region	3	11.2	.73	.5531
Turf Type	1	39	.30	.5897
Region* Turf Type	3	39.2	.26	.8571

†Kenward-Rogers method used to obtain Denominator degrees of freedom

Table A-7. ANOVA for Experiment 1: Comparison of *P. annua* populations from golf course putting greens and fairways with elevation.

Source	Num df	Den df †	F	p
Elevation	14	466	2.32	.0042
Turf Type	1	466	5.07	.0248
Elevation* Turf Type	12	466	1.46	.1374

†Kenward-Rogers method used to obtain Denominator degrees of freedom

Table A-8. Perenniality ratings of *Poa annua* plants collected from golf course roughs.

Course	Hole	Rating
Dixie Red Hills GC	1	5
Dixie Red Hills GC	1	4
Dixie Red Hills GC	5	5
Dixie Red Hills GC	5	4
Dixie Red Hills GC	9	5
Dixie Red Hills GC	9	5
Dixie Red Hills GC	9	5
Dixie Red Hills GC	9	4
Green Spring GC	10	4
Green Spring GC	10	4
Green Spring GC	10	5
Green Spring GC	10	5
Green Spring GC	10	4
Green Spring GC	16	5
Green Spring GC	16	4
Green Spring GC	16	5
Green Spring GC	16	5
St. George CC	9	5
St. George CC	9	5
St. George CC	9	5
St. George CC	9	4
St. George CC	17	5
St. George CC	17	5
St. George CC	17	5
St. George CC	17	5
St. George CC	17	5

Table A-9. ANOVA for Experiment 1: Analysis of region and golf course maintenance effects on perenniality of *Poa annua* populations.

Source	Num df	Den df †	F	p
Region	3	4	2.41	.2072
Maintenance	6	4	1.44	.3768
Region* Maintenance	1	4	.43	.5486

†Kenward-Rogers method used to obtain Denominator degrees of freedom

Table A-10. ANOVA for Experiment 1: Analysis of region and age effects on perenniality of *Poa annua* populations.

Source	Num df	Den df †	F	p
Region	3	4	2.78	.1739
Age	3	4	.26	.8528
Region* Age	4	4	2.95	.1596

†Kenward-Rogers method used to obtain Denominator degrees of freedom