THE SEED BIOLOGY OF *FRANKENIA JOHNSTONII* CORRELL (FRANKENIACEAE)

THESIS

Presented to the Graduate Council of
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For the Degree of

Master of Science

By

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INTRODUCTION

The importance of biological diversity has received much attention in recent years. In 1991, the Ecological Society of America listed biodiversity as an area of highest research priority (Lubchenco, 1991). Biodiversity allows for a greater variety of genetic material in a population, which increases the likelihood of species being able to adapt to environmental change. Without a pool of genetic diversity, adaptation may not be possible and extinction could occur. A report from the Center for Plant Conservation (1988) identified 253 plants in the United States that may go extinct in five years and another 427 that may go extinct in ten years. Three-fourths of these species occur in only five states or territories: California, Florida, Texas, Hawaii and Puerto Rico. Texas lists 23 plant species as endangered and five as threatened (TPWD, 1997).

Maintaining biological diversity requires an understanding of the biology of the species to be preserved. Unfortunately, little is known about the reproductive biology of most rare plants (Karron, 1991). Conservation of rare or endangered plant species has, in the past, been based on animal models due to the paucity of research on reproductive biology of rare or endangered plant species appearing in the scientific literature (Falk and Holsinger, 1991). Most plant conservation programs focus on habitat preservation that involves knowledge of the demographic features, such as population size and growth rates. However, demographic features provide only limited information because long-term survival of endangered species depends on gene flow (Barrett and Kohn, 1991). In plants, genetic variability depends on two mechanisms of gene flow, the seed and pollen.

An understanding of seed biology is critical in evaluating the survival of an endangered plant species. Determining percent seed viability and seed set is crucial in evaluating long-term survival rate. Because of the genetic challenges to the long-term survival of rare plants, persistent seed banks could be of particular importance (Falk and Holsinger, 1991). Soil seed banks act as genetic reservoirs and are of importance because they affect evolutionary potential of plant populations (Templeton and Levin, 1979; Brown and Venable, 1986; Levin, 1990; Kalisz and McPeek, 1993; McCue and Holtsford, 1998). Seed banks could positively alter long-term population growth rates (Cohen, 1966; Kalisz and McPeek, 1992), and could place restraints on possible extinction time (Kalisz and McPeek, 1993).

Recruitment and establishment of the seedling are crucial for maintaining high population numbers of species that regenerate by seed. There can be high mortality rates of seedlings due to desiccation and burial of seedlings, particularly in arid or sand dune areas. Biotic factors, such as predation, disease and competition, also play a role in seedling mortality. Sometimes seedlings are lost because germination occurs too far below the soil surface for emergence to be possible. Seedlings can also be lost to grazing. Seed dispersal can affect seedling establishment. Suitable safe sites for seeds might be in the vicinity of the parent plant rather than farther away; this is often true of desert plants (Ellner and Shmida, 1981).

Genetic variability can be decreased if a species contains only a few individuals. Reproductive strategy is important in the distribution of genetic variation, but it can also affect population size (Lande and Barrowclough, 1987; Center for Plant Conservation, 1991; Menges, 1991; Given, 1994; Weller, 1994). Small numbers of individuals can lead to inbreeding depression resulting in an increase in homozygosity which can lead to a decline in vigor (Ellstrand, 1992). Stochastic events can further reduce population size (McCue and Holtsford, 1998). Even if protected by law, survival of rare or endangered plants may be impossible due to low numbers of individuals of a species and lack of genetic variability if there is no persistent seed bank.

Therefore, an understanding of the reproductive biology of a particular plant species is critical to understanding factors that result in species rareness, in determining the classification of a species as rare or endangered and in constructing a management program for long-term survival. This study is concerned specifically with reproductive biology of the endangered halophyte *Frankenia johnstonii* Correll (Caryophyllidae: Frankeniaceae).

About 80 species are recognized in the family Frankeniaceae with most species occurring in the genus *Frankenia* (Whalen, 1987). There are 14 American species of *Frankenia,* three of which occur in the United States; *F. salina* (Molina) I. M. Johnston in California, *F. jamesii* Torr. and *F. johnstonii* in Texas (Whalen, 1987b). *Frankenia johnstonii* is an endemic perennial shrub (Figure 1) that occurs on open or sparsely vegetated areas on saline clays or sands in Starr, Webb and Zapata Counties of South Texas and Nuevo León, Mexico. It is the only endangered or threatened taxon of the genus. This species was listed as federally endangered on August 7, 1984 (United States Fish and Wildlife Service, 1984) and state endangered on March 5, 1987 (Texas Parks and Wildlife Department, 1987).

Frankenia johnstonii was first collected by Correll in 1966 from a single population in Zapata County, Texas. That same year, he named and described this plant as a new species in honor of M. C. Johnston, hence the common name Johnston's Frankenia (Correll, 1966). Correll and Johnston (1979) describe *F. johnstonii* as a woody shrub reaching 3 dm in height and

Figure 1. Growth habit of *Frankenia johnstonii*.

having a dark-brown, woody taproot system that gives rise to elongated, ascending recurved stems; leaves are bluish-green, small, to 13 mm long and 4 mm wide, distinctly petioled with margins revolute; upper leaf surfaces are covered with short, white trichomes; flowers are sessile and occur singly at the apex of axillary branchlets; flowers are small, white and have 5 sepals, 5 clawed petals, 6 stamens and styles that are 3-cleft. The ovary is compound, formed from three carpels with a 3-cleft style. The fruit is a small (2.8-3.5 mm long, 1.2-1.4 mm wide), single-celled capsule (Figure 7).

In 1973, Turner described *Frankenia leverichii* from a population located north of Monterrey, Mexico (Turner, 1973). According to Whalen (1987b), only trivial characters distinguished *F. johnstonii* and *F. leverichii.* Therefore, she gave *F. leverichii* varietal status under *F. johnstonii.*

Texas populations of *F. johnstonii* occur on open or sparsely vegetated rocky, gypseous hillsides or saline flats in the South Texas Plains vegetation zone (United States Fish and Wildlife Service, 1988). *F. johnstonii* occupies a very specific niche in the Tamaulipan thornscrub, inhabiting saline areas, an edaphic environment difficult for most plants to colonize. The dominant community type is thorny scrubland, with associated vegetation mostly saline shrubs and herbs, such as *Isocoma drummondii* T. & G. and the halophytic grass, *Sporobolus pyramidatus* Lam. Other associated vegetation include members of the Cactaceae such as *Ancistrocactus sheeri* Salm-Dyck, *Opuntia engelmannii* Engelm. and *O. leptocaulis* DC.; composites such as *Varilla texana* Gray and *Isocoma coronopifolia* (Gray) Greene; and members of the Fabaceae, *Acacia berlandieri* Benth., *A. rigidula* Benth., *Prosopis glandulosa* Torr., and *Larrea tridentata* (DC.) Coville, a member of the Zygophyllaceae (Janssen, personal communication).

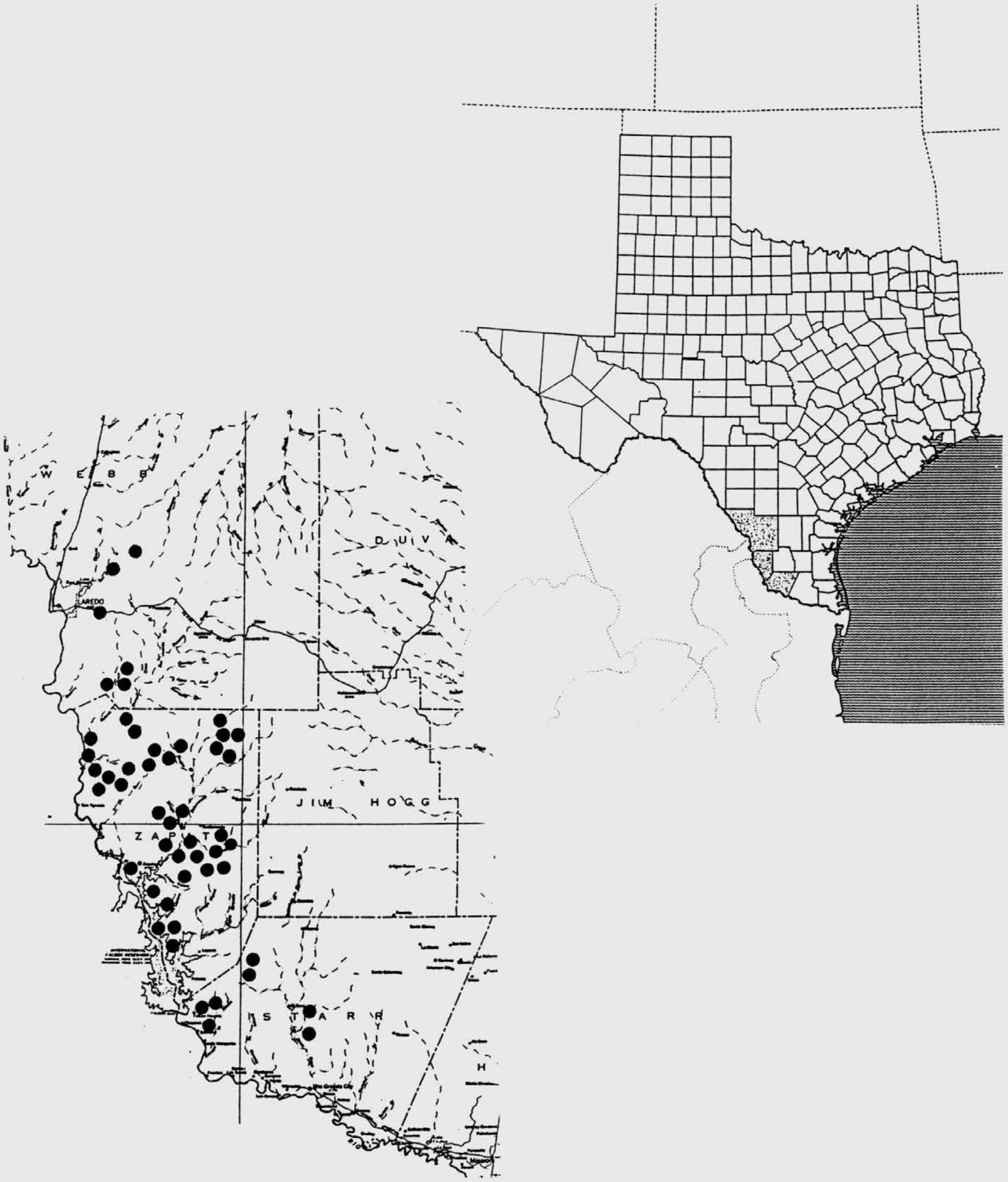

Figure 2. County map of Texas indicating documented population sites of *Frankenia johnstonii* in 1998.

In 1980 only five populations of *F. johnstonii* were known in Texas: two located in Zapata County and three in Starr County (Turner, 1980). There was also one known population in Nuevo Léon, Mexico (Janssen and Williamson, 1994). Today about 50 populations are documented (Figure 2), with about 80% of the populations located in Zapata County (Janssen, personal communication).

A knowledge of reproductive biology is essential in evaluating causes of species rareness, yet the existing scientific literature offers little information concerning the reproductive biology of *F. johnstonii.* Whalen (1980) considered this halophytic plant a relatively primitive species with no close relatives, restricted to a highly specialized gypsiferous habitat and showing little propensity to reproduce. Turner (1980) noted difficulty in germinating seeds. Successful recovery and management of endangered plant species involves knowledge of underlying biological processes that affect population stability, such as duration in the seed bank, survivorship and fecundity (Pavlik, 1996a). Evaluating which factors are most responsible for the decline will aid in constructing a program aimed at recovery. Therefore, this study was undertaken to examine aspects of the reproductive biology of *F. johnstonii.*

The objectives of this study are to determine phenology and reproductive capacity; percentage seed set; seed viability; the presence or absence of a persistent soil seed bank; and seedling recruitment and establishment.

METHODS AND MATERIALS

Description of Study Sites

Data for this study were collected from three sites, two in Zapata County and one in Starr County, Texas (Figure 3). One of the populations studied in Zapata County is designated as Zapata County population A (Figures 3, 4) and is characterized by Tamaulipan thorn-scrub that opens up to saline flat almost 4.83 km long and 0.4 km wide populated by 30,000 to 50,000 plants of *F. johnstonii*. The soils in the area are of the Maverick-Catarina Complex underlain by the Jackson Group formation (Janssen and Williamson, 1994). The other population studied in this county is designated as Zapata County population B (Figures 3, 5) and consists of nine sub-populations with approximately 4,700 individuals. Soils in the area are of the Maverick-Catarina Complex, underlain by the Yegua geologic formation (Janssen and Williamson, 1994). The Starr County population (Figures 3, 6) studied is located just east of El Sauz. It consists of about 1,000 individuals scattered within a 0.2 km strip of land and is the most atypical of all the sites, having Copita fine sandy loam soils underlain by the Catahoula and Frio geologic formations (Janssen and Williamson, 1994).

Climatological Data

Climatological data for Zapata County and Starr County were obtained from the Department of Commerce National Climate Data Center based in Asheville, North Carolina. Monthly average means of precipitation and temperature were provided for the time period between January, 1993 through December, 1996. This information was used to determine

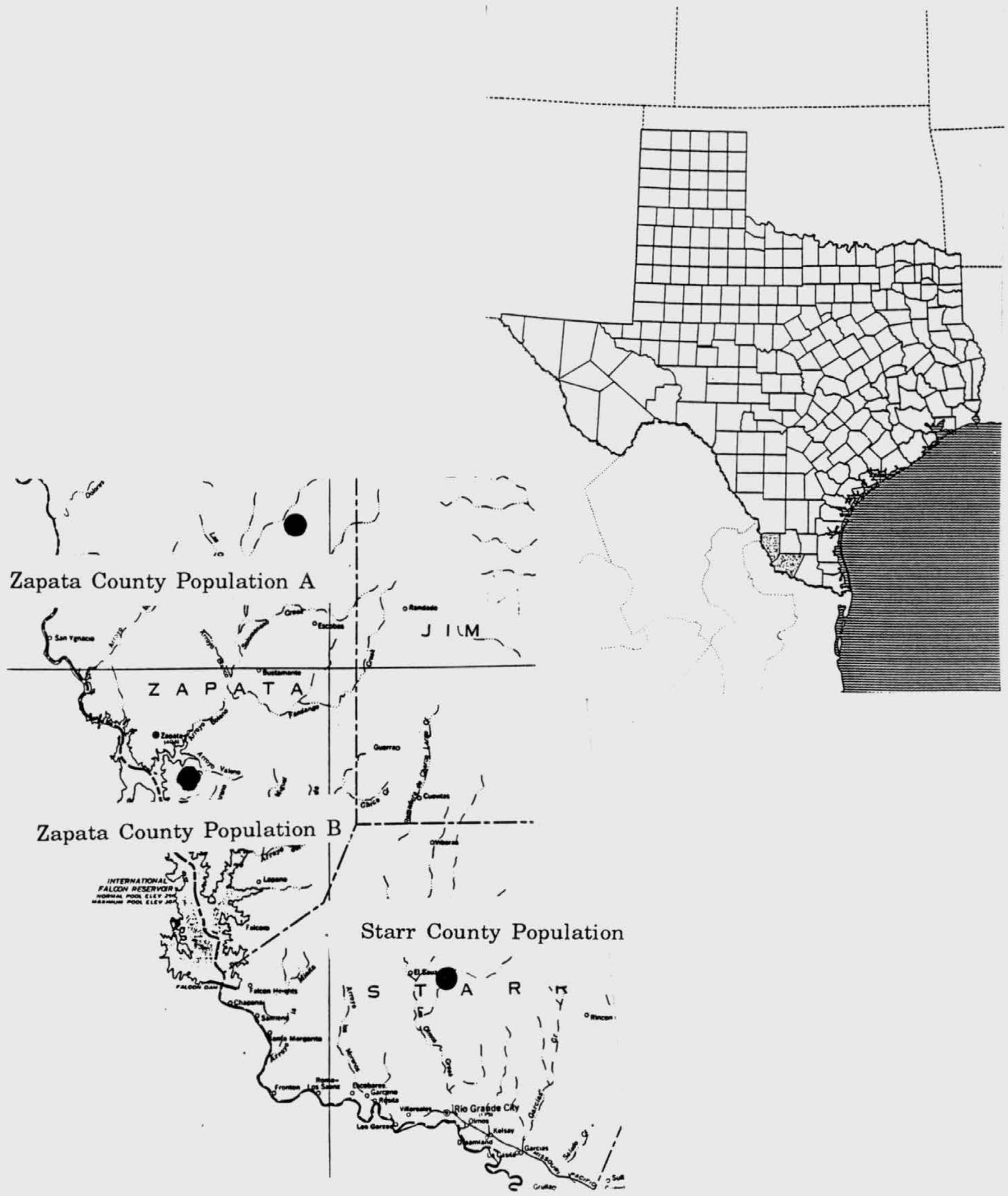

Figure 3. County map of Texas indicating locations of the three population study sites of *Frankenia johnstonii*.

Figure 4. Population site of *Frankenia johnstonii* in Zapata County, Texas designated population A.

Figure 5. Population site of *Frankenia johnstonii* in Zapata County, Texas designated population B.

Figure 6. Population site of *Frankenia johnstonii* in Starr County, Texas.

phenological trends of *F. johnstonii* associated with varying degrees of temperature and rainfall amounts.

Phenology and Reproductive Capacity

Seasonal trends in flowering and fruit production of *F. johnstonii* were monitored at Zapata County population A and the Starr County population using a technique for monitoring non-rhizomatous perennial plant species (Lesica, 1987). Two permanent belt transects were established each consisting of 50 adjacent 1 m^2 quadrats along one side of a 50 m tape stretched tightly between two pieces of iron reinforcing rod marking the starting and ending points. The quadrat side was to the left of the tape when looking from start point to end point. Two 1 m sticks marked in 10 cm increments were used to delimit each 1 m^2 quadrat. The tape acted as the bottom side of the quadrat. The meter sticks were moved along the tape as each quadrat was inspected. The number of individuals at the post-seedling stage, vegetative stage, at anthesis and in fruit were counted and recorded on data sheets monthly from July, 1993 to June, 1995. Data were not collected at either population in November, 1993, March, 1994, November and December, 1994. Data were also not collected in February, 1994, September-December, 1994 and May, 1995 at Zapata County population A. The populations occur on private property and landowner permission for access was not granted during those months. Data were correlated with climatological data to determine seasonal trends.

Seed Set

Fruits (n =87) of *F. johnstonii* (Figure 7) were collected from the Starr County population on November 11, 1995. Fruit collection was limited due to

Figure 7. Flowers and fruits of *Frankenia johnstonii*.

the endangered status of this species. Fruits were determined to be mature if they could be easily removed from the plant. The fruits were placed in paper bags and transported to the physiology laboratory at Southwest Texas University. To determine the percentage seed set, fruits were dissected and the number of mature seeds and the number of ovules that did not develop into seeds were counted. Due to the small size of the fruit, double-sided tape was used to hold the fruit in place on a microscope slide for dissection and examination.

Seed Viability

Seeds of *F. johnstonii* were tested for viability using the tetrazolium staining method (Grabe, 1970; Copeland, 1981). The seeds (n = 78) were dissected from capsules collected from the Starr County population in November, 1995. The seeds were placed in petri dishes, covered with a 0.1% tetrazolium solution and allowed to stand for one hour to ensure penetration of the stain. Embryos were considered viable if they stained red. Non-viable embryos do not stain.

Soil Seed Bank

To determine the presence or absence of a persistent seed bank for *F. johnstonii,* soil samples were collected from each of the three populations. Ten soil samples were taken from each site approximately every six weeks for one year. A 50 m transect was set up in an area of each population. The samples were selected randomly within a 10x10 m square on either side of the transect using a random numbers table. Samples were taken using an auger 5 cm in diameter. After removal of some of the surface litter, such as larger rocks and twigs the auger was inserted into the soil to a depth of 2.5 cm (Gross, 1981;

Thompson and Grime, 1979). Each of the ten soil samples from the 10x10 m plots was placed in a separate paper bag. The soil samples were then placed in flats about 2.5 cm deep to simulate field soil depth and kept in the greenhouse at Southwest Texas State University under conditions suitable for germination. Seed germination was monitored.

Seedling Recruitment

Seedling recruitment was monitored within the 50m belt transects established to study phenology and reproductive capacity (see above). Seedlings were defined as individuals with one to two small stems and a few leaves per plant. Seedling positions were mapped on a data form with corresponding boxes for each quadrat along the transect. Seedling recruitment data were recorded at each transect on a monthly basis over a two year period from July, 1993 to June, 1995.

RESULTS

Climatological Data

Climatological data for Zapata and Starr Counties, obtained from the National Climatic Data Center in Asheville, North Carolina is shown in Figures 8–11. Normal annual precipitation in Zapata County is 50.1 cm. Average annual rainfall in 1993 measured 47.2 cm, 49.2 cm in 1994, 39.9 cm in 1995 and 32.8 cm in 1996. Highest rainfall amounts in 1993 occurred in June and September, producing 15.7 cm and 10.8 cm respectively. In 1994, only April and September had precipitation amounts over 7 cm, with April reaching 9.1 cm and September recording 8.3 cm. Highest rainfall amounts in 1995 occurred in September, with 11.1 cm and in November, with 10 cm. In 1996, August showed a monthly rainfall average of 8.6 cm, the highest monthly amount of that year.

The average annual precipitation in Starr County is 56.6 cm. In 1993 the average annual rainfall was 66.9 cm, 30.7 cm in 1994, 43.3 cm in 1995 and 23.1 cm in 1996. Highest rainfall amounts in 1993 occurred in June producing 33.7 cm and September with 14.1 cm. In 1994, October produced the most rainfall with 7 cm. August, September and October of 1995 showed highest monthly rainfall amounts of 6.4 cm, 13.6 cm and 5.5 cm respectively. Highest recorded monthly precipitation for 1996 was 10.4 cm in August.

The normal annual average temperature in Zapata County is 23°C. The annual average temperature for 1993 was 22.9°C. No annual average was available for 1994. 1995 and 1996 had an annual mean temperature of 23.8°C. In 1993, June, July and August had maximum temperatures of 40°C, 38.9°C and 39.4°C respectively. October and November had temperatures below 0°C. May, June, July and August of 1994 had maximum temperatures of 37.8°C, 40.6°C, 41.1°C and 38.3°C respectively, representing the warmest months. Only February had below freezing temperatures for that year. Months in 1995 with temperatures exceeding 37.7°C occurred in April, May, June, July, August and September, with April experiencing 45.6°C. No months experienced temperature below 0°C in 1995. April through September of 1996 had days in which the temperature exceeded 37.7°C, with August reaching 41.7°C. January, February, March, November and December had days experiencing temperatures below 0°C.

Average annual temperature in Starr County is 23.3°C. Average annual temperature for 1993 was 23°C. Average annual temperature for 1994 was unavailable. 1995 had an average annual temperature of 23.6°C and in 1996 the annual mean was 24.4°C. April, June, July, August and September of 1993 had maximum temperatures of 37.7°C, 38.9°C, 38.3°C, 38.9°C and 38.9°C respectively. October and November had temperatures below freezing and one day in December experienced a temperature of 0°C. May, June, July and August of 1994 had temperatures above 37.7°C and only January showed below freezing temperatures. Temperatures exceeded 37.7°C in March through September of 1995, with May reaching 43.3°C No months showed below freezing temperatures, but January and February had temperatures reaching 0°C. In 1996, February through September experienced temperatures at or above 37.7°C, with the highest temperature of 42.8°C occurring in August. Below freezing temperatures of -5°C, -4.4°C and -5°C, respectively occurred in January, February and December.

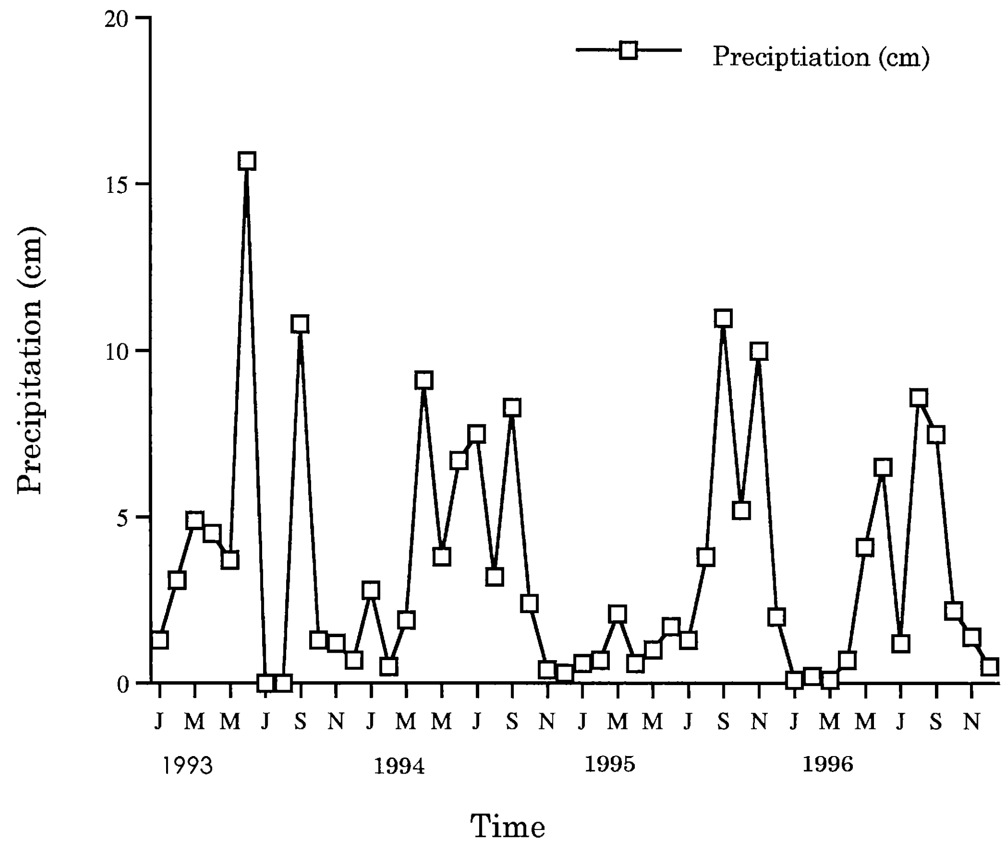

Figure 8. Average monthly rainfall in Zapata County from January, 1993 to December, 1996.

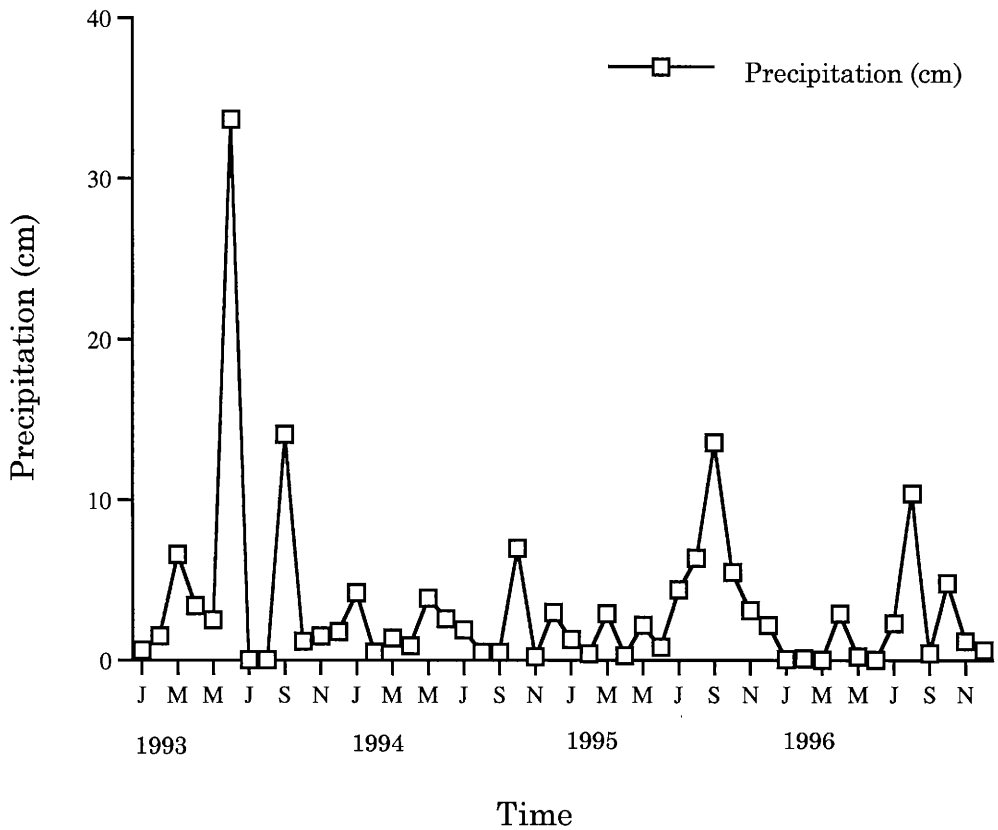

Figure 9. Average monthly rainfall in Starr County from January, 1993 to December, 1996.

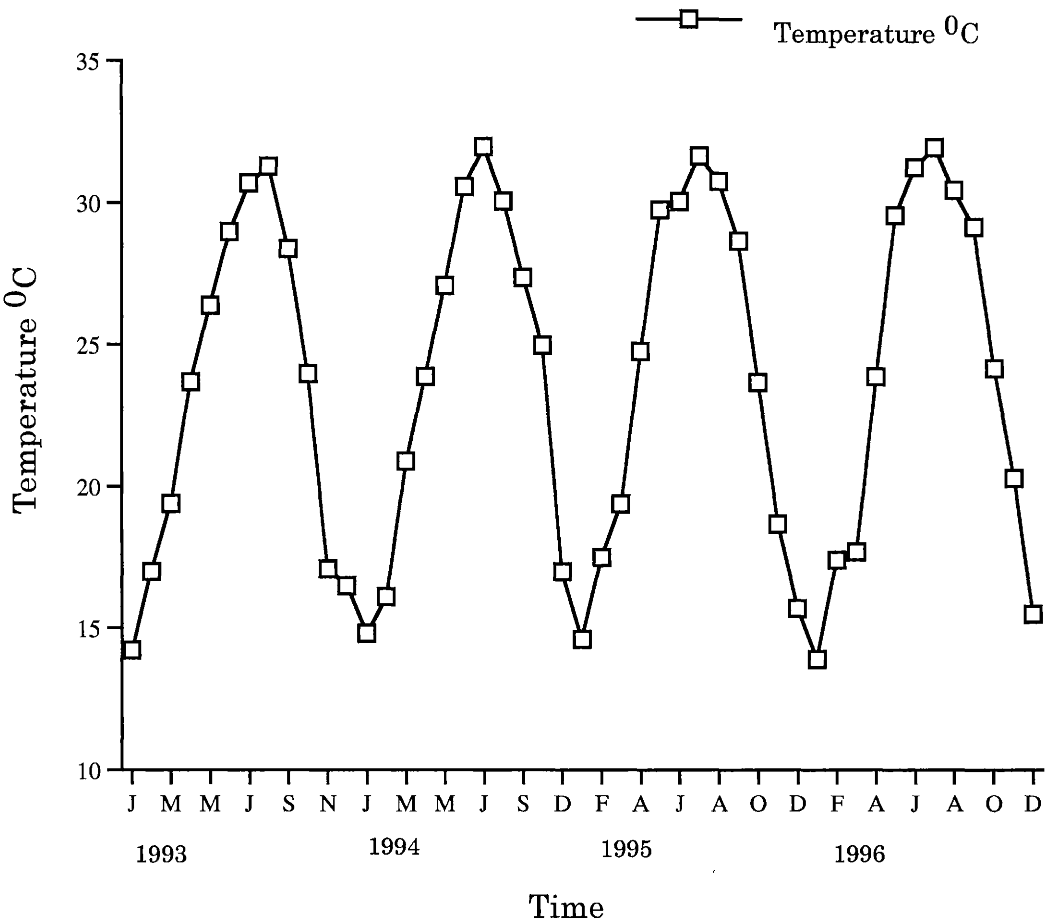

Figure 10. Average monthly temperature in Zapata County from January, 1993 to December, 1996.

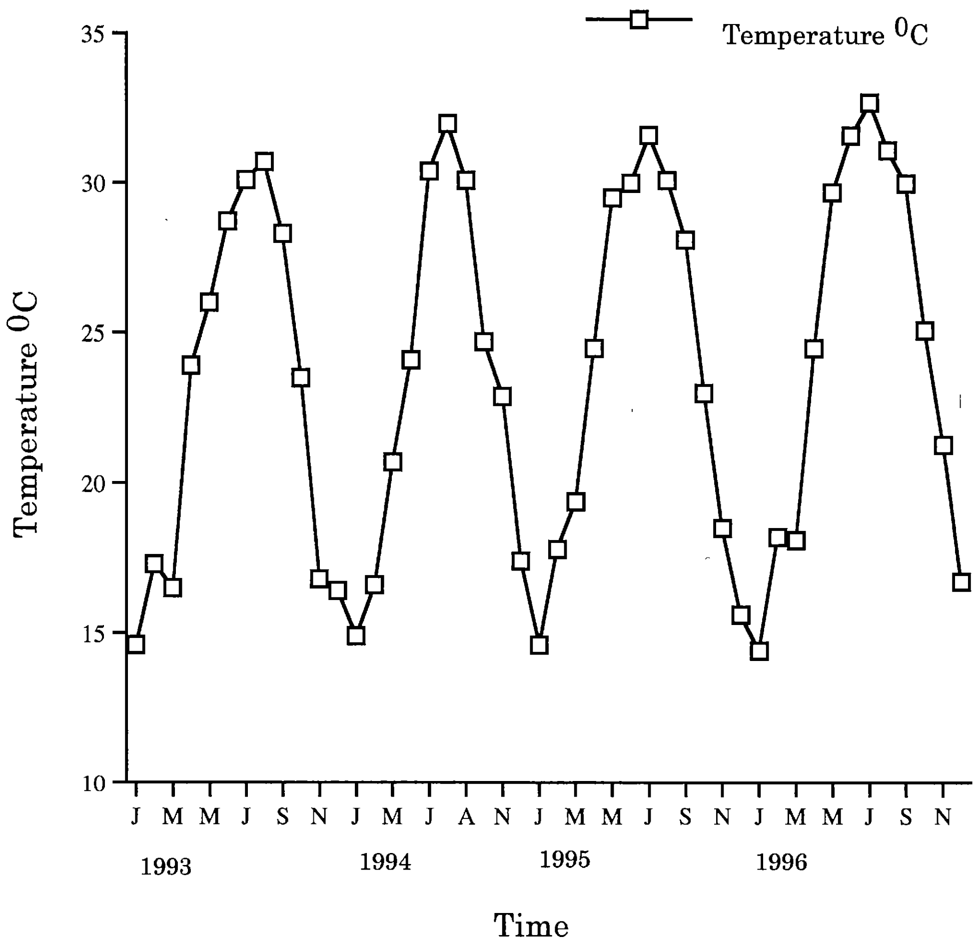

Figure 11. Average monthly temperature in Starr County from January, 1993 to December, 1996.

Phenology and Reproductive Capacity

A two year study (year 1: July 1993–June 1994; year 2: July 1994 – June 1995) of phenology and reproductive capacity was conducted at two populations (Zapata County population A and Starr County population). This study revealed that plants are capable of flowering throughout the year, although flowers are not as abundant in the winter months. Plants tend to produce a greater number of flowers in the spring and early summer and fruit production is also greatest at this time. Fruit set was low, 37% in the Zapata County population and 32% in the Starr County population.

A total of 88 individuals were at the reproductive stage in the Zapata County population A transect during the two year study period (Figure 12). Data were not collected during November, 1993 and February and March, 1994. In July 1993, 85 plants were in bloom, but no fruits were observed. Plants were not in bloom and there was no fruit production during August, September, October and December of 1993 or January of 1994. Plants were in flower during April (n=81), May (n=81) and June (n=77) of 1994. Fruit production also occurred during these months with 1, 75 and 45 plants in fruit respectively. Fruit to flower ratio was 0:18,512 in July, 1:14,635 in April, 7,528:3,844 in May and 957:9,314 in June (Figure 13).

During the second year of this study, plants did not flower or set fruit in January, 1994 (Figure 12). Plants were in flower and/or fruit all other months of observation (Figure 12). Data were not collected during September–December, 1994 and May, 1995. In July, 1994 there were no plants in flower, but 85 plants were in fruit. In August of 1994 there were 30 plants in flower and 27 in fruit. In February and March of 1995 there were 23 and 59 plants in flower respectively, but no fruit production. In April, 1995 there were 71 plants in flower and 84 were in fruit, and in June, 1995 30 plants were in flower and 31 produced fruit. Fruit to flower ratio was 5,074:0 in July, 1,286:818 in August, 0:168 in February, 0:685 in March, 3,063:1,968 in April and 8981,105 in June (Figure 13).

The Starr County population had only 19 reproductive individuals located within the transect (Figure 14). During the first year of study plants were in flower in all months except August, 1993. Data were not collected in November, 1993 and March, 1994. In July, 1993 all 14 plants were in flower and one was in fruit. In September, October and December of 1993 there were 6, 11 and 3 plants in flower respectively. No fruits were observed during these months. In January, 1994 there were 7 plants in flower, but no plants in fruit. In February, April and May of 1994 there were 5, 14 and 15 plants in flower respectively, but no plants in fruit. In June there were 14 plants in flower and 14 plants in fruit Fruit to flower ratio was 1:1,091 in July, 0:17 in September, 0:212 in October, 0:18 in December, :46 in January; 0:51 in February, 0 609 in April, 0:373 in May, and 130:731 in June (Figure 15).

During the second year of study, flowers were produced during each month of observation (Figure 14). Data were not collected during November and December of 1994. In 1994 there were 13 plants in flower and 3 plants in fruit in July; in August 14 plants in flower and 9 in fruit; in September 14 plants in flower and 5 in fruit and in October 11 plants in flower and 10 in fruit. In the months of observation in 1995 there were 2 plants in flower, but no fruits observed in January; in February there were 12 plants in flower and 4 in fruit; in March there were 13 in flower and 9 in fruit; in April there were 17 in flower and 13 in fruit; in May there were 14 in flower and 14 in fruit; and in June there were 14 in flower and 19 in fruit. Fruit to flower ratios were 95:498 in July, 121:76 in August, 18:447 in September, 235:118 in

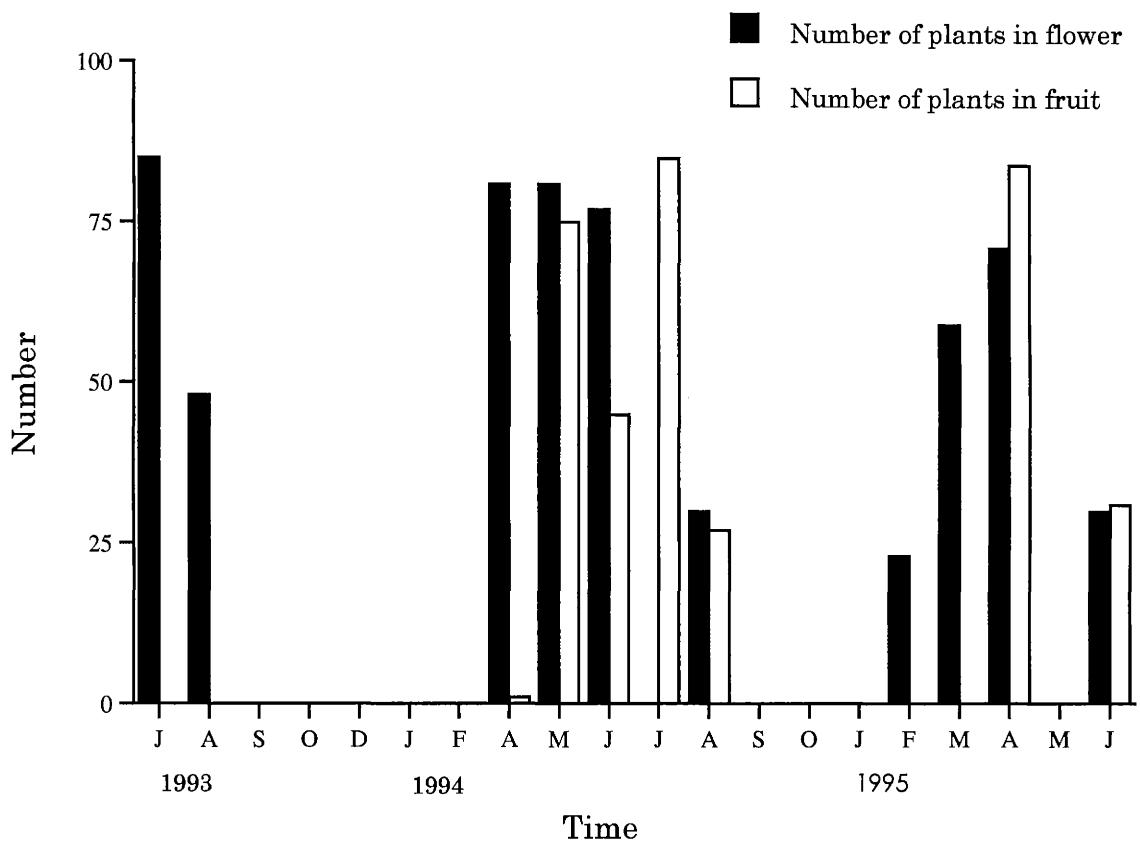

Figure 12. Number of *Frankenia johnstonii* plants in flower and in fruit on a monthly basis from July, 1993 to June, 1995 in Zapata County population A.

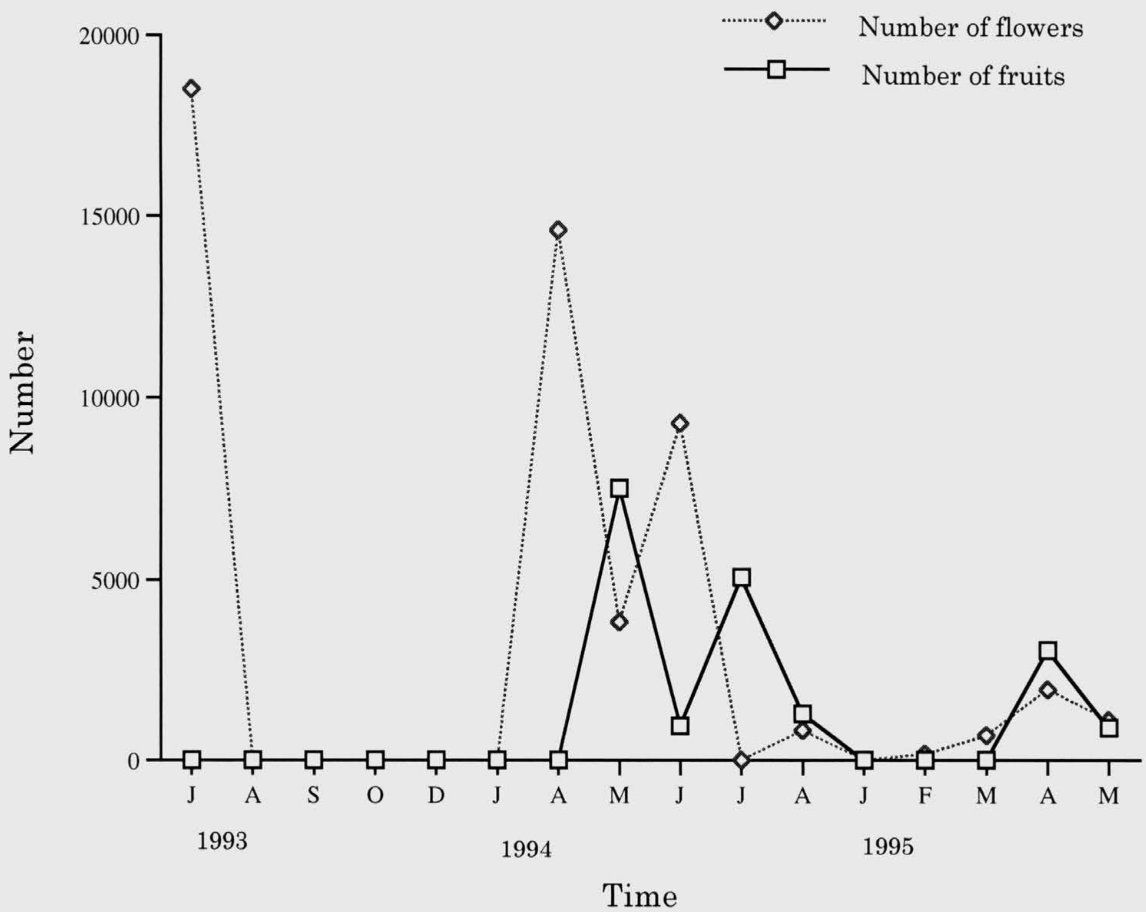

Figure 13. Number of *Frankenia johnstonii* flowers and fruits produced on a monthly basis from July, 1993 to June, 1995 at Zapata County population A.

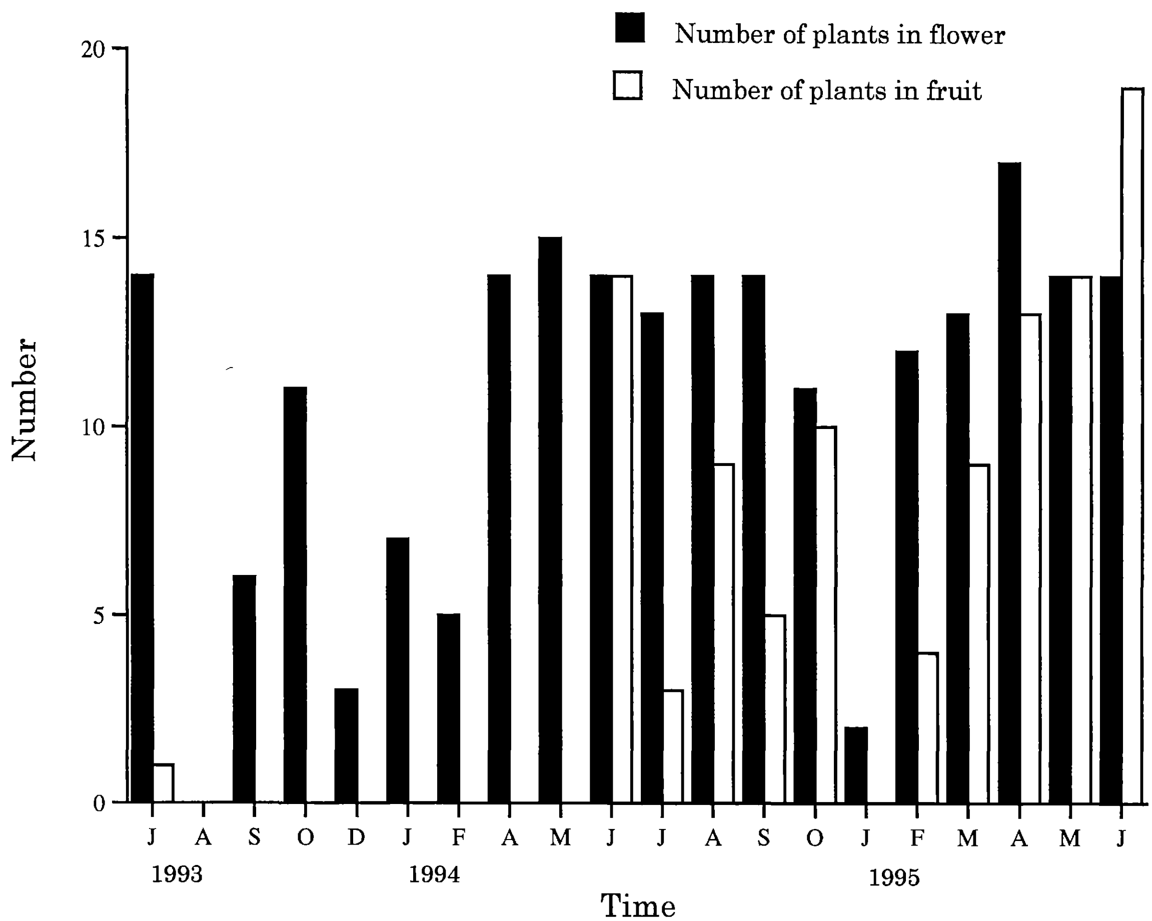

Figure 14. Number of *Frankenia johnstonii* plants in flower and in fruit on a monthly basis from July, 1993 to June, 1994 in the Starr County population.

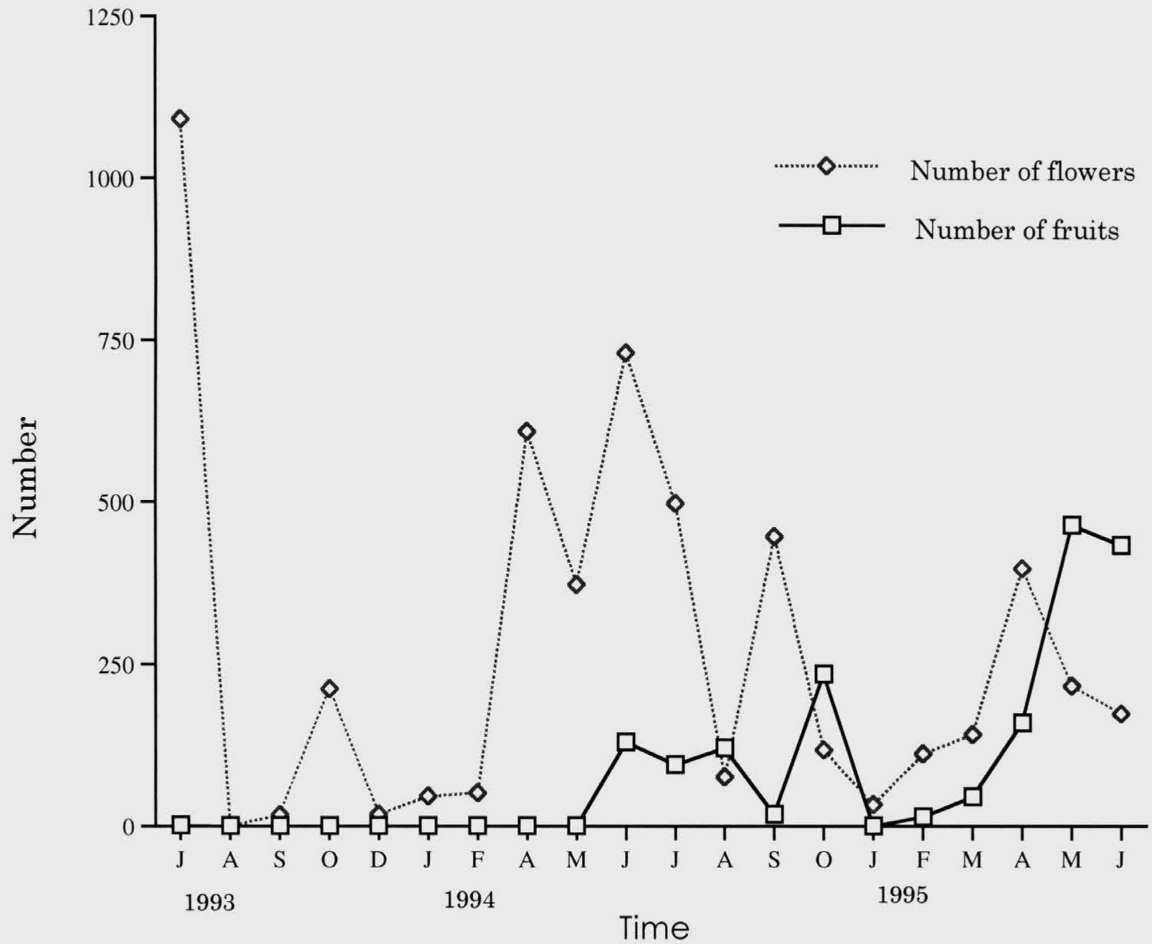

Figure 15. Number of *Frankenia johnstonii* flowers and fruits produced on a monthly basis from July, 1993 to June, 1995 in the Starr County population.

October, 0:33 in January, 14:112 in February, 45:142 in March, 160:398 in April, 465:217 in May, and 434:174 in June (Figure 15).

Seed Set

The ovary typically contains three ovules. Examination of the fruits revealed that typically only one of the three ovules develops into a seed. The other two ovules abort. Dissection of mature fruits (n = 87) collected at the Starr County population exhibited a 26% seed set.

Seed Viability

Tetrazolium tests of seeds (n = 78) dissected from mature fruits collected from the Starr County population exhibited 31% viability (24 viable; 54 nonviable).

Soil Seed Bank

At the conclusion of the one year study, four *F. johnstonii* seedlings had germinated. Two seeds in soil collected from the Starr County population and one seed in soil collected from Zapata County population B in April, 1996 germinated and produced seedlings in June, 1996. In October of 1996 a fourth seedling was observed in soil collected in June, 1996 from the Starr County population.

Seedling Recruitment

At the beginning of the seedling recruitment study (July, 1993) 93 individuals were located within the Zapata County A population transect, seven of these were identified as seedlings (Figures 16, 18). By June, 1995, a total of 32 new seedlings had been observed (Figures 16, 18). New seedlings (Figures 8, 10) were observed during 1993 in August (n=3), September (n=3), October (n=12) and December (n=2). In 1994, new seedlings were observed in April (n=3), May (n=1), July (n=1), and in August (n=1). In 1995, new seedlings were observed in February (n=2), March (n=1), April (n=2), and June (n=1). Seedling mortality occurred in December, 1993 (n=1), June, 1994 (n=1), January, 1995 (n=1), March, 1995 (n=2) and June, 1995 (n=2) (Figures 16, 18). At the conclusion of the study, 32 of the 39 seedlings observed over the study peiod survived, resulting in an 82% recruitment.

In the Starr County population 24 plants were located within the transect in July, 1993, ten of these were seedlings (Figures 17, 18). New seedlings were observed in the Starr County population in October, 1993 (n=2). In 1994 new seedlings were observed in February (n=1), April (n=2), May (n=1) and July (n=1). In 1995 one new seedling was observed in January. One seedling suffered mortality in October, 1994 (Figures 17). A total of 17 of 18 seedlings observed were recruited over the two year study resulting in a recruitment of 94.7% (Figures 17, 18).

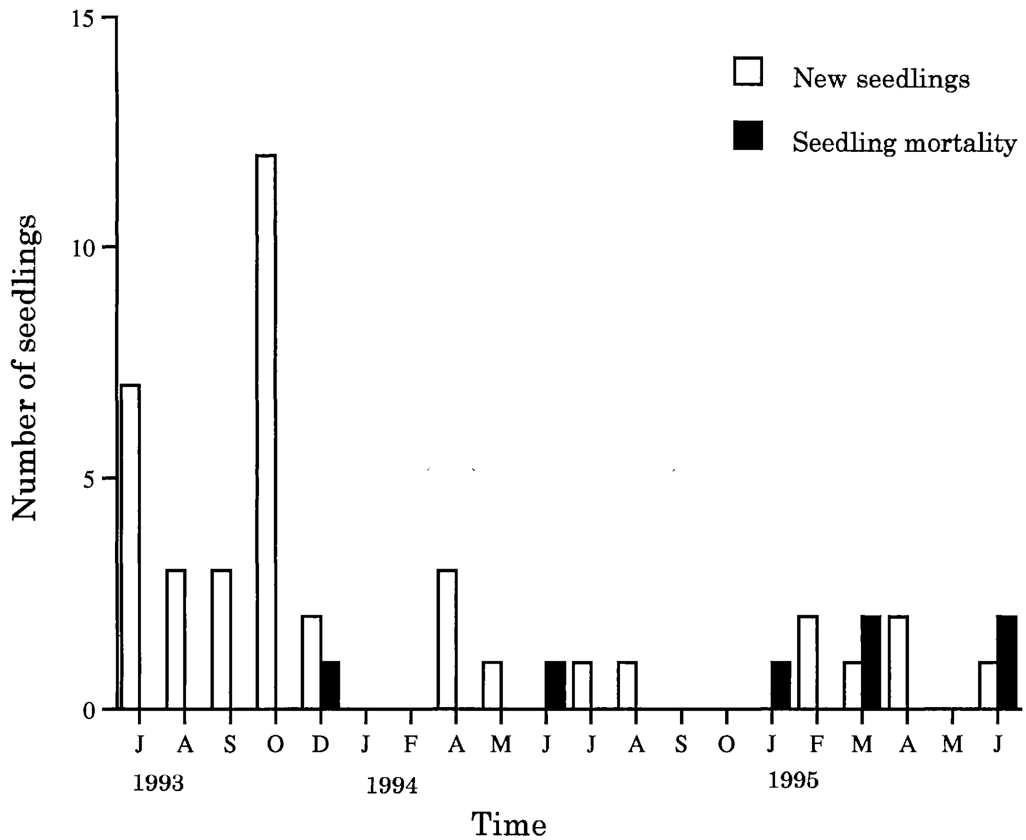

Figure 16. Number of seedlings recruited and seedling mortality of *Frankenia johnstonii* on a monthly basis from July, 1993 to June, 1995 within belt transect in Zapata County population A.

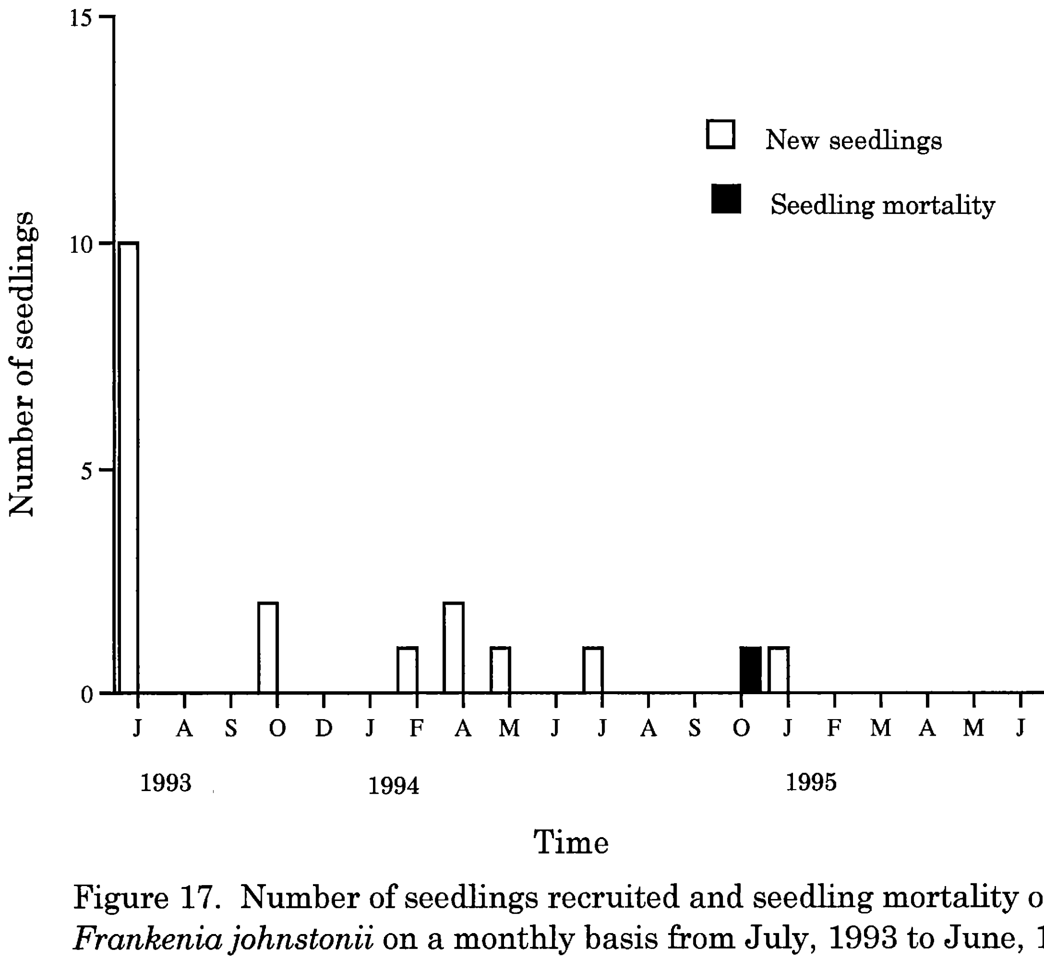

Figure 17. Number of seedlings recruited and seedling mortality of *Frankenia johnstonii* on a monthly basis from July, 1993 to June, 1995 within belt transect in the Starr County population.

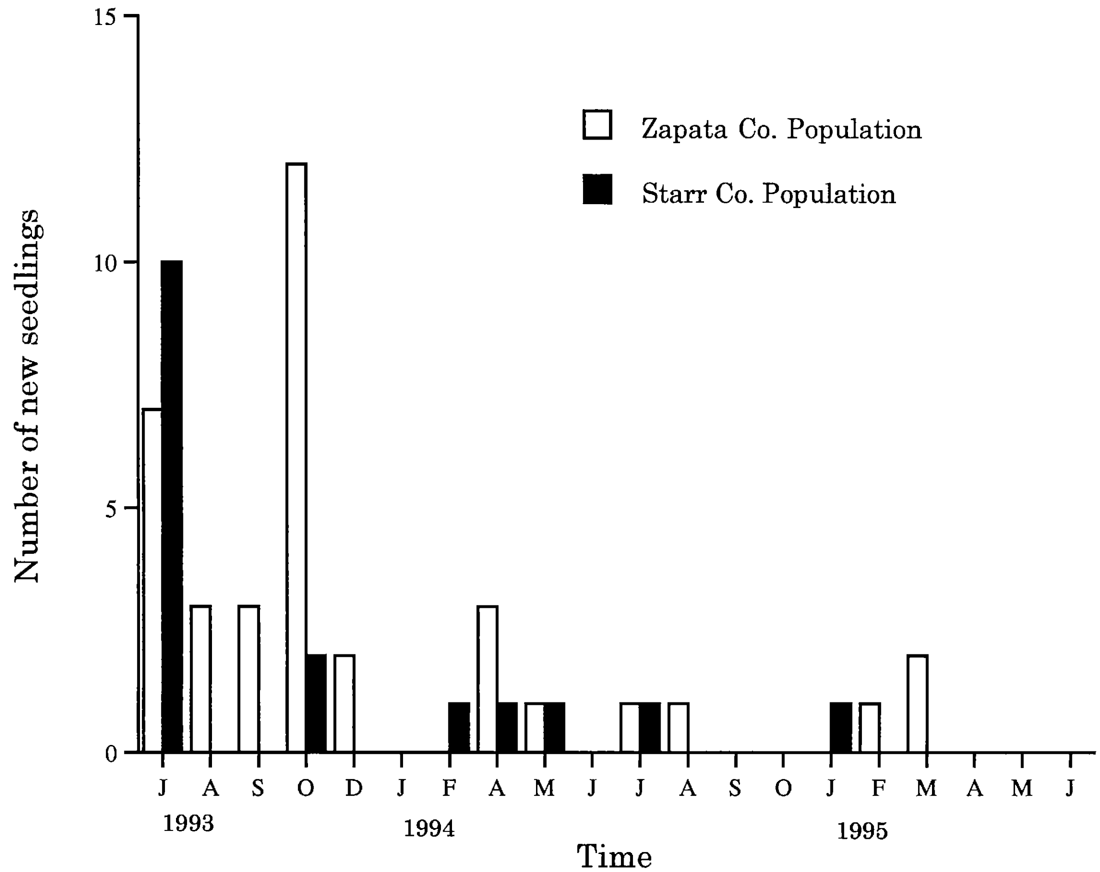

Figure 18. Number of new seedlings of *Frankenia johnstonii* recruited monthly in the Zapata County and Starr County populations from July, 1993 to June, 1995.

DISCUSSION

Large size individuals producing many flowers and many ovules per ovary create a potential for population growth and stability. Consequently, population size of an endangered plant species can be limited by production of viable seeds, particularly when a species is not known to reproduce asexually (Pavlik et al., 1993). Seed production depends on plant size, fruit to flower ratio and the number of ovules that actually develop into seed (Gross, 1981; Lee and Bazzaz, 1982; Hirose and Kachi, 1986; Weins et al., 1987; Winn and Werner, 1987). *Frankenia johnstonii* exhibits low fruit to flower ratios, seed set and seed viability.

Both intrinsic and extrinsic limitations can reduce plant size, fruit to flower ratio and seed to ovule ratio (Pavlik et al., 1993). Intrinsic limitations include genetically programmed fruit or ovule abortion, especially in outcrossing species (Weins et al., 1987, 1989). Although the mechanism is not known, a regular pattern of ovule abortion was noted in *F. johnstonii.* Ovule abortion resulted in a low seed set (26%). Seed viability was also low (31%).

Extrinsic limitations include abiotic resource levels (van Andel and Vera, 1977; Bookman, 1983; McCall and Primack, 1985). Also, predation on seeds, fruits or portions of the whole plant can limit plant size, fruit to flower ratio and seed to ovule ratio (Janzen, 1971; Lee and Bazzaz, 1982; Evans et al., 1989).

Frankenia johnstonii showed annual variation in flower production. This appeared to be correlated with the variation in rainfall amounts over the two year study period. Correll and Johnston (1979) indicate that *F. johnstonii* flowers during the months from November to April. However, this study revealed that plants exhibited flower production after rainfall all through the year, with a peak flowering period during spring and early summer. The majority of plants were at anthesis in April, May and June, months that typically receive the most rainfall. Limited precipitation at other times of the year may place an extrinsic restraint on flower, fruit and seed production.

Temperature may also play a role in flower and fruit production. Plants were observed to be in flower during the winter months. However, the number of plants in flower and the number of flowers per plant was much lower than in spring and summer and there was almost no fruit production. Browsing pressure is also high in the winter. Increased browsing coupled with decreased precipitation and lower temperatures during the winter months could be factors resulting in reduced flower and fruit production.

Seeds of *F. johnstonii* showed only a 31% viability. Turner (1980) also noted that seed viability was less than 50%. Seed set from fruits collected in November, 1995 at the Starr County population was relatively low at 26%, when compared to the 55% seed set found in fruits collected from a Zapata County population in May, 1994 (Janssen and Williamson, 1994). Disparity in seed set could be the result of a difference in vigor between the two populations.

Thompson and Grime (1979) described seed banks as either transient or persistent. Transient seed banks exploit gaps that become available for colonization by seasonally predictable damage and mortality in the vegetation. Seeds will germinate in these areas soon after release and do not remain persistent in the soil. Persistent seed banks are those in which seeds remain viable in the soil for at least one year. They tend to occur when disturbance of the established vegetation is temporally and / or spatially unpredictable. This study was not designed to provide a complete assessment of seed flora but to detect the presence or absence of a persistent soil seed bank in populations of *F. johnstonii*. Over the one year study only four seedlings germinated from the soil samples taken. Germination was observed in soil samples collected in spring and early summer, the time when plants are largest and flower production is at its peak. It does not appear from this study that *F. johnstonii* has a reservoir of buried viable seeds that would account for a persistent seed bank. It is likely that most seeds remain in the litter of the soil. This could be advantageous because seeds are small and probably unable to emerge if germination occurs too far below the soil surface. However, this could also lead to herbivory or seeds being removed, by biotic or abiotic means, to an unsuitable habitat. Structural features of the seed may also preclude the formation of a persistent soil seed bank. Seeds have a thin seed coat (Whalen, 1980) that may not provide sufficient protection for long term survival in the soil. However, a thin seed coat may be advantageous in the process of seed germination. Whalen (1980) found that seeds readily germinate after a few days of exposure to water. Rapid germination could be a mechanism for exploitation of short periods of favorable environmental conditions. A thin seed coat would favor rapid imbibition and subsequent germination.

Although seed set and seed viability are low, seeds that do germinate exhibit a high rate of recruitment. Seedling recruitment in the Zapata County population was 82% and the Starr County population, which was much smaller, had a 94.7% recruitment. Fruits have no apparent specializations for dispersal and seedlings are always found in close proximity to the parent plant, resulting from a seed shadow that is strongly leptokurtic. Callaway (1992) found that biogenic safe sites for oak seedlings were provided by shrubs and that this could have affected recruitment. This has also been suggested for some desert species (Turner et al.,1966). The parent plant may provide a safe site for the seedlings of *F. johnstonii*, reducing the possibility of trampling and increasing the chance of recruitment.

Studies have indicated that timing of germination and seedling size can be critical factors in determining the fate of seedlings, with larger seedlings having better survivorship and ability to reach reproductive stage sooner than smaller seedlings of the same cohort (Cook, 1979, 1980). In *F. johnstonii* timing of germination is variable and seedling survival could be dependent on the amount of rainfall after germination. The largest number of seedlings observed in one month occurred at Zapata County population A in October, 1993, following a month in which rainfall amounts reached 10.8 cm. Increased precipitation amounts during the months before new seedlings were observed could have promoted rapid growth and provided a better chance of successful survival and establishment. Although small seedling size can be a contributing factor to seedling mortality (Fenner, 1985), five of the unrecruited seedlings at the Zapata County population had aerial diameters ranging from 4 cm to 20 cm. Seedling size did not appear to be a factor in the loss of these seedlings. Seedling loss in *F. johnstonii* seems to result primarily from browsing, trampling and drought stress. It is not well understood how seedling size and survivorship relate where drought stress and herbivory also play important roles (Parker, 1982).

Suggested potential threats to *Frankenia johnstonii* include loss of habitat due to overgrazing and root-plowing and low reproductive potential (Turner, 1980). This study has shown that this endangered species exhibits low fruit to flower ratio, low seed set and low seed viability. These reproductive factors may place constraints on the success of the taxon. However, a species may also be rare due to a specialized habitat that is not widely distributed (Fiedler and Ahouse, 1992). *Frankenia johnstonii* does have a specialized habitat requirement of saline soils; a habitat limited in distribution. However, since this type of habitat is not readily colonized by many other species, competition is limited.

At the time of listing only five populations were known. A knowledge of habitat preference coupled with extensive field surveys have increased the known populations to 50 today. *Frankenia johnstonii* does not reproduce asexually (Whalen, 1987), therefore an individual must produce at least one seedling to maintain population stability. This study has shown that although seed set and seed viability are low, seeds that do germinate have a high rate of recruitment and populations do not appear to be experiencing decline in size. Since this taxon is a long-lived perennial there is a high probability of an individual producing at least one seedling during its lifetime, thus maintaining population stability. An improved understanding of the reproductive biology of this taxon resulting from this study together with a novel, successful landowner conservation program lead by Gena Janssen of TPWD may lead to delisting of this endangered species. Such a recommendation is currently under consideration.

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