



# Distribution, abundance, and ecology of the threatened Gibson's Big Sand Tiger Beetle (*Cicindela formosa gibsoni* Brown) in the Elbow Sand Hills of Saskatchewan

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## Abstract

Gibson's Big Sand tiger beetle, *Cicindela formosa gibsoni* Brown, occurs primarily in the Saskatchewan sand hills and was recently listed as threatened in Canada due to habitat loss caused by dune stabilization. Herein, we report on a 3-year population study initiated in 2016 to better understand the distribution, abundance, and ecology of *C. f. gibsoni* in the Elbow Sand Hills, a large active dune complex in southern Saskatchewan. Estimated adult population size for the dune complex varied from a low of 1106 (95% confidence interval (CI) 975–1237) to a high of 1474 (CI 1350–1598), possibly due to inter-annual variation in May–June rainfall. Adult abundance varied substantially between interdunal swales (0–137 individuals), with the highest numbers occurring in sparsely-vegetated habitats on the stoss side of the dune complex where the rate of encroachment by vegetation is highest. Approximately a third of the total population is concentrated within a relatively small area (~6 ha) in the northwestern region of the dune complex, although the specific cause for this localized distribution is not clear. Our findings suggest that the distribution of *C. f. gibsoni* within the dune complex is not limited by prey availability or larval habitat quality but is instead related to the amount of sparsely-vegetated habitat. We hypothesize that sparsely-vegetated areas allow beetles to shuttle between exposed and shaded microhabitats, thereby assisting in thermoregulation and maintenance of high body temperatures that are optimal for foraging.

**Keywords** Coleoptera · Dune stabilization · Maxithermal · Population size · Sand dunes · Temperature

## Introduction

Sand dune ecosystems are well-known for supporting diverse and highly specialized plants and animals, many of which are of conservation concern in Canada (Wolfe 2010; Acorn 2011). A large proportion of these threatened species occur in sparsely-vegetated microhabitats between

active and fully stabilized sand (Wolfe 2010). The extent of this “edge” habitat is highly dynamic and sensitive to changes in disturbance frequency, climate, precipitation, land use, and other processes that increase or decrease dune activity (Hugenholtz and Wolfe 2005; Wolfe et al. 2007; Acorn 2011). Progressive dune stabilization, beginning in the 1930s (i.e., after the Dust Bowl drought), has led to a significant reduction in both the edge habitat and total area of active sand across the Canadian Prairies (Wolfe 2010). In addition, most of the remaining sandy habitat is composed of small, highly fragmented patches (Wolfe 2010). Although dune activity is sensitive to climate, changes in land-use practices, fire suppression, and loss of bison are also thought to contribute to dune stabilization (Wolfe et al. 2007; Wolfe 2010; COSEWIC 2012). Trends toward stabilization are expected to continue in this region and will likely result in further habitat loss for many sand-associated species (Wolfe et al. 2007).

Population data are critical for assessing extinction risk and developing recovery strategies for threatened species;

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however, this knowledge is lacking for most insects. Indeed, information on the population demographics for all sand-associated insect species listed as ‘Special Concern’ or higher by COSEWIC (Committee on the Status of Endangered Wildlife in Canada) is either incomplete or unavailable (COSEWIC 2006, 2007a, b, 2012, 2014). Obtaining accurate estimates of population size for some insect groups (e.g., moths) may be difficult or near impossible due to their small size, short life-cycle, nocturnal activity, or mobility. In contrast, many tiger beetle species are well-suited to population studies due to their large size, ease of identification, diurnal activity, propensity to fly short distances, and habitat specificity (Knisley and Hill 2001; Gowan and Knisley 2014; Knisley et al. 2016; Knisley and Brzoska 2018). In addition, many tiger beetle species require a mixture of semi-vegetated and open-sand habitats and are thus good indicators of environmental change and the effects of dune stabilization (Knisley 2011; Gowan and Knisley 2014; Knisley and Brzoska 2018).

Gibson’s Big Sand tiger beetle (*Cicindela formosa gibsoni* Brown) (Fig. 1) occurs primarily in sandy blowouts and along the periphery of larger active dunes in southern Saskatchewan, Canada, although small disjunct populations also occur in Colorado, Montana, and Wyoming (COSEWIC 2012; Knisley et al. 2014; M. Brust, personal communication). This species is one of the largest tiger beetles in North America and *C. f. gibsoni* is distinguished from other *C. formosa* subspecies based on the pale white maculations covering most of the elytra (Freitag 1999; Pearson et al. 2015). This adaptation is thought to afford greater thermal tolerance and camouflage in sand dune habitats (Gaumer 1977; Schultz and Hadley 1987; Acorn 1992).

*Cicindela formosa gibsoni* was identified as ‘Threatened’ by COSEWIC in 2012 and was recently listed under Schedule 1 of the Species At Risk Act (SARA) in early 2018 (Government of Canada 2018). Habitat loss and ongoing

stabilization of remaining open-sand habitats are identified as the primary threats to this species (COSEWIC 2012; Knisley et al. 2014); however, absence of information on population size and trends is also a major conservation concern. Studies of population dynamics in the Coral Pink Sand Dune tiger beetle, *Cicindela albissima* Rumpff, have demonstrated a strong link between rainfall and annual fluctuations in population size (Gowan and Knisley 2014; Knisley et al. 2018). In addition, water supplementation studies with *C. albissima* have shown that watered patches attract more adults, have greater larval recruitment, and faster larval development than unwatered plots (Knisley et al. 2018). Although it is unclear if populations of *C. f. gibsoni* respond similarly to fluctuations in rainfall, these studies suggest that the negative effects of habitat loss for this species could be compounded by other factors influencing population dynamics (e.g., drought).

This study was initiated in 2016 to better understand the distribution, abundance, and ecology of *C. f. gibsoni* in the Elbow Sand Hills, a large active dune complex in southern Saskatchewan. Abundance surveys were conducted in 50 interdunal swales of the active dune complex, providing detailed information on abundance trends and habitat specificity, as well as an overall estimate of the adult reproductive population size between 2016 and 2018. In an effort to better understand the habitat requirements of *C. f. gibsoni* and its preference for partially vegetated habitats, we also evaluated the relationship between adult abundance and several environmental factors (e.g., prey abundance, shelter, soil moisture, larval habitat quality) that are known to influence tiger beetle distributions (Knisley and Hill 2001; Knisley et al. 2017).

## Materials and methods

### Study area

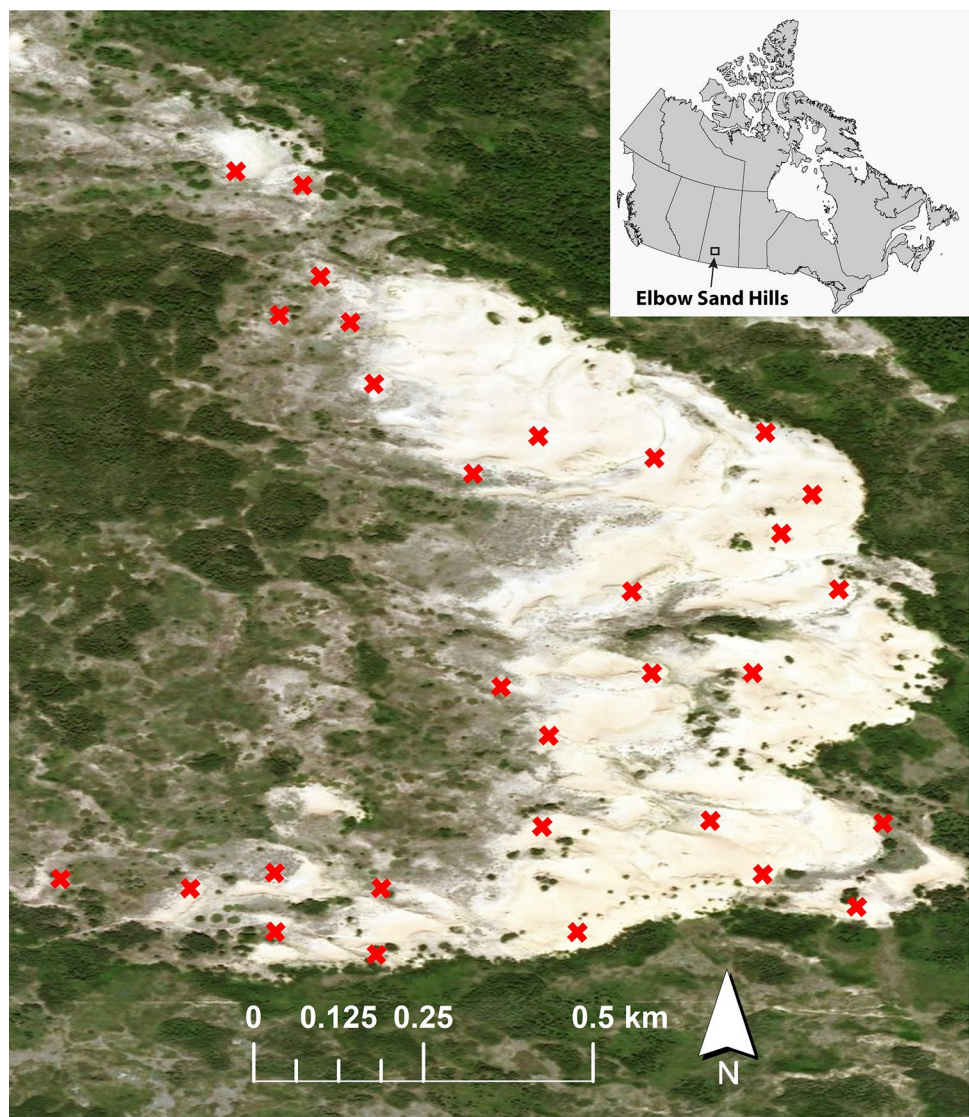
The Elbow Sand Hills are located within Douglas Provincial Park, approximately 80 km south of the City of Saskatoon. These sand hills formed after the retreat of the Laurentide Ice Sheet ca. 14,000 years BP (Dyke et al. 2003) and the subsequent draining of sediments from Glacial Lake Birsay southeastward through the Qu’Appelle Channel (Scott 1971). Most of the dune field is stabilized by vegetation except for a large active dune complex (Fig. 2) northeast of the Douglas Provincial Park campground. Here, parabolic dunes consist of elongated arms that are held in place by vegetation while the bulk of the sand drifts eastward.

Since the early to mid-1900s, dune activity in the Elbow Sand Hills has been decreasing, with rates of stabilization exceeding that of dune migration or reactivation (Hugenholtz and Wolfe 2005; Wolfe et al. 2007). Between 1939



**Fig. 1** Gibson’s Big Sand tiger beetle (*Cicindela formosa gibsoni*) photographed at the Elbow Sand Hills

**Fig. 2** Map of the active dune complex in the Elbow Sand Hills, southwestern Saskatchewan, Canada. Red markers indicate the location of pitfall traps and the center position of distribution buffers. (Color figure online)



and 2004, the average lee side (down-wind) migration of the main dune complex was approximately 0.35 m/year, while the rate of vegetative encroachment on the stoss (up-wind) side was considerably higher at roughly 1.6 m/year (Wolfe et al. 2007). During this 65-year period, the area of active sand in the main complex declined from roughly 67 to 31 hectares (Wolfe et al. 2007). Model predictions of stabilization suggest that the dunes will remain active well after 2100, although the amount of active sand remaining will be very small (<10 hectares, Wolfe et al. 2007).

### Estimating abundance

Abundance surveys for *C. f. gibsoni* were conducted in 50 interdunal swales of the active dune complex between late May and early July between 2016 and 2018. The boundaries between swales corresponded to natural features like dune crests, tree lines, and game paths and were recorded using

a handheld GPS. Adult *C. f. gibsoni* emerge from the pupal stage in the fall and hibernate to re-emerge when spring conditions are suitable (Pearson et al. 2015). Our surveys were conducted following the spring emergence and therefore provide an estimate of the breeding population for each year.

Population size was estimated using removal methods described in Otis et al. (1978) and White et al. (1982). This approach is considered the most accurate method for determining tiger beetle population size (Knisley et al. 2016). Beetles were captured with nets by observers moving in a zig-zag pattern from one end of the swale to the other (Gowan and Knisley 2014). Captured beetles were counted, sexed, placed individually in vials, and kept in a cooler, thus completing a single 'removal'. Three or more removals were conducted in succession for each swale and, upon completion, beetles were released (Gowan and Knisley 2014).

The assumptions of this method are that the population is 'closed' and sampling effort is equal for each removal.

Because consecutive removals within a swale were conducted over a short time (h), immigration/emigration within the swale was minimized and the assumptions of a closed population were easier to meet (Gowan and Knisley 2014). Equal sampling effort was achieved by using the same observers when moving through the sampling area to capture beetles. To help ensure consistency in capture probability, surveys were only conducted when soil temperatures ranged between 20 and 50 °C: the approximate thermal minimum and maximum for *C. f. gibsoni* activity. In rare cases where there was no rainfall for extended periods (> 1 week in 2017) and the upper limit of the beetle's activity decreased (~42 °C), surveys were halted. Soil temperature was measured prior to each removal survey using an OEM infrared thermometer, No. 25245.

### Habitat characteristics

To better understand factors influencing the distribution of *C. f. gibsoni* across the dune complex, we recorded the location of all captured beetles in 2017 and 2018. We placed a large, orange spray-painted washer wrapped in flagging tape at the capture location of each beetle during abundance estimates and recorded the location using a handheld GPS after completion of all removal 'passes'. Efforts were made to ensure that the washer was placed as close as possible to the location the beetle was initially spotted, and to retrieve the washer should we fail to capture it. The marked location thus approximates the preferred habitat of *C. f. gibsoni*.

The relationship between adult counts and environmental factors was then evaluated for data collected in 2018 at 30 randomly selected locations throughout the dune complex, with a minimum distance of 60 m between locations. At each location, we counted the number of captured adult beetles within a 30 m buffer using geographic information system (GIS) software and related this measure to prey abundance, percent cover of vegetation, depth to moisture, and larval abundance for that location. Prey were captured using a modified pitfall trap (0.75 L, 11.2 cm diameter) equipped with a smaller 0.5 L inner cup and a plastic lid containing 16 holes (0.80 cm diameter) arranged in a 4 × 4 square. This design helped prevent accidental capture of *C. f. gibsoni* while still allowing capture of smaller invertebrates to determine prey abundance. Each trap was filled with approximately 150 mL of preservative consisting of a 50:50 mixture of propylene glycol and water. A small plywood lid (15 × 15 cm) was suspended from corner posts above the trap to help reduce evaporation and prevent debris from clogging the opening of the trap. Although drifting sand accumulated in some of the traps, they did not completely fill with sand and thus remained functional. Traps were operated for two weeks in May 2018 and visited at weekly intervals to collect

samples and replenish the preservative. Although a variety of invertebrates were captured in our pitfall samples, we used the total number of ants, identified using the key by Glasier et al. (2013) as a measure of prey abundance as they were the only prey we saw adults actively consuming. Given that food is generally a limited resource for all tiger beetle life stages and is important in the production of eggs (Pearson and Knisley 1985), we expected adults to be distributed in areas with high prey abundance. Voucher specimens for the ants collected in our study are deposited in the Troutreach Saskatchewan collection in Saskatoon, Saskatchewan, Canada.

Percent cover of vegetation was estimated in 1 m<sup>2</sup> quadrats distributed along three 60 m transects intersecting the pitfall trap. The first quadrat was positioned at 0 m along the transect with subsequent quadrats distributed every 10 m thereafter. Because the transects overlapped at the 30 m position, this quadrat was only counted a single time, for a total of 19 quadrats per location (Online Resource 1).

Tiger beetles use a range of behavioural adaptations to assist in thermoregulation (e.g., stilting, Pearson et al. 2015) and help maintain high body temperatures that are optimal for foraging (Dreisig 1980, 1985). Indeed, tiger beetle activity is strongly influenced by temperature and many species use shade from vegetation or topographical features to help regulate body temperature. Thus, adults in our study may be more abundant in sparsely vegetated habitats because they provided a mixture of shaded and exposed microhabitats that beetles can utilize for thermoregulation (Acorn 1991). Conversely, adults may be less abundant in open-sand habitats because they do not provide shade, and less abundant in completely vegetated areas because thick vegetation tends to interfere with tiger beetle locomotion and flight. We therefore expected a non-linear response between adult abundance and vegetation cover.

Rainfall and soil moisture are important environmental factors that affect tiger beetle populations living in arid conditions (Knisley and Gowan 2009; Gowan and Knisley 2014; Knisley et al. 2018). High amounts of rainfall and soil moisture, for example, are beneficial for oviposition, larval survivorship and recruitment, development rate, and prey abundance (Knisley and Gowan 2009; Knisley et al. 2018). Knisley and Gowan (2009) also suggest that the timing of rainfall during the reproductive and larval development periods of tiger beetles may be more important than total rainfall. In terms of its effects on the total population size, rainfall primarily influences larval survival and the number of adults emerging the following year (Knisley and Gowan 2009; Gowan and Knisley 2014). Historical rainfall and temperature data for the May–June were obtained from the Elbow CS weather station (climate.weather.gc.ca), located approximately 13 km north-west of the main dune complex (51°7'48" N, 106°34'48" W). This period corresponds to

the main reproductive and larval development period for *C. f. gibsoni*.

Larval abundance was determined by counting the number of larval burrows within a 10 m radius of each pitfall trap. Larval burrows of *C. f. gibsoni* differ from other tiger beetle species and are easily recognized by a small pit-like depression at the opening of the larval chamber (Gaumer 1977). Because tiger beetle larvae tend to plug their burrows during prolonged periods without rain or at high sand temperatures (Gowan and Knisley 2014), we restricted larval surveys to a two-day window following significant rainfall events (ca. 5–10 cm). In addition, we recorded depth-to-moisture (nearest 0.5 cm) at each location next to the pitfall trap following a period of 10 days without rain. We reasoned that larval abundance and depth to soil moisture are a good measure of larval habitat quality, and that the distribution of adult beetles may correspond to the availability and quality of this habitat.

## Data analysis

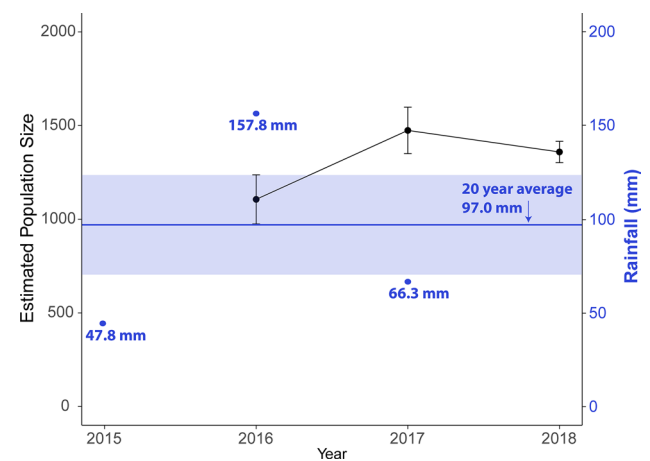
Data collected using removal methods were analyzed using Program CAPTURE (White et al. 1982) to produce estimates and associated variances for each swale individually. Confidence intervals for the total population estimates were calculated by multiplying the standard error (square root of the total variance) by the Z-score (1.96) for the 97.5th percentile point.

Relationships between adult counts and environmental variables were analyzed using negative binomial regression (generalized linear model) in R statistical software (R Development Core Team 2013). We used a multi-hypothesis framework to test which factors best explain the distribution of *C. f. gibsoni* within the dune complex. To do this, we developed a set of a priori biologically plausible models (Table 1) and evaluated the models using Akaike information criterion ( $AIC_c$ ) with small sample correction (Anderson et al. 2000). The most supported candidate model had the smallest  $AIC_c$  and the largest Akaike weight ( $w_i$ ). We then assessed the distribution of *C. f. gibsoni* using results from that model.

## Results

### Adult abundance and distribution

Adult population size averaged 1313 individuals over the course of our three-year study, with relatively low inter-annual variation (SD 118 individuals; Fig. 3). Population size was lowest in 2016 and highest in 2017, following years of below-average and above-average May rainfall, respectively (2015: 8.3 mm, 2016: 85.4 mm; 20-year average: 36.5 mm, 95% confidence interval 20.1–53.0 mm, Fig. 3). Adult abundances were consistently highest in the north-west swales (swales 45–50, Fig. 4), representing an average of 33.3% of the total population each year (SD 5.5%, range 27.2–37.9%), although high numbers of adults were also observed in semi-vegetated swales in the southwest and central regions of the dune complex. Density of adults was highest in swale 48, with an average of 209 individuals/ha (SD 43 individuals/ha) over the course of our study. In contrast, adult numbers in the northcentral, southcentral, and eastern regions of the dune complex were generally much

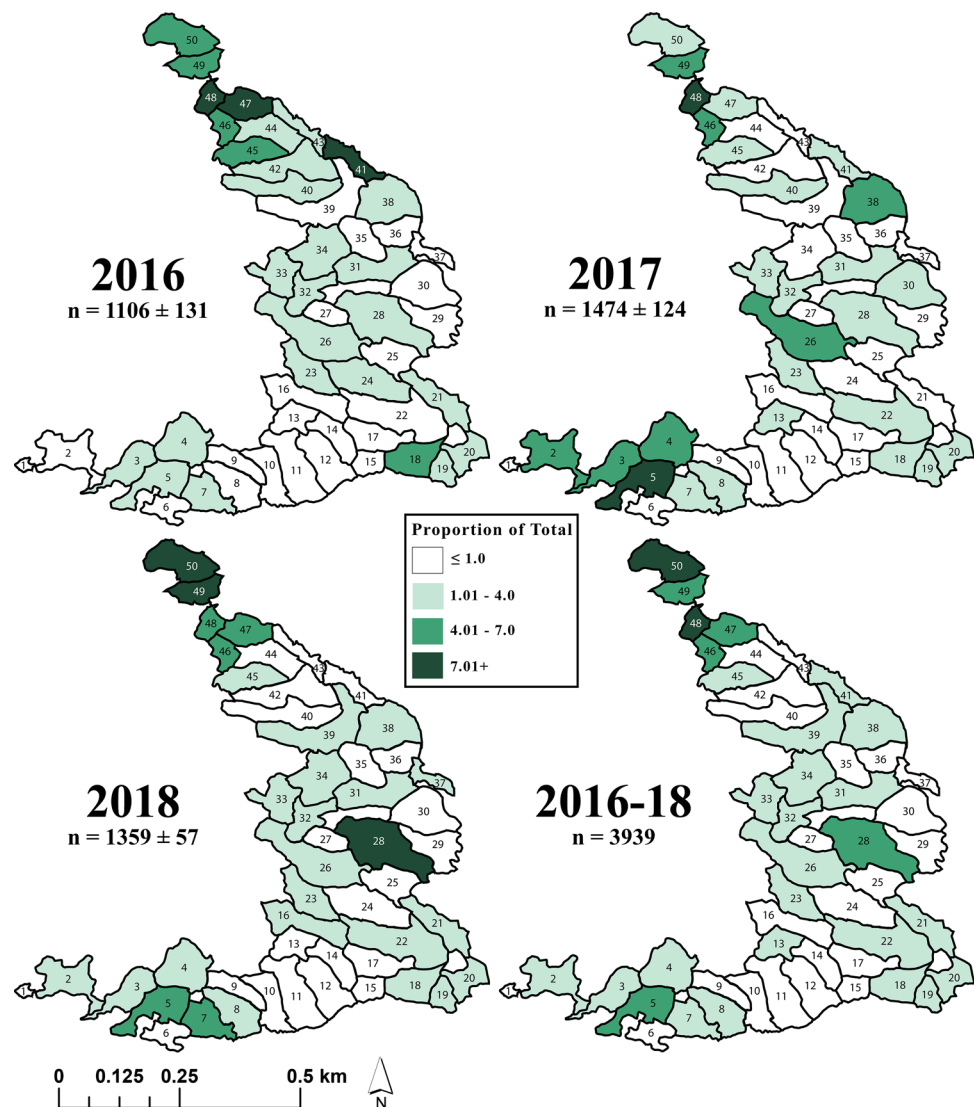


**Fig. 3** Annual population estimates and 95% confidence intervals (left y-axis) for *C. f. gibsoni* in the Elbow Sand Hills between 2016 and 2018. Average (1999–2018) May–June rainfall (right y-axis) from the Elbow CS weather station (approximately 13 km north-west of the main dune complex), including the 95% confidence interval (shaded light blue), are also provided

**Table 1** List of candidate regression models, number of parameters ( $K$ ), deviance explained ( $D^2$ ),  $AIC_c$  scores, differences among  $AIC_c$  scores and the top model ( $\Delta_i$ ), and  $AIC_c$  weights ( $w_i$ ) for explaining the distribution of adult *C. f. gibsoni* within the Elbow Sand Hills

Model #	Model name	Model structure	$K$	$D^2$	$AIC_c$	$\Delta_i$	$w_i$
1	Null model	1	1	0	218.4	15.1	<0.001
2	Prey availability model	Ants	2	0.02	220.1	16.7	<0.001
3	Larval habitat quality model	Larvae + moisture	3	0.21	215.3	11.9	0.003
4	Thermoregulation model	Veg + veg <sup>2</sup>	3	0.44	203.4	0	0.997

**Fig. 4** Proportion of the total population size for each of the 50 interdunal swales in 2016 (top left), 2017 (top right), 2018 (bottom left) and all years combined (bottom right)



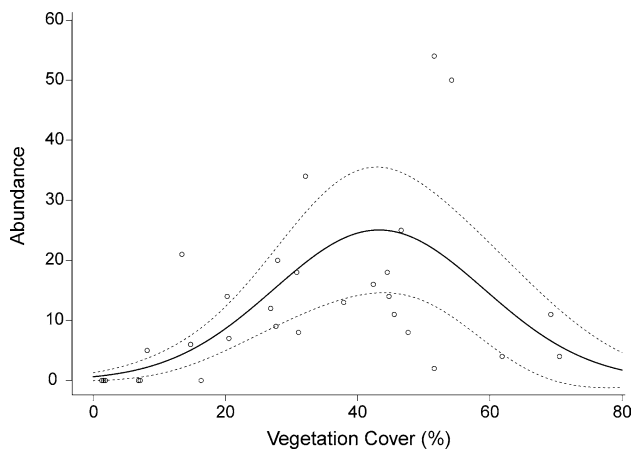
lower across all years (Fig. 4). In fact, we did not record a single adult in our surveys of swales 35 and 36, which are comprised of mostly active, open-sand habitat. Sex ratio of captured females and males was approximately equal (51.4% females) with low inter-annual variation (average: 50.9% females, SD 0.05%).

### Factors influencing the distribution of adults

A total of 384 adult *C. f. gibsoni* were recorded within the 30 m buffer zones around each pitfall trap (range 0–63 adults, mean 16, SD 15.6). In accordance with our analyses at the swale-level, adult counts were highest near pitfall traps located in the northwest and southwest region of the dune complex. We collected a total of 706 ants representing five genera and nine species in our pitfall traps. Two species, *Formica bradleyi* Wheeler and *Lasius neoniger* Emery accounted for 94.3% of the overall total (Online Resource

2). Although ant abundance varied widely between locations (range 0–119 ants, mean 23.5, SD 30.9), the prey availability model was less supported than the null model ( $D^2$ : 0.02,  $w_i < 0.001$ , Table 1), suggesting that the distribution of *C. f. gibsoni* is not related to ant abundance.

Larval abundance in the areas surrounding each pitfall trap also varied widely between locations (range 0–59 larvae, mean 10, SD 13.8). Although the larval habitat quality model had more support than the null model ( $D^2$ : 0.21,  $w_i$ : 0.003, Table 1), the observed positive relationship between depth to moisture and abundance of *C. f. gibsoni* contrasted with our predictions (i.e., high abundance in areas with shallow moisture depth, Table 1). Of the three a priori models we used to explain the distribution of *C. f. gibsoni* within the dune complex, the thermoregulation model had the greatest support ( $D^2$ : 0.44,  $w_i$ : 0.997, Fig. 5, Table 1). The result was a strong non-linear relationship between adult counts and vegetation cover, with peak abundance occurring



**Fig. 5** Relationship between adult abundance of *C. f. gibsoni* and vegetation cover for the 30 randomly selection locations in the dune complex. The dotted lines represent 95% confidence intervals and the solid line is the predicted relationship between abundance and vegetation cover

at approximately 35–50% vegetation (Fig. 5). Beyond this intermediate-level of vegetation cover, adult abundance declined substantially in both open, active-sand habitats with little vegetation (< 10%), and stabilized areas that were almost completely vegetated (Fig. 5).

## Discussion

Previous studies of tiger beetle populations in sand dune ecosystems indicate that rainfall is an important factor influencing inter-annual variation in population size (Knisley and Hill 2001; Gowan and Knisley 2014; Knisley et al. 2018). Although our study spans a relatively short period of only 3 years, our observations of the lowest and highest numbers of adults following years of below-average and above-average rainfall, respectively, suggests that rainfall also influences population dynamics in *C. f. gibsoni*. Large differences in the amount of rainfall observed between 2015 and 2016 (100 mm in May–June) corresponded to a relatively small (368 individuals, 25%) year-to-year change in population size. In contrast, long-term studies of *C. albissima* in the United States documented a decline in population size of 81.1% between 2002 and 2005, following a period of low rainfall between 2001 and 2003 (Gowan and Knisley 2014). Long-term studies are needed to determine potential impacts of multi-year droughts on the population size of *C. f. gibsoni*.

Abundances varied considerably across the dune complex and between sampling years; however, two general patterns in the distribution of *C. f. gibsoni* were notable. First, abundances were highest in the semi-vegetated habitats on the stoss side of the dune complex and in the northwest and southwest swales. In contrast, abundances were much lower

in open-sand habitats on the lee side of the dune complex and in the northcentral and southcentral swales. These findings generally agree with other studies that found *C. formosa* prefers sparse vegetation on blowouts, road cuts, and the periphery of active dune complexes (Hooper 1969; Acorn 1991).

Second, of the semi-vegetated swales, those in the northwest (swales 45–50) consistently supported the largest numbers of *C. f. gibsoni*. Here, approximately a third of the total population is concentrated within a small area about six hectares in size. The reason for such high localized densities of adults in these swales is not clear as macrohabitat characteristics did not obviously vary between this area and the other semi-vegetated swales. Similar localized distributions have been reported in other studies of tiger beetles including *C. albissima* where most of the population is limited to a small core area that contains important larval microhabitat (Knisley and Hill 2001; Gowan and Knisley 2014; Knisley et al. 2017, 2018). Although we recorded large numbers of larvae in swale 48, surveys in the other northwestern swales yielded much lower numbers (range 1–48 larvae, mean 18, SD 18.2), suggesting that localized distributions of *C. f. gibsoni* are not due to the quality of larval habitat per se. Nevertheless, swales in the northwestern region of the dune complex are important habitat for *C. f. gibsoni* and warrant further attention.

Previous studies have demonstrated that prey availability and quality of larval habitat are important factors influencing the distribution of sand dune tiger beetles (Knisley and Hill 2001; Gowan and Knisley 2014; Knisley et al. 2017). Our findings suggest that the distribution of *C. f. gibsoni* within the Elbow Sand Hills is not limited by these factors but is instead related to the greater thermal flexibility available in sparsely vegetated habitats (35–50% cover). Below, we discuss two lines of evidence supporting the inference that *C. f. gibsoni* distributions are influenced by temperature.

First, many tiger beetles use a maxithermal strategy where optimal body temperature occurs near their upper lethal limit (Dreisig 1980). Behavioural adaptations like sun-basking or stiling assist in thermoregulation and maintenance of body temperature even when ambient temperatures are suboptimal (Pearson et al. 2015). Sparsely-vegetated sand, where beetles can shuttle between shaded and exposed microhabitats, provides additional thermoregulatory control by allowing beetles to remain active for longer periods at high body temperature (Dreisig 1980, 1985; Acorn 1991; Hadley et al. 1992). This shuttling behaviour has been documented for numerous tiger beetle species (Dreisig 1980, 1984, 1985; Knisley and Schultz 1990; Hadley et al. 1992).

Second, the presence of extensive white maculations in *C. f. gibsoni* suggests that there is selective pressure for a phenotype with greater thermal tolerance (Acorn 1991). Studies comparing elytral colouration between *C. formosa*

subspecies showed that the heavy white maculations of *C. f. gibsoni* reflected more visible and near-infrared light than the metallic red elytra of *C. f. pigmentosignata* (Schultz and Hadley 1987). Furthermore, when the elytra of these subspecies were heated using artificial light, those of *C. f. gibsoni* were on average 2.2 °C cooler than the elytra of *C. f. pigmentosignata* (Schultz and Hadley 1987). The significance of elytral colouration as an adaptation for greater thermal tolerance is also supported by the prevalence of light colouration observed in open-sand species like *C. lepida* Dejean and *C. limbata* Say (Acorn 1991). In fact, Acorn (1991) suggested that temperature, not predation or competition, best explained the observed habitat associations of sand dune tiger beetles, including *C. formosa*. Existence of prominent thermoregulatory adaptations suggests that temperature is an important factor influencing the distribution and ecology of *C. f. gibsoni*.

Based on our findings, we believe that ongoing dune stabilization poses a significant threat to *C. f. gibsoni* populations. Implementation of management strategies that reduce vegetation cover should increase habitat for this species. Although most *C. f. gibsoni* populations occur within protected areas (i.e., provincial parks), natural disturbances (e.g., fire) that influence dune successional dynamics in these protected areas have been significantly altered. In the absence of management actions, dune stabilization and loss of *C. f. gibsoni* habitat is likely to continue (Knisley 2011).

In their study outlining major impediments to insect conservation, Cardosa et al. (2011) highlight the lack of baseline information on insect abundance and changes through time (i.e., the Prestonian shortfall) and the incomplete knowledge regarding species' sensitivity to habitat change (i.e., the Hutchinsonian shortfall). Our study addressed these ecological shortfalls by providing the first reliable estimate of population size for *C. f. gibsoni* over a three-year period and by examining changes in abundance and vegetation cover that might occur with ongoing dune stabilization. This work, together with other recent studies (Gowan and Knisley 2014; Knisley et al. 2016; Knisley and Brzoska 2018), adds to a growing body of literature demonstrating that tiger beetles are well-suited to the study of population dynamics and environmental change.

## Conclusion

Our population estimates indicate that the number of adult *C. f. gibsoni* varied from a low of 1106 to a high of 1474 individuals, possibly due to inter-annual variation in May–June rainfall. Adult abundances were highest in sparsely vegetated habitats (35–50% cover), especially in the northwestern swales where a third of the population is concentrated within a small area. Distribution of adults was not related to prey

availability or larval habitat quality. Rather, we hypothesize that lower temperature provided by shade in the sparsely-vegetated habitats is the primary factor explaining the distribution of adult *C. f. gibsoni* within the Elbow Sand Hills.

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## Compliance with Ethical Standards

**Conflict of interest** All authors declare that they have no conflict of interest.

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