Simulating the implications of recreational disturbance on Karner blue butterflies (*Lycaeides melissa samuelis*) at the Indiana Dunes National Lakeshore.

Technical report

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Victoria J. Bennett, Oregon State University
Patrick A. Zollner, Purdue University
Vanessa S. Quinn, Purdue North Central University

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Questions regarding this report should be directed to:

Patrick Zollner
Department of Forestry,
Purdue University,
195 Marsteller Street
West Lafayette, IN, 47907-2033
phone: 765-496-9495, Fax: 765-496-2422

e-mail: pzollner@purdue.edu
web: http://www.ag.purdue.edu/fnr/pages/pzollner.aspx

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Summary

Background and approach

Site and wildlife managers globally are under increasing pressure to implement management strategies that address the negative implications of outdoor recreational activities on wildlife (Forrester et al. 2005). Numerous case studies demonstrate that recreation disrupts breeding success, survival, and abundance of a diverse array of species. Identifying the mechanisms and implications of anthropogenic disturbance on wildlife populations, particularly those of conservation concern, may be critical to their preservation. The federally endangered Karner blue butterfly (*Lycaeidea melissa samuelis*) is one such species. Its remaining populations are restricted to small isolated habitat fragments. Understanding the potential factors, such as recreational disturbance, that threaten the Karner blue at these sites is a research priority. However, to date no studies have been undertaken to examine the implications of recreational disturbance on this species or any other butterfly species. Moreover, it may not be appropriate to undertake empirical studies the implementation of which could have detrimental implications for this federally endangered species. To address these issues, we used a spatially-explicit individual-based simulation model (known as Simulation of Disturbance Activities, SODA) to explore the implications of recreation on Karner blue butterfly at the Indiana Dunes National Lakeshore. By applying species- and site-specific parameters (collected via targeted field studies) across a range of scenarios (defined conditions relating to the site composition, recreational usage and wildlife characteristics) we used SODA to explore circumstances beyond the scope of empirical studies alone. This approach, enabled us to investigate 1) how female Karner blue butterflies are affected by recreational disturbance, 2) the impact of disturbance on oviposition rate, 3) the impact of disturbance on host plant usage and 4) how effective alternative management strategies would be at alleviating the negative implications of recreational disturbance. In accordance with species recovery plan research priorities, a primary objective of this project was to identify, devise and inform managers of active management strategies that could be implemented to minimize recreational disturbance to the Karner blue butterfly.

Results

Our simulation exercises revealed that the frequency of disturbance experienced by female Karner blue butterflies due to recreational activities decreased with increasing habitat width from the public access trail. These varied levels of disturbance corresponded closely to oviposition rate. That is significantly fewer eggs were laid by females within habitat extending 10 m and 15 m from the trail. In these extents and up to 20 m from the trail, eggs were not uniformly laid across the available habitat. We found that oviposition events were concentrated to host plants furthest from the trail.

Implications for management

Our findings confirm that Karner blue butterflies are subject to recreational disturbance and that their breeding success can be detrimentally impacted by this disturbance. This impact was found to be directly associated with the amount of suitable habitat that extends from the trail. Our findings indicate that habitat patches in proximity to trails and other public rights of way should extend a minimum of 25 m from that trail. In this way it is possible to offset the implications of recreational disturbance.

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Introduction

The negative impact of eco-tourism and outdoor recreational activities on wildlife is a growing concern for site and wildlife managers globally (Boyle & Samson 1985, Flather & Cordell 1995, Bosworth 2003, Christ et al. 2003). Numerous case studies demonstrate that recreation disrupts breeding success, survival, and abundance of a diverse array of species (Strauss & Dane 1989, Frid & Dill 2002, Beale & Monaghan 2004). Identifying the mechanisms and implications of anthropogenic disturbance on wildlife populations, particularly those of conservation concern, may therefore be critical to their preservation (Gutzwiller et al. 1998, Frid & Dill 2002, Webb & Blumstein 2005).

The Karner blue butterfly (*Lycaeidea melissa samuelis*) is a federally endangered species and its remaining populations are restricted to small isolated habitat fragments across seven states (Clough 1992, Andow et al. 1994, USFWS 2008a, USFWS 2008b). Many of these sites are therefore crucial to the persistence of these butterflies, and act as key source and donor sites in ongoing recovery programs. As part of these active recovery plans, where remnant habitats lay within public lands they are afforded a high level of protection and restoration management (Smallidge et al. 1996; USFWS 2003, MDNR 2007; USFWS 2008c; WDNR 2009). Subsequently, management efforts are focused on ensuring that conditions at these sites are such that population growth is maximized. Any activities reducing the productivity of these sites are a concern and thus a research priority. Subsequently, a species recovery plan was developed in 2003 to address the potential factors threatening population persistence at existing Karner blue sites (USFWS 2003). Among the research priorities identified in this plan, one outlined the need to understand the implications of public access at sites containing the Karner blue and to determine how to offset the negative impacts, if any, through appropriate management.

To date there has been no literature published specifically investigating the effects and/or management implications of human (recreational) disturbance to the Karner blue butterfly or any other butterfly species. Despite this, many studies have documented the consequences of recreational disturbance across a range of taxonomic groups, including birds (Baines & Richardson 2007, Banks & Bryant 2007, Ferandez-Juricic et al. 2007), mammals (Borkowski et al. 2006, Hodgson & Marsh 2007), reptiles (Manor & Saltz 2005, Amo et al. 2006, Dodd et al. 2006), amphibians (Rodrıguez-Prieto et al. 2005) and invertebrates. Of the latter, the majority of studies have focused on addressing the effects of recreational disturbance on marine invertebrate communities, particularly those in intertidal and infralittoral areas, coral reefs, and seagrass meadows (Addessi 1994, Kimberling et al. 2001, Milazzo et al. 2002, Lucrez et al. 2008). We found no published examples of studies on Web of Science (to date) that investigated the implications of recreational activities on terrestrial invertebrates. However, there were a number of studies that explored habitat disturbance by humans. These demonstrated that invertebrate biodiversity was negatively correlated to the degree of disturbance (Ohwaki et al. 2003, Hogsden & Hutchinson 2004). Another pattern that emerged from these studies was that more specialized species (such as species with one specific larval host plant compared to with species that have a number of potential host plant species) are more sensitive to anthropogenic disturbance than generalist species (Ohwaki et al. 2003, Masahiko 2004, Akite 2008; Nilsson et al. 2008). Based on this, many investigators have speculated that specialized species should display a higher level of sensitivity to recreational activities. Consistent with this prediction, a number of wildlife and site managers who have observed and/or raised concerns regarding disturbance-related behavior among specialist butterfly species (pers. comms. Ann Potter, Wildlife Biologist for the Washington Department of Fish and Wildlife, and Heather Keough, District Wildlife Biologist for the USDA Forest Service in Michigan).

The Karner blue butterfly is considered to be a specialist, restricted to wild lupines (*Lupinus perennis*) as its larval host plant and has strict habitat requirements (e.g. pine oak barrens where this lupine spp is found; Lane and Andow 2003). As such we hypothesized that the Karner blue would be sensitive to recreational disturbance (Smith et al. 2002). In May 2008, as part of a Senior Research Grant from Indiana Academy of Science (IAS) we undertook field work to establish whether the Karner Blue at a site (Inland Marsh) in Indiana Dunes National Lakeshore on the southern edge of Lake Michigan was sensitive to recreational disturbance (Fig. 1). From July to August 2008, undergraduates from Purdue North Central University and Butler University carried out targeted surveys to explore the disturbance-related responses of the adult butterfly to trail users. The results of this study revealed that the female Karner blue butterflies were significantly sensitive to recreational disturbance. Females were found to flush when recreationists passed within 421 cm in proximity to them and would fly for longer periods than males following a flushing event before returning to a natural behavior (such as basking, nectaring, mating, and ovipositing). Thus we established that females exhibited sensitivity to recreational activities in proximity. This raised the question 'what are the implications of such disturbance, if any'. Depending on how sensitive females are, the implications could include increased competition for larva host plants furthest from recreational trails (Boggs 2003), a decrease in oviposition rate (i.e. potentially decreasing the number of eggs laid over an individual's flight period; Rutowski 2003) and higher energetic costs incurred due to exhibiting disturbance-related behavior (Gibbs et al. 2010). Ultimately, these lead to a reduction in breeding success and potentially adult survival (Doak et al. 2006).

As part of an Illinois-Indiana Sea Grant and in line with recovery plan research priorities, we explored the effects of recreation on ovipositing Karner blue butterflies, a life history period when the butterfly is particularly vulnerable to disturbance (Boggs 2003). For this project, we adopted a simulation modeling approach. Many studies have shown that simulation models provide an effective means to investigating anthropogenic disturbance on wildlife (Finke et al., 2008; Friar et al., 2008). This is particularly true when dealing with wildlife species for which field studies that capture, disturb and/or kill (directly or indirectly) individuals are discouraged (Murphy 1988, Brown & Boyce 1998). Another clear advantage of this approach is that it provides invaluable insights into the consequences of disturbance and management options without conducting years of complex and potentially detrimental empirical investigations (Murphy 1988). Simply put simulation models can provide a less intrusive means of exploring the implications of recreation on wildlife within a relatively short time scale (Beissinger et al. 2006, Beale 2007, Drewitt 2007). This is especially important when working with species of concern that require wildlife and site managers to implement management and recovery strategies immediately (Williams et al. 2002, Dale 2003; Lurz et al. 2003). Modeling simulations therefore represent essential tools that can not only be used to inform management and restoration efforts at existing sites(West and Caldow 2006; Montgomery et al. 2009), but also at sites selected for reintroduction schemes (Knight & Temple 1995, Larson 1995, USFWS 2003). To demonstrate this, we used a spatially-explicit individual-based simulation model (known as Simulation of Disturbance Activities - SODA) to explore the implications of recreation on the breeding success of the Karner blue butterfly along the Inland Marsh trail in the Indiana Dunes National Lakeshore.

Figure 1 Map of Indiana Dunes National Lakeshore. Zoomed section represents Inland Marsh Trail.

Objectives

To use a simulation tool parameterized with empirical data collected in 2009 and 2010:

1) To assess how recreation influences the behavior of the endangered Karner blue butterfly at Indiana Dunes National Lakeshore, IN.

2) To identify and predict the implications of such disturbance-related behavior on oviposition rate and larval host plant selection by the Karner blue butterfly.

3) To identify and devise active management strategies and site designs minimizing recreational disturbance to the Karner blue butterfly at sites with existing populations and restored sites proposed for the species re-introduction.

These measures will comprise vital contributions to fulfilling the objectives and goals set out in the Karner Blue Species Recovery Program which both Illinois and Indiana are required to address.

Approach

In 2010, the Illinois-Indiana Sea Grant award enabled us to use the field data collected in 2009 along with additional data collected in 2010, to parameterize an existing simulation modeling tool, Simulation of Disturbance Activities (SODA; Bennett et al. 2008, Bennett et al. in revision). By employing this model, we were able simulate the daily movement patterns of virtual female Karner blues and their responses (such as flushing) to a variety of recreational activities in a site-specific virtual environment. Through a series of simulation runs we were able determine if females are spending significantly extended periods of time exhibiting disturbance-related behavior, the extent to which oviposition rate varies among females disturbed by a range of recreational circumstances, and host plant selection. For the latter we were able to map the patterns of oviposition activity across available host plants. We determined if there are any significant implications of recreational disturbance on host plant selection and to what extent (i.e. we revealed whether there were any gradients of disturbance). As part of this project, we also explored whether current site-specific habitat management practices were alleviating, exacerbating, or having no influence upon the implications of recreational disturbance. We intended that this research would provide valuable insights that could be used to inform management and restoration efforts not only at existing sites, but also at sites selected for reintroduction schemes (Chan and Packer 2006). This in turn complies with recovery plan objectives to establish viable Karner Blue populations. We therefore envisage that the management and site recommendations established from our investigations will feed directly into the active recovery plan programs of these and other endangered and threatened lycaenid butterfly species (Montgomery et al. 2009).

Methods

Model Overview

SODA is a non-species specific spatially explicit individual-based model for exploring the effects of spatial and temporal patterns of anthropogenic disturbance on wildlife (Bennett et al., 2009; Fig. 2). Using site-specific maps created in ArcGIS (ESRI, Redlands CA), SODA simulates the daily movement patterns of individuals and their responses to a variety of human activities (e.g. hiking, dog walking, horse riding, etc). For this project SODA was more specifically used to simulate the oviposition activities of female Karner blue butterflies and their responses (such as flushing) to the types of recreation undertaken along the Inland Marsh public access trail in the Indiana Dunes National Lakeshore (e.g. walking, running, and dog walking).

Another feature of SODA is that it allows users to vary parameters associated with the environment, wildlife and/or recreationists. In this way the user can assess the responses of wildlife to a diverse array of possible scenarios. For example, the user can explore how effective management strategies (or combination of strategies) and restoration efforts will be at a given site. For this project we varied the spatial extent of suitable habitat in proximity to the Inland Marsh trail available to ovipositing females, the extent to which females responded to recreationists and the recreationist density along that trail. Through a series of simulations we explored how alternative scenarios would affect the number of disturbance events experienced by female Karner blue butterflies over the course of the oviposition period, the number of eggs laid and the locations of lupines selected by virtual females.

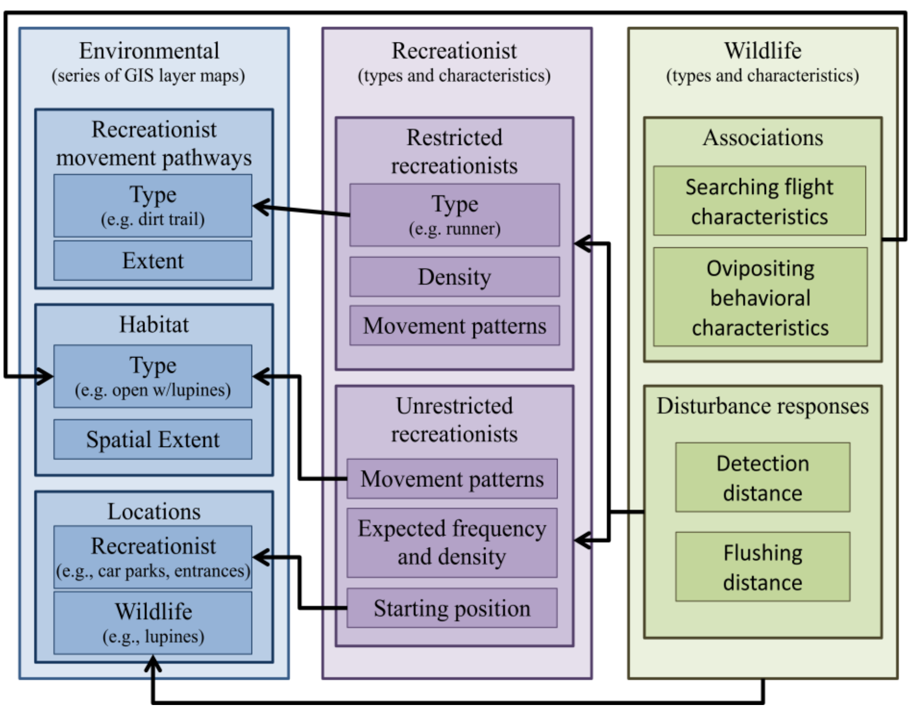

Figure 2: A conceptual delineation of the variables and parameters used to define model structure.

A full model description is provided in Bennett et al., 2009. However, in the following sections we provide a more detailed account of how model parameter space was constructed using empirical data collected from targeted field surveys undertaken in 2009 and 2010. We also discuss the alternative scenarios that were built and tested to help inform future management efforts towards Karner blue butterfly recovery. Finally, we detail how simulation output was analyzed.

Model Parameterization

Temporal Parameters

There are two temporal parameters required to populate SODA. These include the period across which the simulation runs and timestep length (Table 1). The latter dictates how fine-scale the movement paths of virtual wildlife will be and thus the simulation output. Using longer timestep durations such as an hour or day provides more broad movement paths showing, for example, the landscape-scale migration of monarchs (*Danaus plexippus*)), while smaller timesteps of minutes or less provide more detailed movement, such as zigzagging flight patterns of butterflies searching for host plants. For this project we focused on the ability of virtual females to oviposit successfully in the presence of recreationists and on the locations of host plants females selected. To capture this level of detail, timestep length was set at 45 seconds. This was based on observational data that female Karner blue butterflies could locate a host plant and lay one egg within a minimum of 15 minutes (Pickens and Root 2008b). Any disturbance experienced within that time would result in a female restarting the process (i.e. beginning with searching for a suitable host plant). Applying 45 second timesteps enabled us to collect data on the number of eggs successfully laid, the number of disturbance events experienced by individuals and the locations and frequency at which host plants where selected.

Simulations were also set to run for a duration that represented the oviposition period of female Karner blues. The maximum number of eggs laid by wild females taken into captivity is 88 (Herms et al. 1996). Assuming that females could have laid eggs prior to capture and that females consistently lay across a period of several days (Knutson et al. 1999; Grundel et al. 2000; Guiney and Andow 2009), we set simulation length at 4 days, encompassing 96 potential oviposition events.

Table 1 Temporal parameters used to populate SODA.

Temporal scales	
Length of simulation e.g., year, season or activity period	4 days
User specified timestep length	45 seconds

Virtual Environment

A virtual environment representing the types and extent of habitat, the position and extent of the trail, and spatial arrangement of host plants at the Inland Marsh site was built in ArcGIS using trail maps, aerial photographs and habitat assessments conducted during field surveys. By applying conditions equivalent to the existing site, we were able to 1) simulate more realistic patterns of movement by virtual butterflies, 2) validate our model output with the patterns and behaviors observed in the field and 3) provide valuable insights on future site management for the Karner blue population at Inland Marsh.

Table 2 provides all the basic parameters used to construct the GIS maps associated with each simulation run in SODA. Each comprised three GIS shape files; one representing the full extent of the trail at Inland Marsh, one delineating the spatial arrangement of individual lupine plants within 'suitable habitat'(discussed in more detail in the Scenario section below) and one map representing the habitat composition of the site. For the latter, we simplified the habitat types to characterize 'suitable' (with lupines) and 'unsuitable' (without lupines) habitat.

Initially, we produced a habitat map which encompassed all the areas at Inland Marsh that we found to contain lupines and a breeding population of Karner blue butterflies. However, as areas containing lupines were separated by a minimum of 100 m from each other, individuals moving between these patches would be effectively dispersing. In other words, females would not be laying eggs during this movement behavior. Studies have shown that individuals can travel a maximum of 100 m over several days (Knutson et al 1999). As our simulation length only encompasses 4 days than simulating this 'between patch movement' would make it difficult to distinguish whether oviposition success was reduced as a result of this movement or by recreational disturbance. Furthermore, we do not know the probability of inter-patch movement, a parameter we would need to simulate the movement dynamics of the butterfly appropriately. Therefore, we parameterized the model to minimize females moving between habitat patches. As studies and field observations suggest a female first locates an area with a number of suitable host plants. That female then will remain in the area once she starts to lay a clutch of eggs (Pickens and Root 2008b). However, we did allow virtual females to be flushed out of the suitable habitat by recreationists. We set up each simulation so that if the females were flushed into unsuitable habitat there was a 50% probability that they would return to the suitable habitat patch. This parameter was based on the return rate of flushed Karner blues observed and recorded in the field surveys (Pers Obs.).

In addition, to enable us to more clearly demonstrate the implications of recreation on Karner blue oviposition, the quality of suitable habitat represented in our simulations was reduced to one patch. This patch represented an existing area of suitable Karner blue habitat that runs parallel to the Inland Marsh trail for over 300 m. A 100 m length segment of this area was depicted in the habitat maps used to populate SODA. This segment was deemed sufficient to capture the movement and oviposition behavior of individual butterflies over the course of the simulation. For practical purposes, it also allowed us to explore host plant competition more effectively (discussed in detail in the Scenarios section below) and minimize the length of simulation run times, so they were not unnecessarily long.

Table 2 Spatial parameters used to populate SODA.

Environmental characteristics		
Spatial scale		
User specified unit		Meters
Habitat patches		
Type	Managed habitat containing	Unsuitable habitat

	lupines	
Location and size	**Varies with width from public access trail:** a) 10 m b) 15 m c) 20 m d) 25 m e) 30 m	Represents all other habitats found in the Inland Marsh site.
Paths	**Consistent through scenarios:** 1 designated trial equivalent to that present at the Inland Marsh site.	
Host plants		
Number	Varies with width of habitat a) 75 (10m) b) 104 (15m) c) 145 (20m) d) 178 (25m) e) 203 (30m)"	
Spatial arrangement	5 randomly distributed	1 evenly distributed

Wildlife Parameters

As part of an IAS Senior Research Grant award, undergraduates from the Purdue North Central University and Butler University undertook targeted observational surveys to explore the responses of Karner blue butterflies to recreation along the Inland Marsh trail. From late-July to the end of August 2009, observers positioned along the trail recorded all activities exhibited by Karner blues in the presence and absence of recreationists. Behavior such as basking, nectaring, flushing (a disturbance response), searching flight, ovipositing, mating and interactions with conspecifics were noted, along with the duration of these activities, distances travelled after being flushed and the locations of butterflies when basking, nectaring, mating and ovipositing. From these observations we extracted data recorded on ovipositing females only. We established that three behavioral modes would be required to simulate the movement dynamics of ovipositing females. These included two natural behaviors; host plant searching flight and ovipositing, and one disturbance response; flushing. Durations collected on ovipositing females in 2009 enabled us to set temporal parameters (Table 1). While searching distances, host plant selection criteria, turning frequencies and flight speeds enabled us to simulate a host plant searching behavior equivalent to female Karner blues observed in the wild. The latter two parameters were collected during additional surveys undertaken in 2010.These were conducted specifically to provide more detailed data in the movement characteristics of Karner blue butterflies.

From the 2009 survey data, we also established parameters that characterized the disturbance-related behavior flushing. These parameters included detection distance (the distance from recreationists that females flush) and flushing distance (the distance individuals fly once flushed before returning to a natural behavior). Table 3 provides all the values used to parameterize the female Karner blue butterfly behavior in the absence and presence of recreationists.

Table 3 Wildlife parameters used to populate SODA.

Wildlife	
Number of butterflies per simulation	5 females
Behavioral modes	1) Ovipositing
-	2) Searching for host plants (flying)
Ovipositing	
Egg laying frequency	1 per 15 minutes
Maximum number of eggs laid	96
Searching	
Flight speed	0.55 m per timestep
Turning frequency	0.239
Probability of selecting an alternative host plant per oviposition event	100%
Search distance minimum	5 m
Search distance maximum	100 m
Behavioral responses to disturbance	Flushing
Detection distance	3 scenarios generated:
	1) 0.62 m (minimum)
	2) 1.74 m (average)
-	3) 4.21 m (maximum)
Flushing distance	3 scenarios generated:
	1) 0.55 m (minimum)
	2) 1.65 m (average)
-	3) 3.85 m (maximum)

Recreationists Parameters

From the observational field surveys conducted in 2009, three types of recreationist were found to regularly use the trail at the Inland Marsh site during the adult flight period of the Karner blue butterfly. These included walkers, runners, and runners with dogs. Field surveys showed that on weekdays (when the surveys were undertaken) there would be an average of 3 recreationists on site when the butterflies were active. To ensure that the probability of disturbance was equivalent to that experienced by butterflies in Inland Marsh, recreationists were set to persist throughout the duration of the simulation so they would travel back and forth along the trail as realistically as possible.

Table 4 provides the parameters used to populate SODA, including the characteristics that define each type of recreationist.

Table 4 Recreationist parameters used to populate SODA.

Recreationists	
Type	1) Walker
	2) Runner
-	3) Runner with unleashed dog
Speed	1) 7 m/TS
	2) 14 m/TS
-	3) 14 m/TS
Persistence	288 TS
Density	3 scenarios generated:
	1) 3 (recorded)
	2) 6
-	3) 9
Frequency	
Daily activity patterns	10am to 4pm
Associations between type of path and type of HMO	All recreationists are associated with designated path.

Scenarios

To explore the effectiveness of alternative management strategies using SODA, we constructed a series of scenarios (simulations with alternative parameter spaces). Each scenario allowed us to explore and compare how simulated wildlife individuals would respond under a different set of defined conditions. For this project, we varied the spatial extent and arrangement of host plants, the density of visitors at the site and extent to which female Karner blue butterflies responded to recreationists using the trail. The details of these alternative scenarios are discussed below.

Spatial extent of host plants

To explore whether the extent of suitable habitat from the trail influences the reproductive success of the Karner blue butterfly, we created a series of scenarios in which the width of suitable habitat was varied. Five alternative habitat-associated GIS maps were generated containing suitable habitat extending for 10 m, 15 m, 20 m, 25 m and 30 m from the trail respectively (hereafter referred to as 'habitat extents'; Table 2). Note that at Inland Marsh site suitable habitat currently extends 10 m to 20 m from the trail.

By creating these alternative scenarios we were able to explore whether the extent of suitable habitat from the trail increases disturbance rates, decreased oviposition rates and increased host plant competition (i.e. eggs are not evenly distributed across the available host plants).

Spatial arrangement of host plants

As the positions of individual lupine plants in the wild are not fixed from year to year, but instead dynamic (dictated by seed dispersal and inter- and intra- plant competition), we had to ensure that the virtual movement patterns of butterflies generated in our simulation exercises were not dependent on the spatial arrangement of lupines applied to SODA. To test this we created a set of scenarios in which the spatial arrangement was varied. Using Hawth's Analysis Tools for ArcGIS (Beyer, 2004) we randomly generated the locations of lupine plants within areas of suitable habitat. To maintain the density of lupines throughout our simulations, we increased the number of lupines to correspond with habitat extent (totals provided in Table 2). In addition, the minimum distance between lupines was set at 1 m. This represented an average distance equivalent to that observed in the habitat assessment surveys conducted at Inland Marsh. For each of the 5 alternative habitat extents we generated five randomly distributed host plant scenarios and 1 uniformly distributed host plant scenario. Thus a total of 30 sets of GIS maps were built each representing an alternative habitat-associated scenario.

Visitation

As field surveys were only conducted on weekdays, this provided a minimum representation of the visitor numbers expected at Inland Marsh. By only applying this level of visitation we may be underestimating the level of disturbance experienced by Karner blue butterflies and in turn underestimating the impact of disturbance on oviposition rates and host plant selection. Note that the weekend usage of the Inland Marsh trail by recreationists could potentially span 50% of the period individual females spend ovipositing. Thus to explore the outcome of increased visitor numbers we generated two alternative recreation-associated scenarios. These were based on the actual carrying capacity of the parking facility available at Inland Marsh. This delimits the maximum number of visitors that could potentially be using the site at any one time. The parking facility consists of 19 parking spaces. Thus we explored the potential implications of a full parking facility. We assumed that the types of recreationists visiting the site on weekends would be similar to those visiting the site on weekdays and we assumed that the density and distribution of these types of recreationist would also be similar. Subsequently, we generated a scenario with 6 walkers, 6 runners and 6 runners with dogs. A second alternative scenario was generated to explore the implications of a half full parking facility. This intermediate scenario included 3 walkers, 3 runners and 3 runners with dogs.

Disturbance responses: a sensitivity analysis

Over the surveys undertaken in 2009, the responses of female Karner blue butterflies to recreationists were recorded. These results demonstrated a range of responses with some individuals being very sensitive to disturbance and others being tolerant. For example, sensitive individuals were flushed by visitors at further distances and fly for longer before returning to a natural behavior. To explore the implications of this range of responses for individual female Karner blue butterflies, we conducted a sensitivity analysis. We built 3 alternative wildlife-associated scenarios; 1) incorporating the maximum response parameters recorded in field surveys, 2) comprising the minimum response parameters recorded and 3) an average of all the response data collected.

Replicates

A total of 150 scenarios were constructed consisting of various combinations of the 30 habitat, 3 recreation and 3 wildlife-associated alternative parameters. For each scenario, we ran the simulation 6 times which gave us the movement patterns and oviposition choices of 30 virtual female Karner blue individuals. In total 900 simulations were run.

Analysis

For each simulation output, we determined the number of disturbance events experienced by virtual butterflies, the number of eggs laid (out of a maximum of 96), the number of timesteps spend at a particular host plant and the distance from the trail of that host plant. While the former two represent variables pertaining to individual virtual females (as replicates), the latter two represented a combination of data collected from replicate simulations (i.e. the 6 simulations which only varied in number seed). This enabled us to gain clearer patterns of host plant selection. For this, we disseminated visitation and lupine positions into zones. Each zone encompassed 2.5 m of the suitable habitat extending out from the trail. A total of 12 zones were determined, starting at 0 m from the trail and extending to 30 m (the edge of the furthest extent of suitable habitat simulated). The number of timesteps in which butterflies spent on lupines within each zone were tallied for each of 150 alternative scenarios.

Statistical analyses were undertaken to assess any significant differences between disturbance and oviposition rates of individual butterflies among different scenarios, to establish if there was any significant variation in the distribution of lupine visitation across suitable habitat within scenarios and whether the pattern of distribution significantly changed with increasing habitat extent.

We used a series of ANOVAs (analysis of variance, PROC GLM) and regression analyses (PROC REG) to analyze our data. We conducted four separate series of analysis that focused on each alterative set of scenarios relating to habitat (i.e. the spatial extent of habitat and the spatial arrangement of host plants), recreation (i.e. visitor density) and wildlife (i.e. the level of disturbance responses by butterflies). For each set, an ANOVA was used to compare 1) disturbance rates, and 2) oviposition rates, and a regression analysis was used to compare host plant selection among the various zones.

Results

Each of the sections below represent one of the four sets of analysis we conducted to explore each of the alterative sets of scenarios relating to habitat (i.e. the spatial extent of habitat and the spatial arrangement of host plants), recreation (i.e. visitor density) and wildlife (i.e. the level of disturbance responses by butterflies).

Spatial extent of host plants

Frequency of disturbance

The frequency of disturbance experienced by female Karner blue butterflies decreased exponentially as the width of suitable habitat extending from the trail increased (Fig. 3). A one-way ANOVA confirmed that this frequency of disturbance significantly differed between habitat extents ($F_4=20.25$, $P<0.0001$).

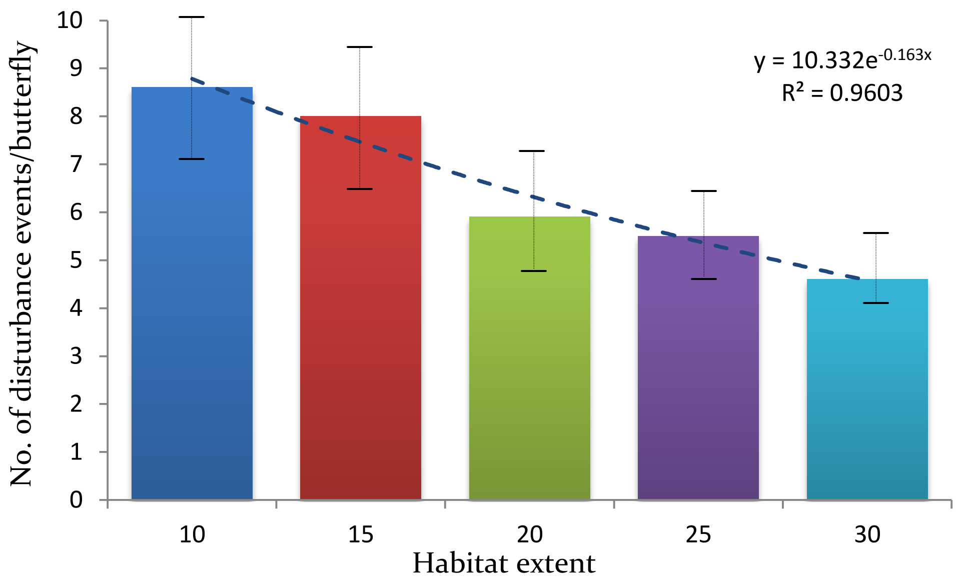

Figure 3: Level of disturbance experienced by virtual female Karner blue butterflies within different habitat extents along the Inland Marsh trail. In this chart the level of disturbance is represented by the average number of disturbance events experienced by individuals across all the scenarios run. An exponential trendline best fit the data and error bars delineating standard deviations are included.

Oviposition rate

Fig. 4 shows that the virtual Karner blue females were closer to achieving their oviposition potential when habitat extended 20 m or more from the trail. The difference in oviposition rate between 10 m & 15 m habitat widths, and 20 m, 25 m, & 30 m widths was greater than 10%. A one-way ANOVA confirmed that this increase in oviposition rate was significantly different ($F_4=90.68$, $P<0.0001$).

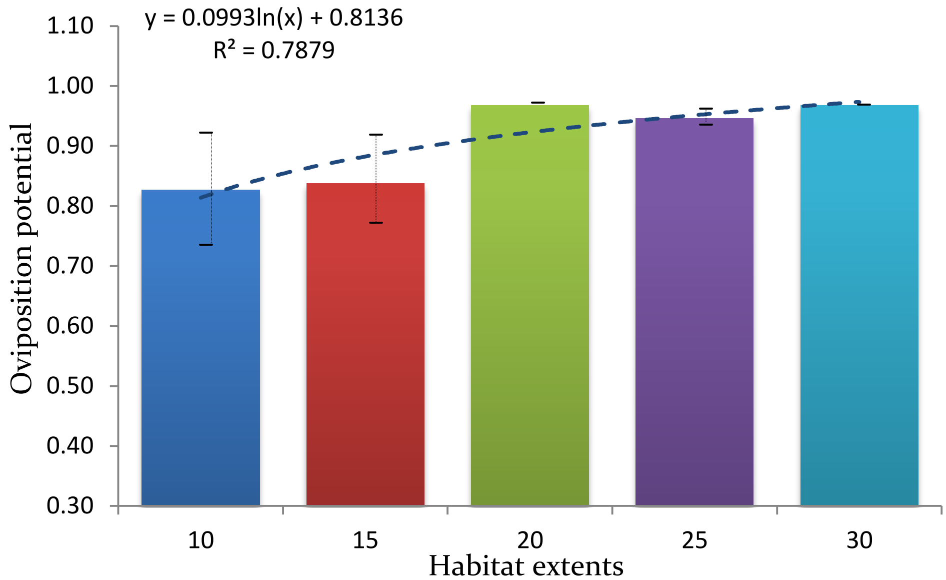

Figure 4: Oviposition potential reached by virtual female Karner blue butterflies within different habitat extents along the Inland Marsh trail. This chart represents the average oviposition potential of individuals across all the scenarios. A logarithmic trendline best fits the data and error bars delineating standard deviations are included.

Figs. 5 and 6 further reveal that there are two factors that contribute to the reduction in oviposition rate of female Karner blue butterflies. The first is that the number of females flushed from their habitat patch without returning was much higher among the smaller habitat extents. The second is that among those individuals that remained in the patch for the duration of the simulation, laid significantly lower numbers of eggs in the smaller habitat extents

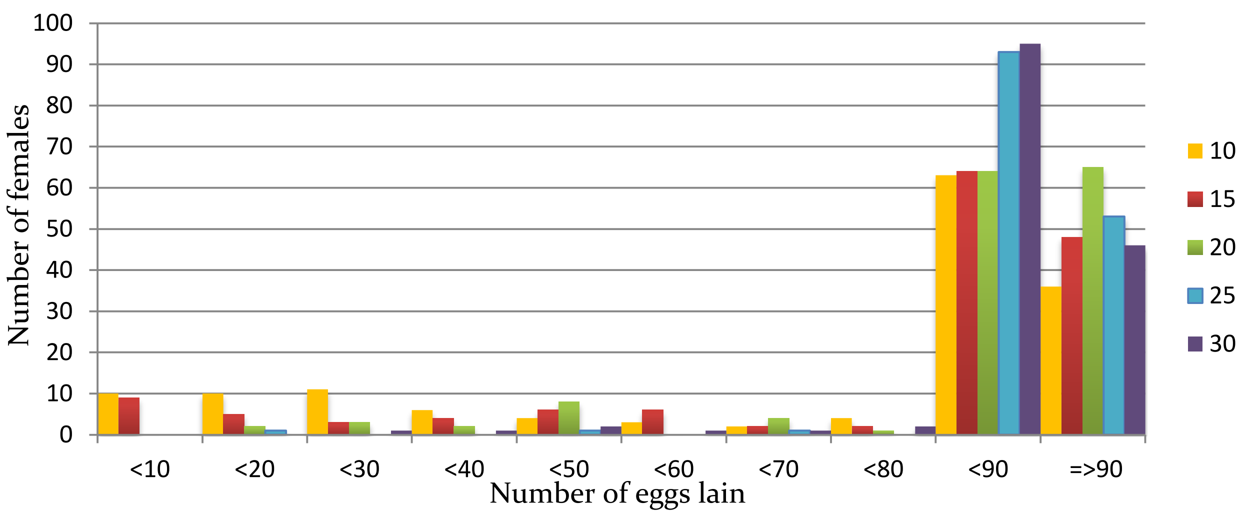

Figure 5: Distribution of virtual female Karner blue butterflies based on oviposition success within suitable habitat varied by width in the presence of the minimum number of recreationists (as an example) expected along the Inland Marsh trail. The legend represents each habitat extent.

Fig. 5 shows that not only were more females flushed from habitats extending 10 m to 20 m from the trail but that virtual individuals were consistently flushed throughout the duration of the simulation. In comparison, Fig. 6 more clearly reveals that the number of eggs lain by females across the duration of the simulation increases with increasing habitat width.

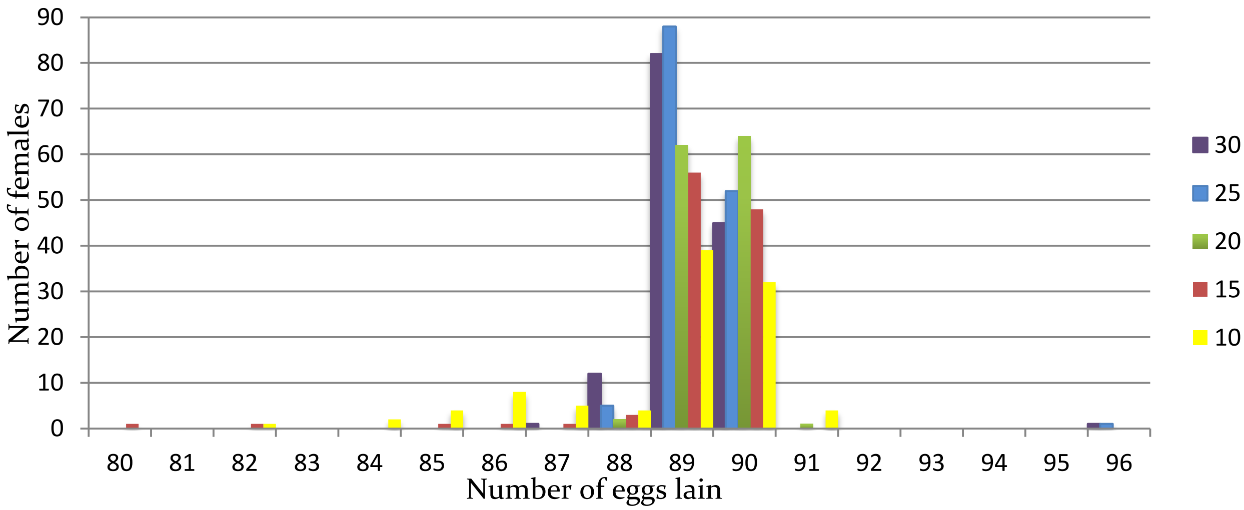

Figure 6: Distribution of virtual females that lay between 80 and the maximum number of eggs in different habitat extents in the presence of the minimum number of recreationists expected along the Inland Marsh trail. The legend represents each habitat extent.

Host plant selection

Across all the scenarios simulated, host plant selection by virtual female Karner blue butterflies varied significantly (F_5=84.56, P<0.0001). In a regression analysis this variation was attributed primarily to habitat extent (R_2=0.2165) and secondarily to the positions of host plants within these extents (R_2=2604). In other words, among the 5 different habitat extents the distribution of host plants selected by females varied; a pattern that can be seen in Fig. 7. It illustrates that in habitats extending up to 20 m from the trail, the number of visits and/or length of time females spent at host plants was not evenly distributed across the habitat patch. Instead visitation was concentrated to host plants furthest from the trail. In comparison, across habitat patches that extended beyond 20 m, host plant selection was more uniformly distributed.

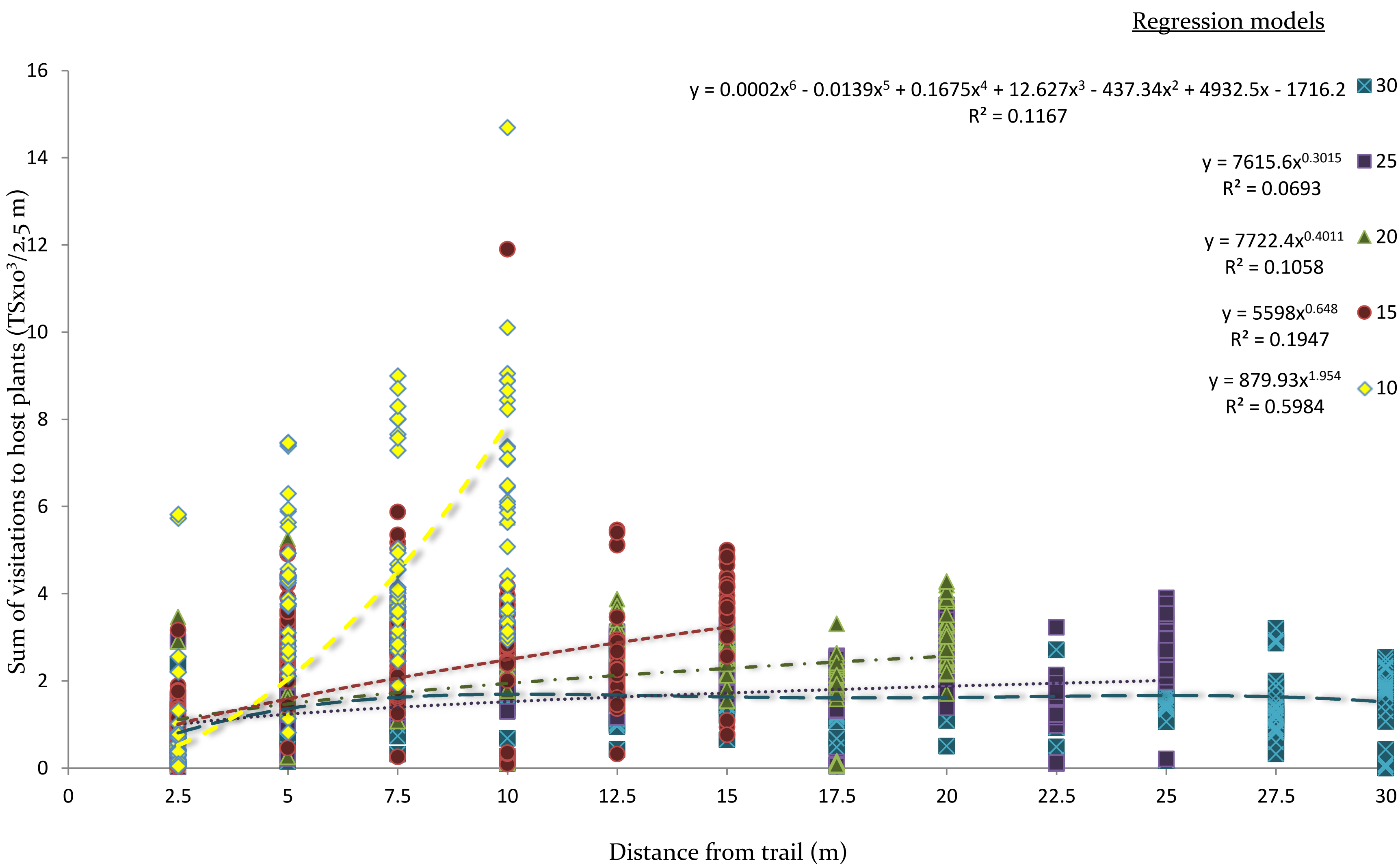

Figure 7: Distribution of host plant selection by virtual female Karner blue butterflies across each habitat extent across all scenarios. Figure reflects the sum of timesteps butterflies host plants within 2.5m intervals from the trail. Included are regression models that best fit the data for each habitat extent.

Spatial arrangement of host plants

Frequency of disturbance

A multivariate ANOVA revealed that the spatial arrangement of lupines significantly changed the amount of disturbance experienced by virtual Karner blue butterflies within and between scenarios (F_5=1256.02, P<0.0001). Interestingly, a distinct pattern of variation occurred across habitat extents. In habitat patches 10 m in width the level of disturbance experienced by individuals was highly variable (F_5=9.95, P<0.0001). Among 15 m wide patches, individual responses showed some significant variation (F_5=2.60, P=0.0268). In 20 m habitat extents there was no significant variation among individual butterflies (F_5=1256.02, P=0.3072). While in 25 m and 30 m extents, variation significantly increased (F_5=3.40, P=0.0060 and F_5=4.67, P=0.0005 respectively).

In addition, we undertook a regression analysis in which we excluded uniform spatial arrangements from the analysis. We considered this arrangement of lupines to be a hypothetical and unnatural. We therefore had concerns that arrangement could strongly influence the levels of variation occurring among different scenarios. Our analysis revealed it did not (compare Fig. 7 with Fig. 8).

Oviposition rate

A multivariate ANOVA revealed that the spatial arrangement of lupines significantly varied the oviposition rate of virtual Karner blue butterflies within and between scenarios (F_5=12.41, P<0.0001).

Host plant selection

Regression analysis across all the scenarios revealed that the spatial arrangement of the lupines within habitat patches explained a small degree of the variation in host plant selection by virtual butterflies. Although this was not selected as a significant variable in stepwise model selection, it did raise R_2 values to 0.2611.

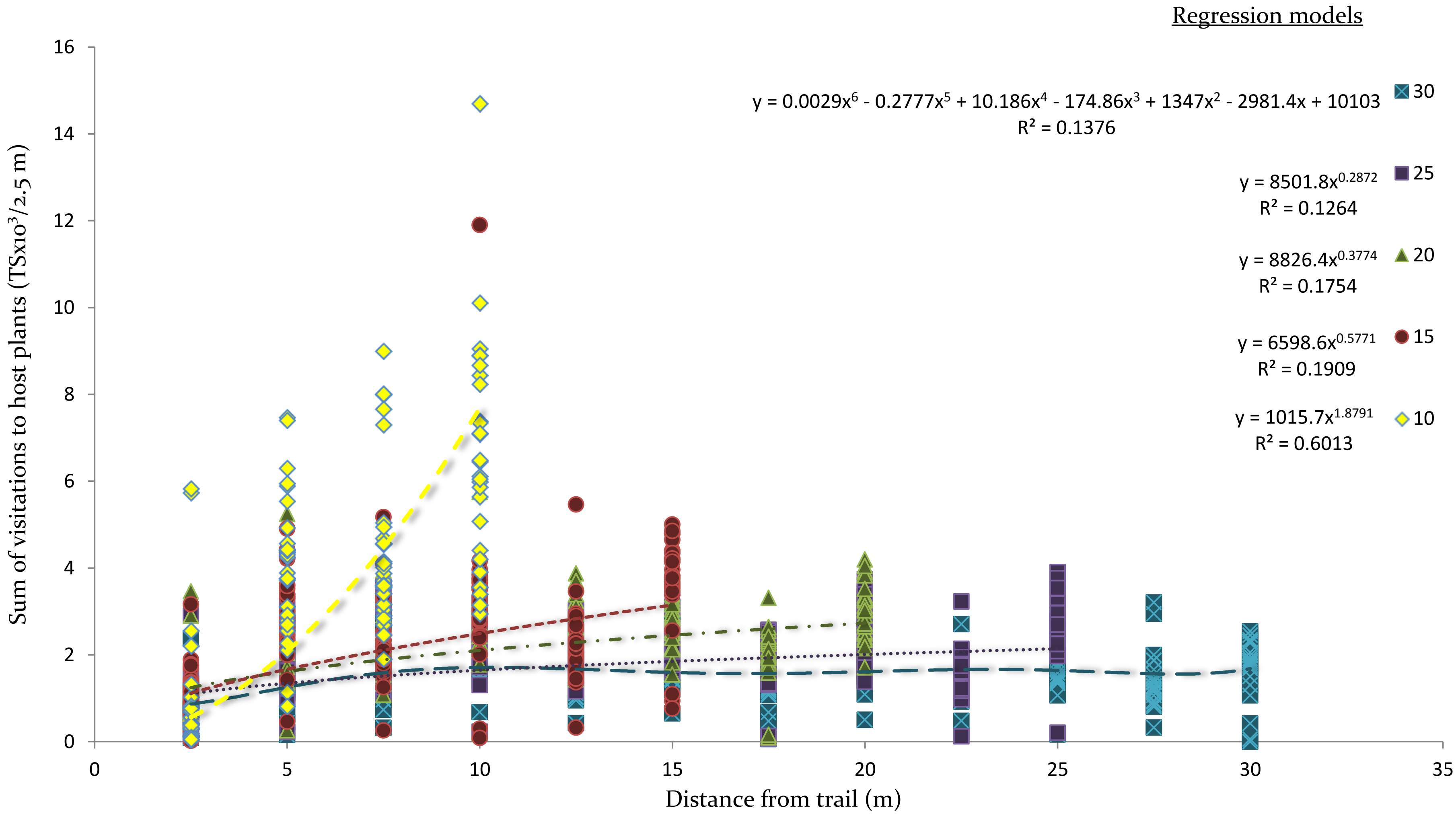

Figure 8: Distribution of host plant selection by virtual female Karner blue butterflies across each habitat extent across all scenarios except 'spaced' scenarios. Figure reflects the sum of timesteps butterflies host plants within 2.5m intervals from the trail. Included are regression models that best fit the data for each habitat extent.

Visitation

Frequency of disturbance

The disturbance experienced by female Karner blue butterflies increases significantly with increasing visitor numbers (F_2=480.70, P<0.0001). Visitor density also contributed significantly to the extent to which virtual butterflies experienced disturbance between habitat extents (F_6=173.67, P,0.0001). Fig. 9 shows this variation between and among each set of scenarios.

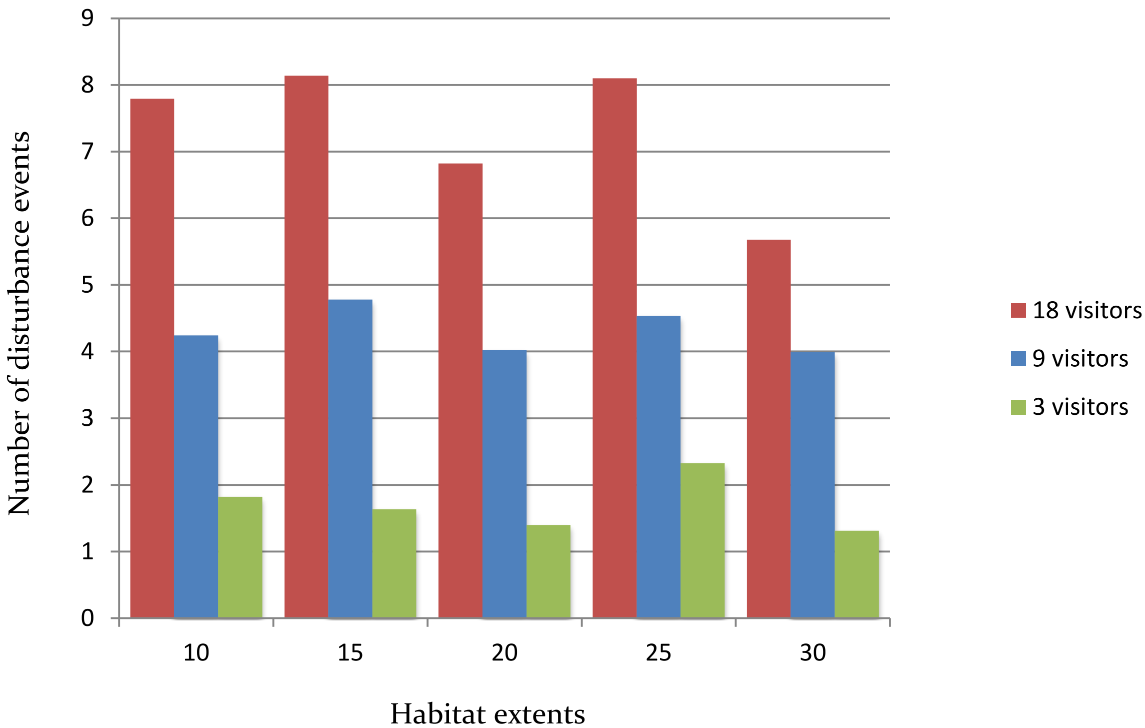

Figure 9: Average number of disturbance events experienced by virtual females in the presence of the maximum (18 visitors), intermediate (9 visitors) and minimum (3 visitors) number of recreationists expected along the Inland Marsh trail.

Oviposition rate

Fig. 10 shows a very similar pattern in oviposition rate between alternative visitor densities. An ANOVA confirmed that there was no significant difference in the number of eggs lain by females Karner blue butterflies across all the extents between the three visitor densities (F_2=1.59, P=0.2048).

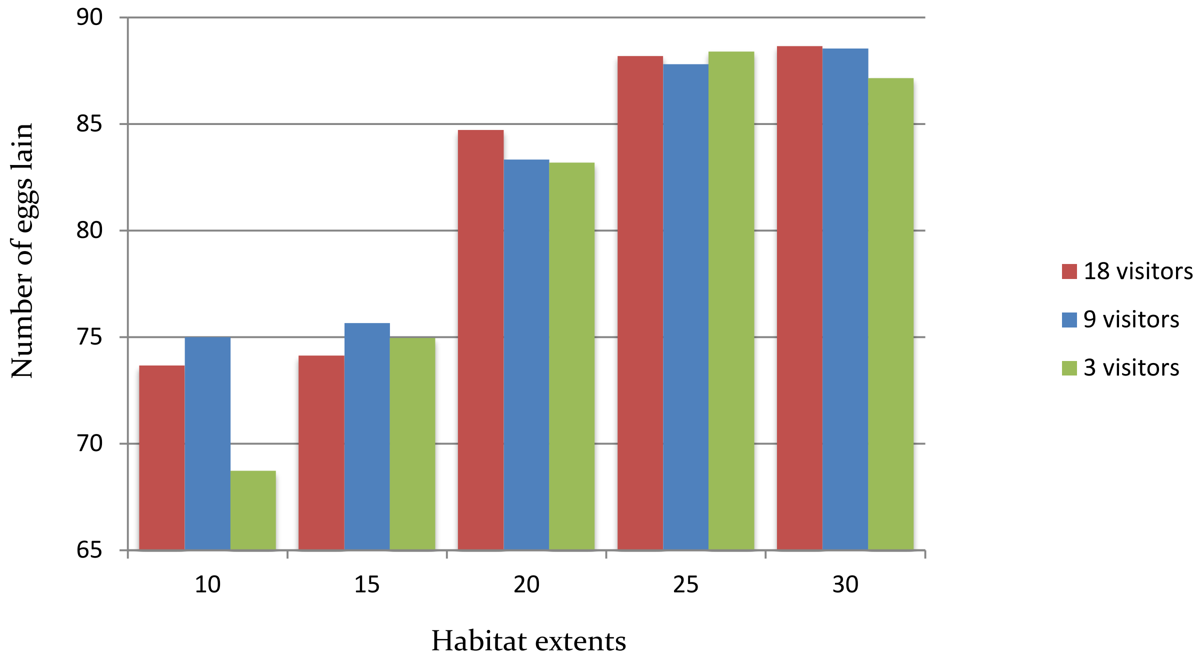

Figure 10: Average number of eggs laid by virtual females in the presence of the maximum (18 visitors), intermediate (9 visitors) and minimum (3 visitors) number of recreationists expected along the Inland Marsh trail.

Host plant selection

A regression analysis incorporating all the scenarios confirmed that the visitor density did not contribute significantly to the host plant selections made by virtual Karner blue butterflies (Fig. 11).

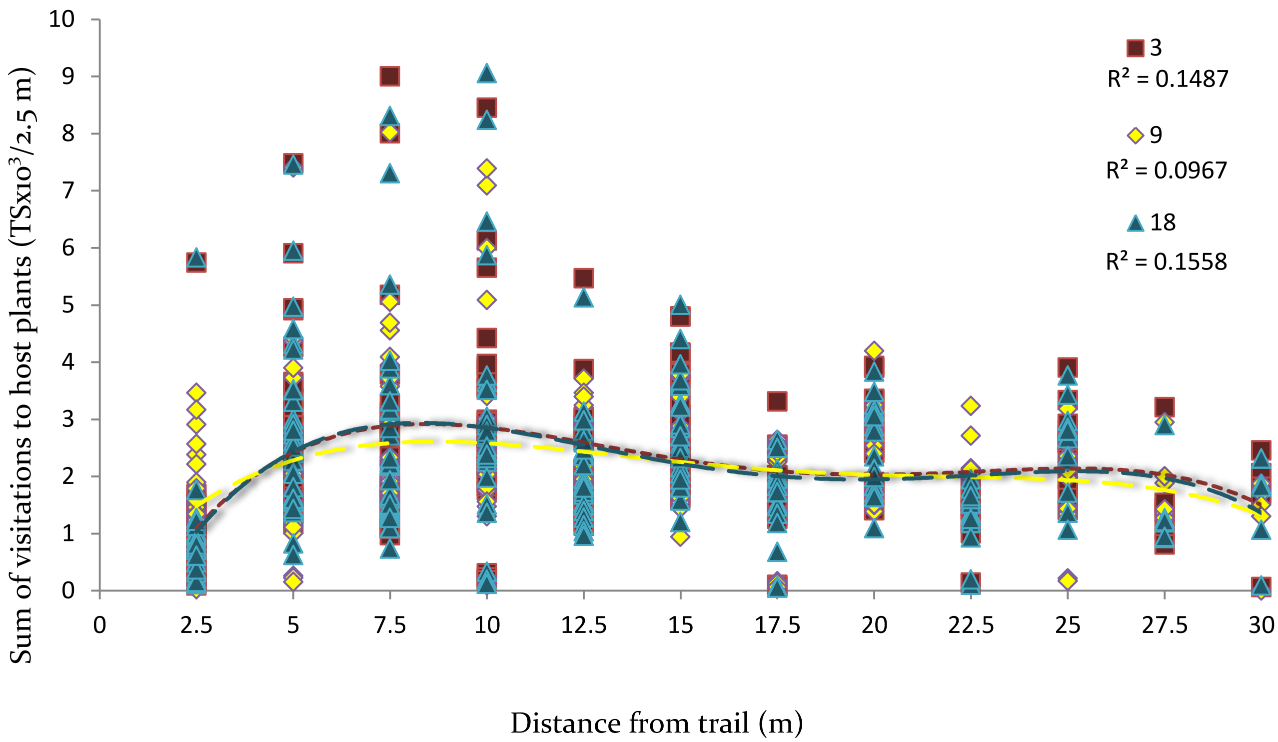

Figure 11: Distribution of host plant selection by virtual female Karner blue butterflies across each habitat extent across at minimum (3 visitors), intermediate (9 visitors) and maximum (18 visitors) numbers of recreationists to use the Inland March trail. Figure reflects the sum of timesteps butterflies host plants within 2.5 m intervals from the trail. Included are polynomial regression models that best fit the data for each habitat extent and there R squared values.

Disturbance responses: a sensitivity analysis

Frequency of disturbance

The disturbance experienced by female Karner blue butterflies was found to vary significantly among and between sets of habitat extents (F_{11}=494.24, P<0.0001). Females that were simulated to be sensitive to recreationists flushed more often when they were restricted to smaller habitat extents (Fig. 12). Note also that the disturbance levels experienced by tolerant and average females were similar to each other.

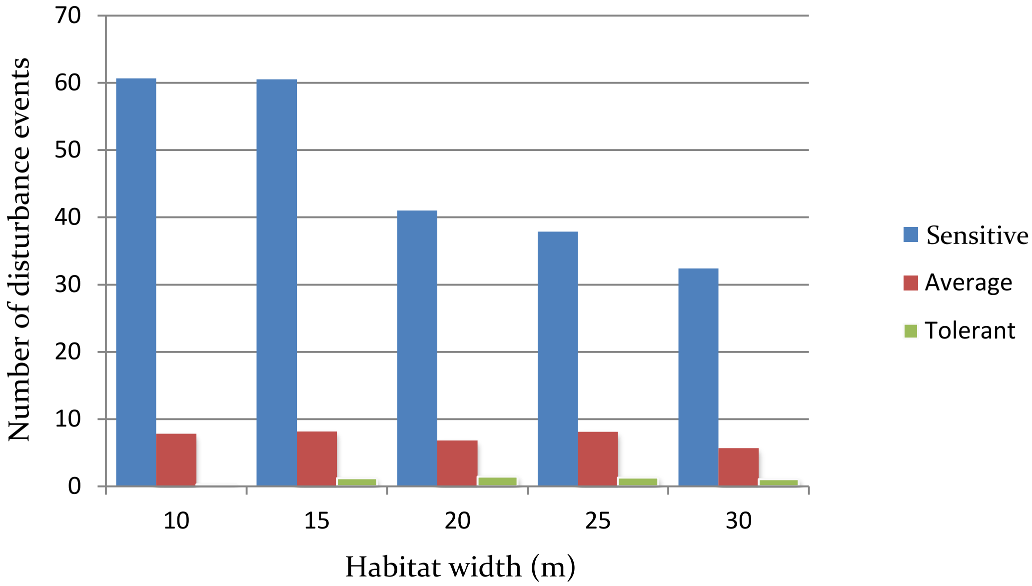

Figure 12: Average number of disturbance events experienced by virtual females exhibiting the maximum (sensitive), average and minimum (tolerant) disturbance responses to recreationists.

Oviposition rate

There was significance difference in the number of eggs lain by females Karner blue butterflies between the three responses levels (F_4=21.88, P<0.0001). Fig. 13 shows that the more tolerant individuals have the higher oviposition rates and the more sensitive individuals have the lowest rates. In addition, a multivariate ANOVA confirmed that patterns of disturbance across habitat extents also varies between the alternative disturbance responses (F_{11}=26.84, P<0.0001).

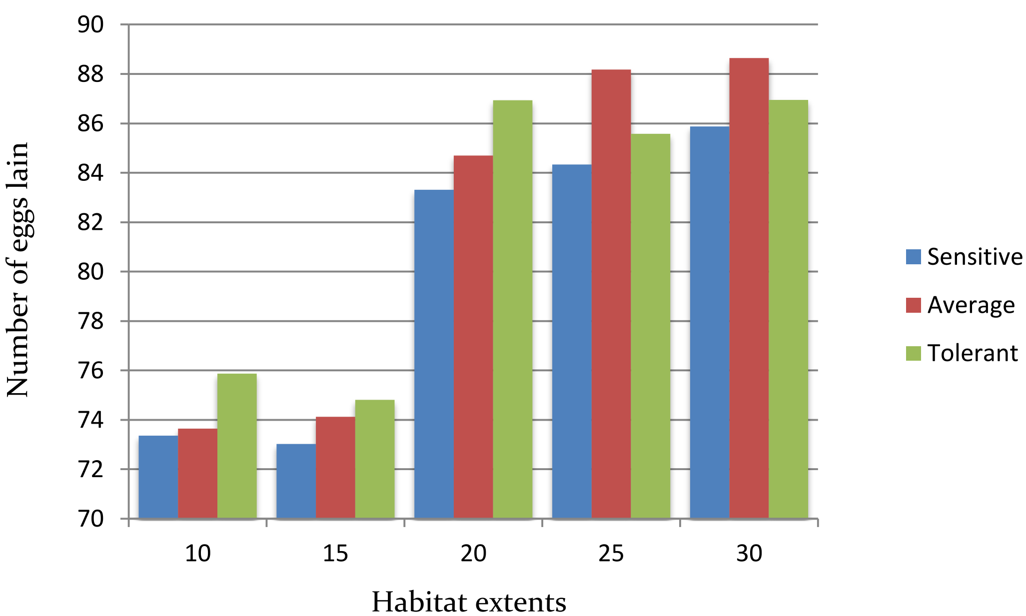

Figure 13: Average number of eggs laid by virtual females exhibiting the maximum (sensitive), average and minimum (tolerant) disturbance responses to recreationists.

Host plant selection

A regression analysis incorporating all the scenarios confirmed that the level of response exhibited by Karner blue butterflies did not contribute significantly to their host plant selections.

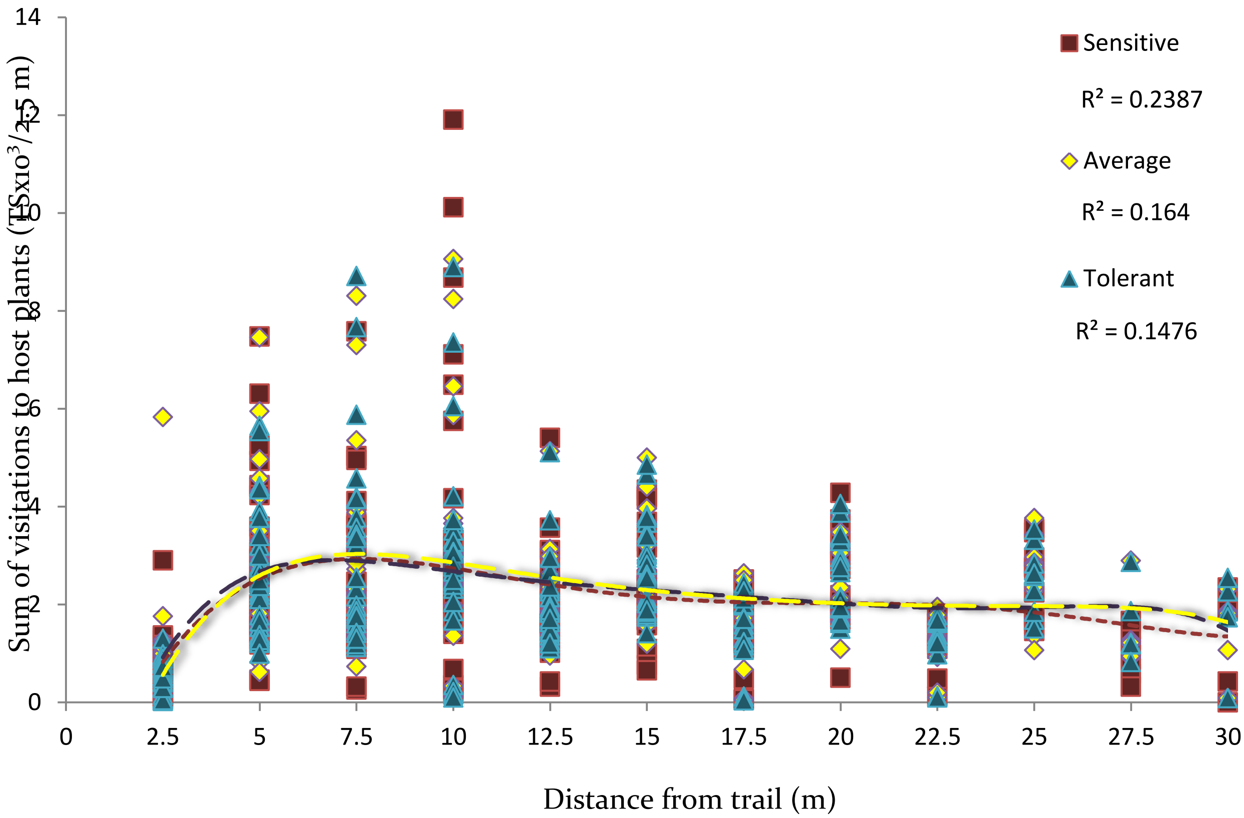

Figure 14: Distribution of host plant selection by virtual female Karner blue butterflies across scenarios in which their disturbance responses were varied. Figure reflects the sum of timesteps butterflies host plants within 2.5m intervals from the trail. Included are polynomial regression models that best fit the data for each habitat extent and there R squared values.

Discussion

Through a simulation exercise we demonstrated the potential implications of recreational disturbance on the breeding success of the Karner blue butterfly. We found negative implications when ovipositing females were flushed by recreationists and that continued disturbance across their oviposition period significantly reduced their breeding success. This supports recovery plan concerns that recreation in proximity to this butterfly species, especially the females, has a detrimental impact on population persistence.

Using SODA, we addressed two of the three potential implications of recreational disturbance that we had identified; oviposition rate reduction and increased host plant competition. Without parameters characterizing energetic expenditure of female Karner blues we could not explore the implications of recreation on adult survival.

As hypothesized, we found that recreation in proximity to ovipositing females lead to a reduction in oviposition rate. Across all of the alternative scenarios we tested (including disturbance-tolerant individuals and minimum visitor densities), only five females out of the 4500 butterflies simulated (i.e. 0.1%) reached their maximum oviposition potential of 96 eggs. This demonstrates that even within a controlled virtual environment in which no other factors are influencing oviposition success, being flushed by recreationists disrupts females to such an extent that it detrimentally influences oviposition rates. Nonetheless, across all the scenarios, the majority of individuals (80%) were able to reach 95% of their oviposition potential. Among the remaining 20%, 8% of the individuals laid less than 50% of their eggs, and 12% laid less than 75%. Note that this does not consider the cumulative effects of other limiting factors. There is the potential that recreational disturbance exacerbates the decline in oviposition rates caused by other factors, such as environmental variables, parasitoids etc. In addition, this does not consider habituation or sensitivity of the butterflies.

Among the alterative sets of scenarios relating to habitat (i.e. the spatial extent of habitat and the spatial arrangement of host plants), recreation (i.e. visitor density) and wildlife (i.e. the level of disturbance responses by butterflies), we revealed significant differences in the levels of disturbance experienced by Karner blue butterflies. Increasing visitor numbers and maximizing the response variables of virtual butterflies to recreation increased the average frequency of disturbance. This increase corresponded very closely to the increase in visitor numbers. By comparison, the frequency of disturbance experienced by individuals with alternative sensitivities to recreationists revealed a skewed pattern of distribution (Fig. 12). This brought to our attention that the average response characteristics we used to parameterize the model did not represent an intermediate of the maximum and minimum response variables that were recorded in the field. This may be attributed to a bias in the field survey technique implemented (Dennis et al. 2006). Individuals that were observed in field surveys were predominately selected from suitable habitat within a 10 m buffer of the surveyor positioned along the trail at Inland Marsh. It is possible that individuals selected in these surveys represented a cross-section of the more tolerant individuals within the population. Across any population or sub-population, general theory dictates that we would expect the responses of individuals from one extreme to another to be normally distributed. Thus if we had collected data from individuals randomly selected across their entire habitat, it more likely that the average responses of Karner blue butterflies would have been higher. As a result, those scenarios that incorporated the average response characteristics may underestimate the disturbance frequencies, oviposition rates and host plant selection gradients we would expect across the entire population. Alternatively, we know very little about the habituation of wildlife to recreational disturbance, particularly among species whose adult life stage may not extend beyond two weeks (Griffin et al. 2007). Field observations suggest that a number of different butterfly species are very sensitive to disturbance when they are newly emerged and become more tolerant over time (Bennett unpublished data). If this is the case this could explain the skewed distribution among the individual response characteristics collected.

Despite this the sensitivity of virtual females to recreation not did explain as much of the variation in oviposition rate (Figure 13). At most this represented an average difference between the extremes of 4%. Similarly, egg-laying potential between scenarios with the minimum and maximum visitor numbers differed by only 6% (Figure 10). Again, this difference could be increased by other contributing factors not included in this simulation exercise.

Among the scenarios in which we varied habitat extent, our simulation exercise revealed some well-defined patterns of disturbance and corresponding implications. Firstly, as habitat width from the trail increases, the frequency of disturbance among virtual Karner blues decreases. Essentially, among the smaller habitat widths there is a greater probability that butterflies will be within the 'detection distance' (the area within which recreationists can cause the butterflies to flush) of the trail. Subsequently, there is a reduction in oviposition rate among those females that are disturbed. However, it is the outcome of the disturbance-related responses that dictates the females' oviposition rates. When individuals are flushed they fly for a certain distance away from the recreationist. If this disturbance-related flight takes them beyond their suitable habitat (i.e. flushed out) they must return to that habitat before they can resume searching for a host plant. This further decreases their oviposition rate. In addition, lost oviposition potential is exacerbated when individuals are flushed from the patch and do not return. These situations may occur when the butterflies find themselves at distances beyond their perceptual range (Enfjall and Leimar 2009). Individual butterflies may continue to fly in the direction they are travelling or implementing some form of searching behavior in order to locate suitable habitat. In these instances, the butterfly may not necessary relocate the habitat from which it was flushed. Essentially, these individuals cease to lay any further eggs at their original habitat patch. At a population-level, this outcome has important implications. If females are hindered from laying eggs within a particular habitat patch, that patch is in effect acting as a sink. As defined in source-sink dynamic theory, a sink habitat represents a habitat that does not contribute to population growth (Doak 2000; Boughton 2003; Dennis et al. 2003; Zhang et al. 2009). Thus highly disturbed patches are not contributing to the long-term survival/persistence of a population. For the Karner blue butterfly it is therefore important that we discern the circumstances in which recreation in proximity restricts female oviposition.

Among the alternative habitat-related scenarios it became clear that the number of females to be flushed was strongly dependent on width of habitat from the trail. For example, across all the 10 m wide habitat scenarios, only 22% of individuals were able reach 95% of their oviposition potential. The majority of the individuals (53%) reached 90% of their potential, while 23% laid less than 75% and 17% of virtual females laid less than 50% of their eggs. At the other extreme, among 30 m wide habitats, 96% of individuals were able reach 95% of their oviposition potential. Of the remaining 4%, only 2% of virtual females laid less than 50% of their eggs. On closer inspection, we found that the simulated movement patterns of these 2% were females that were flushed out of suitable habitat at the edges of the habitat patch. The habitat patch must extent beyond the maximum detection distance plus the maximum flushing distance of butterflies from the trail (Table 2). This is approximately 10 m and thus explains why the majority of females were flushed out of habitat patches 10 m in width from the trail. It also explains why only the few females at edges where flushed out of habitats 20 m to 30 m in width (Fig. 4). However, among scenarios with 15 m habitat widths we see a very similar oviposition rate to that among 10 m widths, though overall oviposition rates appear higher. In these scenarios, 66% of individuals were able reach 95% of their oviposition potential, while 20% laid less than 75% and 15% of virtual females laid less than 50% of their eggs. It is the combination of being disturbed by recreationists during oviposition and host plant searching flight that has resulted in this pattern. A combination of variables we could not have foreseen through empirical studies alone. In attempting to discern why virtual individuals within 15 m habitat had oviposition rates equivalent to those in 10 m habitat extents, we uncovered a cumulative effect. Among the alternative habitat extents virtual females were also subjected to disturbance by recreationists while searching for host plants. This resulted in those females being flushed (i.e. flying in the opposite direction from the source of disturbance). As with the frequency of disturbance during oviposition, individuals had a greater probability of being disturbed among the smaller habitat extents. Those individuals closest to the trail were flushed by oncoming recreationists. This caused the butterflies to then fly parallel to trail away from the source of disturbance. As the recreationists continued to move along the trail they proceeded to disturb the butterfly. In many cases, this resulted in the virtual butterfly eventually being flushed out of the suitable habitat at the far edge. This type of behavior can be observed readily among many species of butterfly (and insects, such as flies, bees, wasps, dragonflies and beetles). It is particularly evident among butterflies that have a preference to basking on the dirt or gravel trails. Subsequently, among the scenarios with habitats widths of 15 m, we found that 34% of simulated females were flushed out of suitable habitat in this manner. This figure drops to 12% among 20 m width scenarios, 5% among 25m width scenarios and as previous mentioned 4% among 30 m scenarios. These results suggest that Karner blue butterflies will frequently be disturbed by recreation in proximity to habitats that extent up to 25 m from the trail. Of those butterflies that are disturbed, this can lead to substantial declines in their individual oviposition potential. However, an overall (potentially population) decline in oviposition rate only occurs within habitats extending up to 20 m from the trail.

When considering the implications of disturbance on host plant selection, our simulation exercise revealed that habitat widths of 25 m or more were required to offset any host plant competition that may occur as a result. It was very evident from Fig. 7 that virtual female Karner blue butterflies concentrated their oviposition activities as far away from the trail as possible in 10 m habitat extents. With more eggs laid on the same lupines, once hatched larvae will be competing for the same food resource. As a bivoltine species, this has more serious implications for the second brood of Karner blue larvae, who are dependent on the plants they were originally laid (Swengel 1995; Brock and Kaufman 2003; Pickens 2007; Pickens and Root 2008a). Subsequent implications may therefore include a reduction in the survivorship of larvae, a decrease in the number of larvae entering pupation, a decrease in emergence, and a reduction in adult fertility and survival (Geister et al. 2008; Gibbs and van Dyck 2010; Gibbs et al. 2010). As the first brood larvae come from eggs that are laid on senescing plants and seed pods, they will more likely to be concentrated to small areas rather than particular host plant. Subsequently, there may have similar implications, but these will probably be diluted by other variables, such as climate, and strongly depend on the density of lupine plants.

By increasing habitat width from the trail, the distribution of oviposition activities by virtual Karner blue butterflies becomes less concentrated. Thus among scenarios depicting habitats extending beyond 25 m for the trail, host plant selection in effect becomes evenly distributed. By ensuring that habitats in proximity to trails are greater than 25 m it may be possible to offset any of the implications that recreational disturbance might cause.

Implications for conservation

The research conducted in this project, including both the empirical fieldwork and theoretical modeling simulations represent one of first studies to explore recreational disturbance on the Karner blue butterfly. Although it was essentially a preliminary investigation it revealed substantial insights into the effects of recreation in proximity to this species. These insights can be used to directly inform active management for this endangered species. In addition, it specially addresses Karner blue recovery plan objectives to collect important ecological data on the Karner blue and associated habitats: Priority Research 3, 5.32 Effects of Humans.

Our findings confirm that Karner blue butterflies are subject to recreational disturbance and that at the Inland Marsh site Karner blues are being disturbed by current recreation. Although we were unable to use parameters that characterized the specific responses of butterflies to the different types of recreation (due to low power of our data) or establish in field surveys the effects of varied group sizes on the butterfly, we found that increasing visitor numbers to represent the current parking capacity did not significantly influence the breeding success of these butterflies. Thus based on our findings, efforts to restrict visitor numbers as a way to offset the implications of recreational disturbance may not be necessary. However, plans to increase parking capacity are not recommended. At the very least, further simulation exercises using SODA should be conducted to test any site development proposed, whether it be increasing the parking facilities or extending a trail.

Our simulation exercise also revealed that the breeding success of Karner blue butterflies at the Inland Marsh site can be detrimentally impacted by recreational disturbance. This impact was found to be directly associated with the amount of suitable habitat that extends from the trail. As a fundamental management practice that is not specific to Inland Marsh, our findings indicate that habitat patches in proximity to trails and other public rights of way should extend a minimum of 25 m from that trail. In this way it is possible to offset the implications of recreational disturbance. This supports efforts to maintain habitats with viable populations and as a result supports the restoration a viable metapopulation across the butterfly's historic range (Hanski 1999, 2003; Guiney et al. 2010). Our study has therefore also addressed Karner blue recovery plan objectives to protect and manage the Karner blue and its associated habitat to perpetuate viable metapopulations of Karner blue butterflies: Stepdown Recovery Objective 1, 1.5 Develop recovery implementation strategies to promote recovery, (USFWS 2003; see also WDNR 2009).

Recommendations for further research

As a preliminary investigation our study has opened up a number of avenues for further investigation. We have identified 'exploring the responses of Karner blue butterflies to different types of recreation' as a research priority. Determining the sensitivity of the Karner blues (primarily females) to the kinds of recreation, including varying group sizes, to occur at sites across the butterfly's range would allow us to determine whether certain activities exacerbate the negative implications of disturbance on this butterfly. Activities such as cycling, horse riding, ATVs and dirt bikes have been identified, along with running, walking and dog-walking acknowledged in this study.

We also suggest that studies are conducted that explore the fitness consequences to this endangered butterfly of continued and cumulative disturbance by recreationists, which in turn can affect the long term persistence and abundance of the blues (Guiney and Andow 2009; Gibbs et al. 2010). Understanding the energetic implications of exhibiting disturbance responses will enable is to assess the impact of recreation on adult survival; an avenue of research that could not be explored in this study.

Furthermore as we do not know the probability of inter-patch movement, a parameter we would need to simulate the movement dynamics of the butterfly more appropriately. Studies that address this need and fed back to into the parameter space in SODA, would be useful to establish movement patterns and oviposition activities of females that flushed out of habitat patches by recreationists.

Using targeting field surveys and simulation modeling exercises equivalent to those conducted in this project, we propose that investigations be undertaken to further explore the effectiveness of a range of management strategies and site designs (such as habitat size, function and structure, and trail placement). This research will provide valuable insights useful not only to inform management and restoration efforts at existing sites, but also at sites selected for reintroduction schemes (Knight & Temple 1995, Larson 1995, USFWS 2003). We therefore envisage that the management and site design recommendations established from such investigations will feed directly into the active recovery plan programs of these and other endangered and threatened lycaenid butterfly species (McIntire et al. 2007; Montgomery et al. 2009).

Outcomes of seed funding

As an outcome of this seed funding we have submitted a proposal to the USFWS to conduct further research. The primary objective of this proposal is to explore (through targeted field design and simulation modeling) the response of ovipositing Karner blue butterflies to human recreational activities along trails and recreational areas within public access sites located across the butterfly's range in Indiana, Wisconsin and Michigan. This will allow us to determine the sensitivity of this butterfly to a wider range of recreational activities. SODA is also being used in a number of ongoing projects to explore the impacts of anthropogenic disturbance on the endangered Indiana bat (*Myotis sodalist*), the threatened Oregon Silverspot butterfly (*Speyeria zerene hippolyta*) and neotropical migrants in Fort Harrison. We are also exploring opportunities to use SODA to assess whether other butterflies species of concern are influenced by recreation including the endangered Fender's blue (*Icaricia icarioides fenderi*) and the candidate species the Taylor's checkerspot (*Euphydryas editha taylori*).

This project has also supported students from Purdue North Central University and Butler University. It has provided internships and student projects, aided field technique demonstrations in practical classes for wildlife majors and has allowed students to develop and give oral presentations at 2 different professional conferences, including Indiana Academy of Science and Midwest Fish and Wildlife Conference.

Finally, we will submit a manuscript to Oecologia which delineates our research undertaken as part of this seed funding.

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