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ATTRACTION OF *CHIRONOMUS SALINARIUS* (DIPTERA: CHIRONOMIDAE) TO ARTIFICIAL LIGHT ON AN ISLAND IN THE SALTWATER LAGOON OF VENICE, ITALY

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ABSTRACT. The attraction of adult *Chironomus salinarius* to incandescent 3-W lamps of 7 different colors used in CDC traps was studied on a small island in the lagoon of Venice, Italy. An ANOVA indicated that the lamp type was a highly significant ($P < 0.01$) factor associated with differences in light trap catch (28% of total variation), as well as catch per lux (18% of total variation). The white lamp attracted higher numbers of adults than the other 6 color lamps. Yellow was the second most preferred, and red was the least attractive. There was a strong linear relationship ($r = 0.93$) between the catch and light intensity, which suggested that intensity was the primary factor influencing catch. However, catch per unit brightness (lux) tended to be inversely proportional to the peak wavelength associated with the lamp color (e.g., the violet lamp had the highest catch/lux, and the red lamp had the lowest). The corresponding regression model, Catch $= 49 + [(48{,}013/\lambda) - 63] \cdot L$, in which the slope associated with light intensity in lux (L) is inversely proportional to the peak wavelength in nm (λ) explained 97% of the variation among lamp catch means. Manipulating light intensity and color could be useful to divert adult *C. salinarius* populations from midge-affected areas for control purposes.

INTRODUCTION

The chironomid, *Chironomus salinarius* Kieffer, inhabiting the saltwater lagoon of Venice, Italy, has been a focus of research for the past decade because of the frequent massive swarms occurring usually during the summer months (Ferrarese and Ceretti 1989, Ferrarese et al. 1990). The lagoon surrounds several islands including Venice, Murano, and Burano, and faces many isthmic and mainland cities as well as the industrial concentration near Marghera harbor northeast of Venice. Waterfront residents, workers, and businesses at these locations often experience serious nuisance and economic difficulties posed by invading midge swarms; the transportation and tourism industries are also adversely impacted. Additionally, there is a threat of slippery conditions due to massive accumulations of dead midges on roads, particularly on driveways in multistory waterfront car parking lots and on runways at the Marco Polo airport adjacent to the lagoon (Ali et al. 1985, 1992). Entry of adult midges into delicate equipment mounted on airplanes also poses a danger and results in economic loss to the aviation industry (Barbato et al. 1990). Confirmation of human allergies resulting from contacts with adult *C. salinarius* in the area have also been reported (Giacomin and Tassi 1988, Marcer et al. 1990).

At present, organophosphate and pyrethroid insecticides used as adulticides are the principal means of control of *C. salinarius* around the lagoon (Ali et al. 1992). These adulticides are applied in the early evening hours because a vast majority (>60%) of the adults eclose within 2–3 h of sunset (Ferrarese and Ceretti 1989). Reduction of midge nuisance by the use of organophosphate larvicides and insect growth regulators, usually practiced in bodies of water up to 200 ha (Ali 1991), has limited practical value in the lagoon of Venice. This is because of the relatively large size, 55,000 ha, of the lagoon, which would require high costs for chemicals and labor. Also, chemicals added to the lagoon would be subject to displacement and dilution by tidal currents. They would also be unacceptable from an environmental standpoint, with possibilities of causing adverse effects on nontarget biota coexisting with *C. salinarius*. In such a situation, environmentally compatible and economical biological and cultural control measures of the pest are desirable in the overall integrated approach to management of *C. salinarius*.

The adult attraction behavior of some midge species to artificial light has been suggested as a manipulative measure for the reduction of midge nuisance (Ali et al. 1984, 1986; Kokkinn and Williams 1989). This type of an environmentally sound method of chironomid management was a part of the ongoing research investigations on *C. salinarius* in the lagoon of Venice, and the results are reported in this paper.

MATERIALS AND METHODS

The study was conducted during September 1991 on the Island of San Francesco del Deserto

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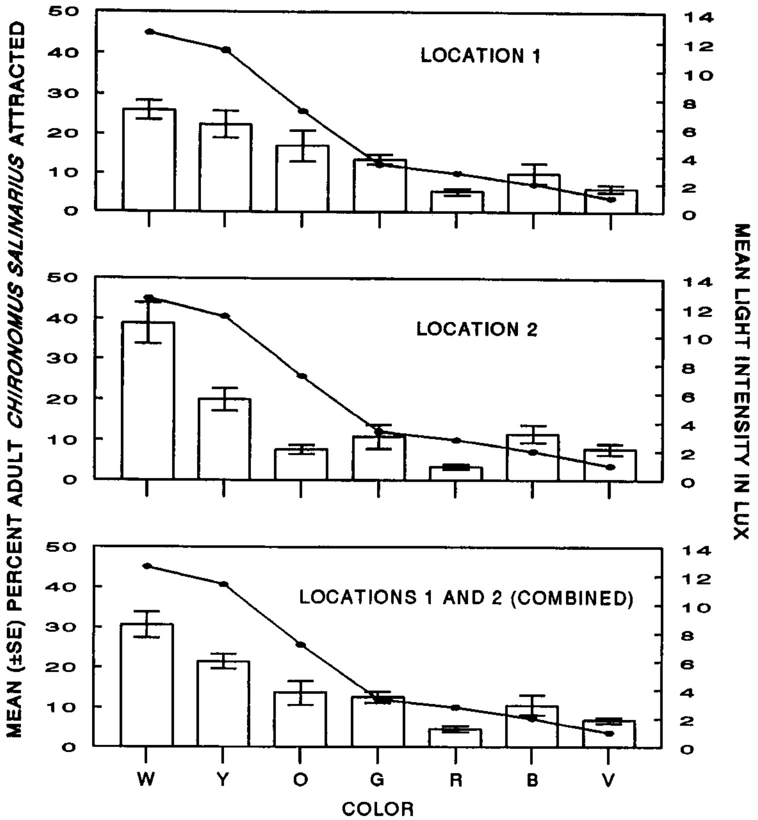

Fig. 1. Attraction of adult *Chironomus salinarius* monitored at 2 field locations on an island near Venice, Italy, to 3-W different color (white [W], yellow [Y], orange [O], green [G], red [R], blue [B], and violet [V]) incandescent lamps utilized in CDC traps. Bars represent the mean percentage of adults attracted to each lamp; the line graphs indicate the mean light intensity of each lamp measured in the laboratory.

located at *ca.* 3 km ENE of the city of Venice (45°26′N latitude and 12°35′E longitude) in the lagoon. The island is roughly oval-shaped and covers about 3.5 ha. There are no inhabitants on the island except for the residential and visiting staff of a Catholic monastery. The island had very few visible electric lamps in use at night and even those in use were turned off when needed. Therefore, the island was suitable for the study as it presented almost no competitive artificial light interfering with the experiment.

The attraction of adult *C. salinarius* to light of different colors was studied by using CDC traps. The traps fitted with lamps were permanently placed in a row 3 m above ground and 20 m apart at 2 waterfront locations on opposite sides of the island. These locations were nearly 200 m apart. At one location, electric supply was available to conduct the study, while at the other location, a portable 2,200-W generator (L'Europea, Milano, Italy) was used to illuminate the lamps in the CDC traps. Suitable step-down transformers for 6 volts output and electric cords were utilized as needed. Incandescent 3-W lamps of 7 different colors (violet, blue, green, yellow, orange, red, and white) were used at each location. These lamps emitted broad bands of wavelengths in the visible spectrum. The specific spectral ranges of these colors in nm as defined by Luckiesh (1946) are as follows: 390–430 (violet), 430–490 (blue), 490–550 (green), 550–590 (yellow), 590–620 (orange), and 620–770 (red). The radiant energy emitted by the white lamp was in all visible wavelengths of 390–770 nm.

To estimate relative brightness of the lamps, light intensity (quantity) of each lamp was measured with a Gossen Mavolux digital light meter (Gossen Gmbh., Erlangen, Germany) equipped with a Gossen photometric sensor. The intensity was measured in a completely dark room. Each lamp was fitted in a CDC trap placed at a fixed location in the middle of the room 2 m above ground level and illuminated. Four intensity readings were taken around each lamp, each at

Table 1. Analysis of variance for adult *Chironomus salinarius* catch and catch/lux on the common logarithm scale.

		Catch[1]		Catch/lux[1]	
Factor	df	SS[2]	F	SS[3]	F
Location	1	5	28.76**	5	28.76**
Event[4]	6	38	41.12**	44	41.12**
Location × Event	6	11	11.99**	13	11.99**
Lamp	6	28	29.89**	18	16.75**
Lamp × Location	6	1	0.95	1	0.95
Lamp × Event	36	11	1.93*	12	1.93*
Error	36	6		7	

[1] Dependent variable transformed to the common logarithm scale to allow fit of log-linear model and to stabilize the variances.
[2] Sum-of-squared deviations presented as a proportion of the total sum-of-squares of 35.68.
[3] Sum-of-squared deviations presented as a proportion of the total sum-of-squares of 31.28.
[4] Event = sampling occasion.
* Significant at the 95% confidence level.
** Significant at the 99% confidence level.

a distance of 1 m from the lamp. The mean lux values for violet, blue, green, yellow, orange, red, and white measured at 1 m from the source were 1.0, 2.0, 3.4, 11.4, 7.2, 2.8, and 12.6, respectively.

To attract adult *C. salinarius,* the traps at each location were operated for a period of 2 h, commencing about half an hour before sunset on each sampling occasion. The traps were rotated 7 times at each location in order for each lamp to occupy, at least once, each permanent field position at a location. The adult *C. salinarius* collected in each trap during each sampling period were counted in the laboratory.

The effect of lamp type (identified by color) on catch and catch per unit brightness (i.e., catch/lux) was examined using a log-linear model (McCullagh and Nelder 1989) blocked on lamp location, sampling occasion, and their interaction, because light trap catches can be envisioned to behave like random events through time (i.e., a Poisson process). As the catches tended to be large, the shape of the distributions was approximately normal. Therefore, the log-linear models were fitted and hypotheses concerning effects were tested using traditional analysis of variance (ANOVA) techniques. It should be noted that scaling catch by lamp intensity to obtain catch/lux is equivalent on the logarithmic scale to subtracting a constant for each treatment. Therefore, the pattern of residuals will be the same for catch and catch/lux, and the F-values will be the same for all terms, except the lamp effect. The adequacy of the ANOVA assumptions was examined after fitting the model by graphically examining the residuals plotted against the predicted values and testing the residuals for normality using the Shapiro-Wilk W test (Shapiro and Wilk 1965). Significant differences in the effects of lamp type adjusted for location and sampling occasion were examined using a multiple-*t* comparison (Dunn and Clark 1974) of all pairwise contrasts of the lamp color effects estimated in the ANOVA. Linear regression using the mean catch by lamp was performed to examine the relationship between catch, lamp intensity (avg. lux), and peak wavelength (nm). The midpoints of the spectral ranges defined by Luckiesh (1946) were used as estimates of peak wavelength in the regression analysis. The mean catch for the white lamp was excluded in the regression against light intensity and peak wavelength because the white lamp emitted a broad range of wavelengths (i.e., no narrow peaks). All statistical analyses were performed using the SAS Institute (1989) JMP® program.

RESULTS AND DISCUSSION

Chironomus salinarius was the only chironomid species taken in the traps. A total of 11,701 adults at location 1 and 6,589 adults at location 2 were caught during the 7 sampling occasions. The total number of adults caught in all the traps on each sampling occasion varied from 145 to 3,570 and 232 to 2,013 at locations 1 and 2, respectively. The mean percent of adult *C. salinarius* collected for each color lamp in the combination of lamps at these locations is presented in Fig. 1. The mean value of light intensity of each lamp is also shown in the figure. At both locations, white lamps with the highest intensity (12.6 lux) attracted higher numbers of adults than the other 6 colored lamps used. Yellow lamps (11.4 lux) were the second most preferred, and red lamps apparently were the least attractive (Fig. 1).

The ANOVA associated with the log-linear

Table 2. Summary of *Chironomus salinarius* catch by lamp color.

	Catch			Catch/lux		
Color	Lux	Mean ± SE	Diffs[1]	Color	Mean ± SE	Diffs[1]
Red	2.8	59 ± 15	rv	Red	21 ± 6	ryo
Violet	1.0	88 ± 23	rvbgo	Yellow	25 ± 6	ryowg
Blue	2.0	138 ± 40	vbgo	Orange	25 ± 9	ryow
Green	3.4	163 ± 41	vbgoy	White	32 ± 6	yowgbv
Orange	7.2	178 ± 62	vbgoy	Green	48 ± 12	ywgbv
Yellow	11.4	281 ± 66	goyw	Blue	69 ± 20	wgbv
White	12.6	399 ± 74	yw	Violet	88 ± 23	wgbv

[1] Means associated with the same letter were not significantly different at an overall confidence level of at least 95% based upon a conservative multiple-*t* comparison (Dunn and Clark 1974) of all pairwise contrasts of the lamp effects adjusted for location and sampling occasion in the ANOVA on $\log_{10}$(catch) and $\log_{10}$(catch/lux). (Note: The order of the means of $\log_{10}$[catch] for orange and green lamps was reversed relative to the untransformed data. Likewise, the order of the means of $\log_{10}$[catch/lux] was reversed for the yellow and orange lamps.)

model fit is presented in Table 1. The fits appeared to meet the key assumptions of the ANOVA. There was no systematic relationship between the mean and variance based upon a plot of the residuals in either fit, and neither Wilks-Shapiro W statistic was significant (i.e., catch: W = 0.98; n = 98; $P > 0.05$ and catch/lux: W = 0.98; n = 98; $P > 0.05$). (Independence was not examined, but the design should have removed this concern.)

As would be expected, midge catches varied by location and sampling occasion. These blocking factors were highly significant ($P < 0.01$), and accounted for 54% of the total variation in catch and 62% of the total variation in catch/lux (Table 1). Lamp type was a highly significant ($P < 0.01$) factor associated with differences in light trap catch (28% of total variation) as well as catch per lux (18% of total variation) (Table 1). There was a significant ($P < 0.05$) interaction of lamp type with sampling occasion. Plots of the lamp effects against occasion showed only minor departures from a systematic pattern with lamp type. Because a goal of this study was to group the lamp types based upon their attractiveness, the interaction sum-of-squares was included in the error variation. This conservative approach insured that significant differences among lamp types had to be greater than the fluctuations in some of the means that occurred among occasions.

A summary of catch and catch per unit intensity (lux) ranked by increasing catch is presented in Table 2. Included in Table 2 are labels indicating the significant lamp color effects based upon the multiple-*t* analysis of all pairwise effect contrasts. The actual *t*-ratios associated with the contrasts are presented in Table 3 for catch as well as for catch/lux. This summary and the plot of average catch against lux (Fig. 2) suggest that the number of midges caught was strongly dependent on the light intensity of the lamps. There was a strong linear relationship ($r = 0.93$) between the catch and light intensity that accounted for 86% of the variation among the means, and the order of the means does not reflect the probable peak wavelength of the lamps. However,

Table 3. Conservative *t*-ratios[1] for all pairwise contrasts of the lamp effects adjusted for location and sampling occasion in the ANOVA on $\log_{10}$(catch) (upper triangle) and $\log_{10}$(catch/lux) (lower triangle).

	Violet	Blue	Green	Orange	Yellow	Red	White
Violet	—	1.97	3.14	2.59	5.54**	2.37	7.32**
Blue	0.85	—	1.16	0.62	3.57*	4.34**	5.34**
Green	1.85	0.99	—	0.54	2.40	5.50**	4.18**
Orange	5.44**	4.60**	3.60*	—	2.95	4.96**	4.72**
Yellow	4.37**	3.52*	2.52	1.08	—	7.90**	1.78
Red	6.56**	5.71**	4.71**	1.11	2.19	—	9.68**
White	3.00	2.15	1.15	2.44	1.37	3.56*	—

[1] Standard error for difference between lamp effects = 0.11. This was calculated by pooling the residual and interaction sum-of-squares to provide a conservative adjustment for a significant Lamp × Event term.

* Significant at least at the 95% confidence level according to multiple-*t* tests of all pairwise contrasts (Dunn and Clark 1974). (Critical *t*-value: $t_{0.9988,36}$ = 3.27 from SAS Institute [1989] JMP® program.)

** Significant at least at the 99% confidence level. (Critical *t*-value: $t_{0.9998,36}$ = 3.90 from SAS Institute [1989] JMP® program.)

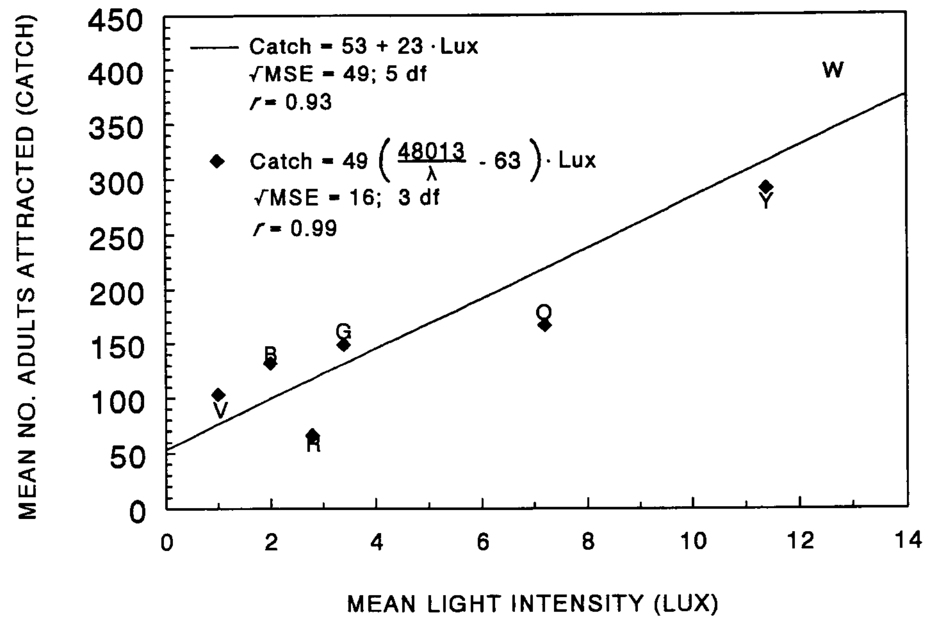

Fig. 2. Relationship between adult *Chironomus salinarius* attraction (catch) and light intensity of white (W), yellow (Y), orange (O), green (G), red (R), blue (B), and violet (V) incandescent lamps used in CDC traps. Fitted values for the regressions on light intensity (lux) alone (——) and peak wavelength (λ) and light intensity (◆) are also included.

when the catches are standardized by lamp brightness (i.e., catch/lux) in Table 2, the order of the catches/lux tends to be inversely proportional to the peak wavelength associated with lamp color. This suggested fitting the regression equation,

$$\text{Catch} = 49 + \left(\frac{48{,}013}{\lambda} - 63\right) \cdot \text{L}$$

$$(r = 0.99;\ \sqrt{\text{MSE}} = 16;\ \text{df} = 3),$$

in which the slope associated with lamp intensity in lux (L) is inversely proportional (with a constant) to peak wavelength in nm (λ). Inclusion of peak wavelength into the model was very significant ($F = 21.48$; df 1,3; $P = 0.02$), and this equation accounted for 97% of the variation among the mean catches. All of the parameters were significantly different than zero at the 95% confidence level according to the *t*-test for regression coefficients (Dunn and Clark 1974).

We suggest that light intensity was the primary factor in attracting adult *C. salinarius*. However, there appeared to be a greater preference for shorter wavelength light when the data were examined on a catch per unit lux scale.

There are several reports on the attraction of freshwater chironomids to artificial light, often in nuisance numbers (e.g., Hilsenhoff 1966, Ali 1980, Beattie 1981). Even marine chironomids have been reported to show a particularly strong attraction to light (Morley and Ring 1972). The widespread distribution of midges of the genus *Pontomyia* in the western Pacific was attributed to their attraction to lights on ships (Cheng and Hashimoto 1978).

Despite numerous records of chironomids as nuisance insects around artificial lights, the only experimental studies on the effects of wavelength and/or light intensity upon chironomid phototaxis are those of Ali et al. (1984, 1986) and Kokkinn and Williams (1989). Among a range of colored incandescent lights presented in a dark room to several midge species, white (highest intensity) was preferred over yellow, blue, green, red, and orange, and among white lamps of various wattage, preference of the tested midges was positively correlated with intensity (Ali et al. 1984). These results were further confirmed by field experiments (Ali et al. 1986). By contrast, Kokkinn and Williams (1989) reported the peak attractivity of the midge *Tanytarsus barbitarsis* was to the near-ultraviolet (370–400 nm) with a 2nd weaker peak between 490 and 510 nm, and concluded that light intensity did not appear to be important in attracting the midge. The spectrum-specific attraction of *T. barbitarsis* reported by Kokkinn and Williams (1989) may be a true phototactic behavior of this species but these authors did not present the actual numbers of midges exposed to the large variety of choices offered in a rather limited space (maximum 0.5 × 0.5 m) in the preference box employed by them.

Phototaxis of adult chironomids, whether light intensity or wavelength related, may be of practical significance. In the Venice situation, the lagoon is surrounded by a high density of homes and businesses interspersed with vast uninhabited or low-density areas. If dimmer or red lights could be used in the densely inhabited areas and high intensity (brighter) lights installed in and around uninhabited or less populated areas, *C. salinarius* would be drawn away from the densely populated areas to the latter areas where suitable control measures could be implemented. The same strategy could be used in the lagoon to draw midges to numerous deserted or uninhabited islands and, perhaps, to boats or buoys placed at some strategic locations. In the case of light spectrum-specific attraction, such as shown by *T. barbitarsis* (Kokkinn and Williams 1989), commercially available lamps that emit light with peaks in the preferred parts of the spectrum may be employed for midge adult diversion, trapping, or decoy purposes.

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