TECHNIQUES FOR EVALUATING PREDATORS FOR CONTROL OF INSECT PESTS

Jerome F. Grant and Merle Shepard
Department of Entomology
Clemson University
Clemson, SC 29631

Abstract: There is a pressing need for standardized techniques for measuring the impact of arthropod predators on insect pest populations. Although the literature is replete with observations of predation in the field, specific techniques which provide a quantitative assessment of the action of predators are limited. Several qualitative and quantitative techniques are discussed, and the major advantages and disadvantages of each are addressed. Qualitative techniques include direct observation, correlation, and seasonal abundance; quantitative techniques include laboratory evaluation, addition, subtraction (exclusion), field-cage evaluation, radiolabeling, and serological tests. Emphasis is on methods for use in field crops.

Key Words: Predators, biological control, natural enemies, evaluation techniques, predator effectiveness.


The importance of arthropod predators in regulating populations of pest species has been recognized for years. Few studies, however, have been designed to provide a quantitative assessment of the action of predators on pest populations. This area of investigation is one of the most difficult yet challenging facets of biological control.

The abundance and diversity of arthropod predators in agroecosystems have been reported by several investigators. For example, Whitcomb and Bell (1964) collected more than 600 species of predators from cotton fields in Arkansas, and Whitcomb (1973) estimated that as many as 1000 species of predators may be present in soybean fields in Florida. Most predators attack a wide variety of species of prey and also may attack other predators; however, they also may contribute some control of a pest species. In fact, most entomologists agree that predators have a regulating influence on populations of pest species. Measurement of the impact of arthropod predators on insect pest populations has been limited by the lack of standardized methodologies for assessing this impact. Thus most published information about the action of predators is largely of a qualitative nature.

General approaches to assessment of predation have been outlined and discussed by numerous authors (DeBach and Huffaker 1971; DeBach et al. 1976; Huffaker and Kennett 1969; Hughes 1973; Pedigo et al. 1983), and Kiritani and Dempster (1973) presented a comparison of several of the major evaluation methods for natural enemies. As early as 1942, Smith and DeBach called attention to the need for methods to quantitatively measure the effects of entomophagous insects on densities of prey (host) populations.

1 Technical contribution no. 2296 of the South Carolina Agricultural Experiment Station, Clemson University, Clemson, SC.
2 Received for publication 22 May 1984; accepted 1 November 1984.
Even today the task of assessing the impact or efficiency of natural enemies on pest populations in the field is difficult. The major difficulty arises from the lack of a 'realistic' method or technique for quantifying the impact of a natural enemy on a pest population. Quantitative information is essential for accurate predictions of actions by predators. Knowledge of predator-prey interactions could be incorporated into a stochastic model in order to refine pest management recommendations.

This paper presents a general outline or overview of several of the past and current techniques that have been used to assess the predatory abilities of individuals, populations or communities of predators. A major objective of this paper is to focus interest on questions such as "Is there a technique that will realistically assess predation in the field?", and "Is there a single technique of predator assessment that can be used as a standard by which predator species may be compared?" It would be ideal if (in certain circumstances) standardized methods were available which could be used to compare results from predator assessment studies. Given that differences in predation due to geography, environmental conditions, time of planting, etc., would occur, one important variable (that is, the type of technique) could be removed which may enable the acquisition of more useful information.

Two general categories of predator assessment are available: qualitative and quantitative. Qualitative methods provide a definitive answer to the question "Does a predator species feed on a particular pest species?" The answer simply will be yes or no; that is, the predator either does or does not feed on the prey. Quantitative methods, on the other hand, provide an answer to the question "How many individuals can a predator kill per unit time?", and provide a quantitative means by which a comparison of predation by different species can be generated. A quantitative evaluation of predation can provide important information on the role of a predator species in the population dynamics of a pest species.

This paper will be directed primarily towards methodologies that are used to assess predation in field-crop ecosystems, and is by no means exhaustive or conclusive. The major techniques that will be discussed are direct observations, correlation methods, seasonal abundances, laboratory studies, "with and without" (addition) methods, exclusion (subtraction) techniques, field-cage evaluations, radioactive labeling and serological tests. These techniques will be the only ones discussed for purposes of this paper; however, many variations on each of these techniques, and also other techniques (such as use of life tables, biological check methods, gut dissections, electrophoresis, paper chromatography, etc.) are available.

Each technique that is available to us has certain advantages and disadvantages that should be weighed against each other, and these will be emphasized in this paper. In many cases, the selection of a technique may depend entirely upon the intent of the study, or the personal preference of the investigator.

QUALITATIVE METHODS

Direct observations in the field

Direct observations provide important information related to predator-prey relationships, and many researchers have used this technique to determine predators of a particular pest. Whitcomb (1967) conducted field observations to
determine predators of bollworm, *Heliothis zeae* (Boddie) (LEPIDOPTERA: Noctuidae), larvae in a cotton field. Other researchers (Buschman et al. 1977; Elvin et al. 1983; Kitamani et al. 1972; Lincoln et al. 1967; Morimoto 1960; Neal et al. 1972; Negm and Hensley 1969; Richman et al. 1983; Roach et al. 1979; Whitcomb and Bell 1964) also have used direct observations to determine predatory species.

Direct observations have three distinct advantages as they allow for: 1) a positive identification of a predator species, 2) possible discovery of predation by a species that previously was not believed to be a predator, and 3) a possible quantitative assessment of attack rate (that is, the numbers of prey attacked per unit time). There are several disadvantages, however, to the use of direct observations: 1) they require a great amount of time for continuous observation, 2) they are tedious, 3) the observer generally disturbs the habitat of the prey while walking through the field making observations, 4) it is very difficult to observe predation at night, 5) when it is necessary to place hosts in the field, it is difficult to simulate their distribution, and 6) some of the prey which are placed in the field may be lost and unaccounted for because of reasons other than predation. Even with its disadvantages, this technique provides useful information relative to predator-prey relationships and is an effective means of predator assessment in combination with one or more of the other techniques.

**Correlation**

The 'correlation' technique is carried out by monitoring populations of pests and predators during several seasons and correlating numbers, or rate of increase, of the prey and numbers of the natural enemies (Fig. 1) (DeBach et al. 1950;
Huffaker and Kennett 1956; Putman and Herne 1964; Wene and Sheets 1962). This technique has been used more often in conjunction with evaluating parasitoids, and may provide a general assessment of the natural enemy complex associated with a particular pest; however, it usually does not provide a definitive assessment of the impact of a specific predator on a pest population. A correlation between numbers provides little information unless there is evidence of a direct causal relationship, as other factors also may affect densities of prey and predators (Kiritani and Dempster 1973). In other words, a meaningful correlation may not necessarily separate the cause from the effect (Huffaker and Kennett 1969).

**Seasonal abundance of predators**

Seasonal and relative abundances of predators have been monitored to determine or assess the most abundant species of predators of a particular pest species (Barry 1973; Bell and Whitcomb 1964; Burleigh et al. 1973; Caron and Bradley 1978; Cosper et al. 1983; Deitz et al. 1976; Elsey 1972; Lentz et al. 1983; Letourneau and Altieri 1983; Marston et al. 1979, 1984; Neal et al. 1972; Pitre et al. 1978; Putman 1967; Raney and Yeargan 1977; Roach 1980; Shepard et al. 1974; Smith and Stadelbacker 1978; Wene and Sheets 1962). For example, populations of a pest and predator may be monitored and insights may be gained into whether or not major predator groups are having an impact on the density of the pest population (Fig. 2). Again, it is tempting to draw a 'cause and effect' relationship from this and indeed if enough data sets are available, certain circumstantial evidence about predator-prey relationships may be gained, but this is usually of little quantitative value.

![Fig. 2. Generalized diagram of comparison of seasonal abundances of prey species and predator species.](image-url)
This technique has been advanced one step further to assess the influence of certain pesticide applications or cultural practices on the seasonal and relative abundances of predators in various cropping systems (Buschman et al. 1984; Elsey 1973; Farlow and Pitre 1983; Harrison 1960; Hull and Starner 1983; Kinzer et al. 1977; Laster and Brazzel 1968; Lingren et al. 1968b; McPherson et al. 1982; Morrison et al. 1979; Price 1977; Price and Shepard 1977, 1978; Ridgway et al. 1967; Rummel and Reeves 1971; Scott et al. 1983; Semtner 1979; Sprenkel et al. 1979; van den Bosch et al. 1966; van Steenwyk et al. 1975). Important information related to predator-prey-pesticide interactions may be obtained from the use of this technique.

QUANTITATIVE TECHNIQUES

EVALUATIONS IN THE LABORATORY

At present much of the quantitative information on predator assessment has been generated from studies in the laboratory (Ables et al. 1978; Best and Beegle 1977; Chiravathanapong and Pitre 1980; Chow et al. 1983; Crocker et al. 1975; Donahoe and Pitre 1977; Grant et al. 1985; Isenhour and Yeargan 1981; Lawrence and Watson 1979; Lingren et al. 1968a; Lopez et al. 1976; Loughridge and Luff 1983; Marston et al. 1978; Nadgauda and Pitre 1978; Propp 1982; Rowlands and Chapin 1978; Sandness and McMurtry 1970; Sloderbeck and Yeargan 1983; Summerlin et al. 1982; Waddill and Shepard 1974, 1975). These studies generally estimate the number of prey killed per unit time by the predator and provide important information relative to predator-prey interactions; however, such studies are usually conducted in small cages, with high numbers of prey and usually under favorable environmental conditions.

The most important advantages of laboratory studies are that they provide information relative to: 1) host preferences, 2) host range of a predator, 3) searching abilities, 4) feeding behavior, 5) attack behavior and 6) functional responses. This approach also can provide information about a predator's preferences for certain stages or species of prey. The major disadvantage, however, to the use of laboratory studies is that they do not provide a realistic means of assessing predation that may occur in a field situation. For example, adult female *Geocoris punctipes* (Say) (HEMIPTERA: Lygaeidae) which were exposed to bollworm and tobacco budworm, *H. virescens* (Fabricius), eggs or first instars in the laboratory consumed an average of 51.0 eggs or 29.6 larvae per 48 h (Lopez 1976). In a field-cage study, however, Richman et al. (1980) found that *G. punctipes* which were exposed to soybean looper, *Pseudoplusia includens* (Walker) (LEPIDOPTERA: Noctuidae), eggs or first and second instars consumed an average of 9.90 eggs or 5.27 larvae per 48 h. Although the host species and experimental designs were different, 81 to 82% more prey were killed under laboratory conditions as compared with results from field-cage evaluations. Similar results have been reported with other predators and prey. The influence of a predator on a pest population can be assessed only in relation to the other factors that also determine population size.

EVALUATIONS IN THE FIELD

Addition ("with and without")

This technique has been used to evaluate certain predator species, and involves the release of predators into a particular field (the 'with' field), while
another field in close proximity is used as a control field (that is, predators are not released in that field; hence, the ‘without’ field) (Huffaker and Kennett 1956). Densities of prey populations are monitored in each field and compared between fields to assess the possible value of the predator species. This method may be an effective means of evaluating imported species provided that their dispersal is confined to the area in which they were released, but may have little benefit in the evaluation of predator species that are established in a given area.

**Exclusion**

The exclusion technique involves the elimination and subsequent exclusion of entomophagous arthropods in a given area through the use of cages (Fig. 3), chemicals, or some other means (Brown and Goyer 1982; Chambers et al. 1983; DeBach 1946, 1955; Debach et al. 1949; Gould and Jeanne 1984; Huffaker and Kennett 1956; Pedigo et al. 1972; Reed et al. 1984; Smith and DeBach 1942). Mortality within this excluded area is then compared with a similar area in which the entomophagous arthropods were not disturbed. The effectiveness of entomophagous arthropods in suppressing noctuid pest populations in soybean fields in South Carolina was assessed during 1980 and 1981 using two exclusion techniques (i.e., cup cages and field cages) (Reed et al. 1984). By using cages, they excluded predators from naturally-occurring *H. zea* larvae, and compared the resulting mortality with that which occurred outside the cages (i.e., mortality of those larvae that were exposed to naturally-occurring predators). Their results illustrated that arthropod predators are efficient in reducing noctuid egg and larval densities in soybean. They concluded that entomophagous arthropods were the principle factor in maintaining the density of this pest species below the economic threshold in one experimental field in July 1981. A cup-cage exclusion technique is one possible method of assessing predator efficiency under field conditions. The applicability of results of exclusion techniques to the actual mortality caused by predator populations under field conditions will depend upon the selection, implementation and utilization of an appropriate experimental design.

Several researchers have assessed predator efficiency through the use of chemical exclusion (Brown and Goyer 1982; Shepard et al. 1977). In Louisiana, Brown and Goyer (1982) found that the total number of defoliators on a season-long basis differed significantly (*P* ≤ 0.05) between the chemically-treated (heptachlor and methyl parathion) plots and the undisturbed or control plots. In South Carolina, Shepard et al. (1977) reported that chemical treatment (methyl parathion and methomyl) of soybean caused a resurgence of populations of several noctuid pests [*green cloverworm, Plathypena scabra* (Fabricius); corn earworm; tobacco budworm; soybean looper; and velvetbean caterpillar, *Anticarsia gemmatalis* Hübner]. They attributed this resurgence of noctuid pest populations to an overall reduction of the naturally-occurring biotic agents.

**Field-cage evaluations**

One of the more common approaches is the use of field-cage evaluations which employ a cage of some size and shape (Fig. 3) (Abdul-Sattar and Watson 1982; Bryson and Schuster 1975; Collins 1980; Greene and Shepard 1974; Hutchinson and Pitre 1983; Irwin et al. 1974; Leigh and Gonzalez 1976; Lingren et al. 1968a; Neal et al. 1972; Reed 1983; Reed et al. 1984; Richman et al. 1980; Ridgway and Jones 1968, 1969; Tejada 1971; van den Bosch et al. 1969). Predators and prey are
Fig. 3. Examples of several types of cages used to assess predator efficiency: A) sleeve-cage, B) large, rectangular cage, C) large, cylindrical cage, and D) cup-cage (Photographs A and B courtesy of D. R. Alverson and A. W. Johnson, respectively).

combined in one cage for a specified unit of time, after which the resulting prey mortality is determined. Another cage containing only the prey (that is, the control cage) is used to assess natural mortality of the prey caused by factors other than natural enemies. The difference in mortality between the control cage and the predator cage is usually assessed as mortality caused by the predator species.

Many shapes and sizes of cages have been used in the evaluation of predators. Several of these cages are shown in Fig. 3. Results of predation by a species would
be somewhat different in each of these cages. There is a need for a standard cage type that could be used to assess predation by the major predators within a specific crop system. Results from studies using standardized cages should provide a more accurate means of predator assessment within a crop system across geographical regions.

Field-cage techniques have been used to evaluate the predator capabilities of single predator species (Barry et al. 1974; Richman et al. 1980) or complexes of predator species (Barry et al. 1974; Reed 1983). Reed et al. (1984) evaluated the effectiveness of individual species and complexes of entomophagous arthropods in reducing noctuid pest populations in soybean. They concluded that predaceous arthropods are of economic importance to soybean growers although they placed no quantitative value on their importance.

The most important advantages of this technique are that it provides a quantitative assessment of predation by single species or communities of predators on single pest species or complexes of pest species under field conditions, and it may be important in providing quantitative values for models that predict densities of pest populations. The major disadvantage, however, is that this technique usually manipulates the habitat in some manner. The microclimate within a cage may differ from that outside the cage, and the behavior of the predator and prey also may be altered when they are confined within a cage. It is difficult to assess the influence of confinement on prey mortality that may be caused by the inability of the predator to disperse. In other words, it may be easier for the predator to locate the prey, thus overestimating actual mortality caused by predation. Also, it is often difficult to locate prey and predators in large cages placed over crops with well-developed canopies.

Radioactive labeling

Jenkins and Hassett (1950) suggested that it may be possible to measure predator-prey relationships using radioactive tracers. Since then, radioactive labeling has become a popular method of evaluating predators in several crop systems (Buschman et al. 1977; Gravena and Sterling 1983; McCarty et al. 1980; McDaniel and Sterling 1979; McDaniel et al. 1978, 1981; Moore et al. 1974; Room 1977). This technique involves labeling larvae or adults with a radioactive tracer, and releasing the labeled specimens into the field or in field cages. Later, suspected predators are collected from the field, taken to the laboratory and analyzed to determine whether or not they are labeled.

Room (1977) described a method for producing 32P labeled Heliothis spp. eggs and larvae for use in mark-recapture studies of non-insecticidal mortality. McDaniel et al. (1978) described a technique for radiolabeling H. virescens eggs by injecting accurately measured doses of 32P into adult females before oviposition. This method provided a consistent method of labeling prey individuals. A similar method was used to qualitatively and quantitatively describe the effects of predators on egg numbers of Heliothis spp. in cotton fields using 32P labeled prey (McDaniel and Sterling 1979). To quantify predation, they placed radioactive arthropods in a Beckman Low Beta Matic II gas counter to determine the disintegrations per min (DPM) per individual. Samples were counted for 10 min with a mean efficiency of 0.28 and a background of 2 counts per min (CPM). They
used the following formula to calculate the number of eggs consumed per predator:

\[
\text{No. consumed} = \frac{(\text{CPI}_t - \text{B})}{(\text{E}) (\text{MC}) (\text{DPM}_{\text{egg}})} (D_t)
\]

where

- \(\text{CPI}_t\) = counts per insect at time \(t\);
- \(\text{B}\) = background of counter (20 \(\text{CPI}\));
- \(\text{MC}\) = minutes sample counted (10);
- \(\text{E}\) = counter efficiency (\(\bar{x}\) of 0.28);
- \(\text{DPM}_{\text{egg}}\) = calculated from McDaniel et al. (1978);
- \(D_t\) = decay for time \(t\).

Using autoradiography techniques, McCarty et al. (1980) identified predaceous arthropods of lepidopterous eggs and early stage larvae of lepidopterous pests of soybean in South Carolina. Radioactive labeling, however, is not limited to crop systems. For example, mosquito larvae and pupae have been labeled to identify their predators in aquatic systems (Baldwin et al. 1955).

Radioactive labeling has certain advantages including: 1) singles out predatory species, 2) fairly easy to read tests, 3) do not have to cage the predator and can obtain an assessment of the natural system, 4) possible to quantify predation, and 5) possible to inject moths for release in the field.

The disadvantages of radiolabeling include: 1) poses a health hazard, 2) can be time-consuming, 3) must follow a definite protocol to meet state and federal regulations, and 4) may get predator-predator interactions. A predator may feed on another predator which has fed on a labeled prey and be classified as a predator of the labeled species. An arthropod also may feed on the frass or remains of a labeled species, become labeled and be classified as a predator of the labeled species. It should be obvious that even if a species is labeled, it may not necessarily be a predator of the labeled prey. This information, however, combined with that obtained from other methods such as laboratory evaluations or direct observations in the field should provide a better understanding of predator-prey interactions.

**Serological tests**

The principle technique used in serological tests is the precipitin test (Brooke and Proske 1946; Dempster 1960; Downe and West 1954; Frank 1967; Gardner et al. 1981; Hall et al. 1953; Lesiewicz et al. 1982; Lund and Turpin 1977; MacLellan 1954, 1963; Rothschild 1966; Service 1973; West 1950). Basically, it involves collecting the prey species from the field; preparing an antigen from the prey species; and injecting this antigen into a rabbit to produce a specific antibody. The antibody can then be used to test the gut contents of suspected predators. A positive reaction demonstrates that the gut of the predator contains prey parts (antigen). The major advantage of this technique is that it allows for an evaluation of predation under 'natural' conditions; that is, there is no disturbance or manipulation of the habitat except for the collection of possible predators from the field. However, there are several disadvantages including: 1) preparation of the antigen is time-consuming and tedious, 2) requires a certain expertise in technique, 3) may get a cross-reaction especially with a crude technique or unrefined antigen, 4) can generally only be used as a positive or negative record of predation; usually little information can be discerned about the amount of predation; and 5) may get...
possible predator-predator interactions as discussed earlier for the radioactive labeling technique. More advanced serological techniques such as an enzyme linked immunosorbent assay (ELISA), passive haemagglutination inhibition assay and a latex agglutination test have been used to identify predators and to obtain quantitative data on predation (Greenstone 1977, 1979; Ohiagu and Boreham 1978; Ragsdale 1980; Ragsdale et al. 1981).

**Other quantitative techniques**

Quantitative methods which are conducted under field conditions provide a more accurate method of assessing predator efficiency. In the case of holometabolous insect pests, there are four stages of development (egg, larva, pupa and adult) that may be attacked by a predator species. The egg and pupal stages usually are immobile, making it relatively simple to obtain a quantitative assessment of predation in the field. Known numbers of eggs or pupae can be distributed in a field, left for a given period of time, and then counted to determine the number missing, eaten or destroyed (Buschman et al. 1977; Elsey 1971, 1972; Fletcher and Thomas 1943; Grant and Shepard, unpublished data; Gravena and Sterling 1983; Katanyukul and Thurston 1973; Marston et al. 1984; Negm and Hensley 1969). During 1973, Marston et al. (1984) conducted a weekly study to measure the season-long predation of eggs of the cabbage looper, *Trichoplusia ni* (Hubner) (Lepidoptera: Noctuidae), in soybean in Missouri. By placing eggs on the underside of soybean leaflets (one egg per leaflet) for 24 h, they found that the seasonal average for egg predation during a 24 h observational period was 29.9%. Buschman et al. (1977) also conducted a weekly survey to determine the rate (per 24 h) of predation on velvetbean caterpillar eggs in soybean. They placed egg-laden soybean plants in a soybean field and estimated that the mean rate of predation per 24 h on eggs placed in the field was 26%.

Many techniques have been investigated for assessing egg predation in the field, and each variation may result in somewhat different quantitative values. For example, we investigated the use of several techniques for the evaluation of predation on *H. zea* eggs in a soybean field (Grant and Shepard, unpublished data) (Table 1). Results were highly variable between the different methods used, primarily because of differences in the numbers of eggs exposed to natural enemies. Placement of eggs individually or in groups on the leaflet also affected the mean number of eggs missing per 24 h (Table 2). Eggs in our studies were attached to the plant with egg albumin. Results from other techniques using other substances may differ. It is desirable to standardize a rapid and efficient technique which could quantify the rate of egg predation of certain lepidopterous pest species in various cropping systems. Such research provides a quantitative value attributed to predation per unit time. Although the use of this method may provide important information for pest management decisions, the quantitative value is usually attributed to the predator complex in general and not to a specific species of predator.

A more difficult task is to obtain a quantitative value for predation on the larval and adult stages. These forms are mobile, making it almost impossible to quantify predation using the method described for eggs and pupae. Because larvae are responsible for much of the damage caused by holometabolous insects, it is important to develop a method which will provide a quantitative value of predation on larvae under field conditions.
Table 1. Comparison of mean *Heliothis zea* egg loss per 24 h among five evaluation techniques in a soybean field near Florence, SC (17-18 August 1983).

<table>
<thead>
<tr>
<th>Evaluation technique*</th>
<th>Mean (± SE) no. H. zea eggs missing/24 h</th>
<th>Mean (± SE) percentage of H. zea eggs missing/24 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eggs laid on foliage in lab — taken to field†</td>
<td>26.40 ± 12.04</td>
<td>37.42 ± 11.74</td>
</tr>
<tr>
<td>Eggs laid on foliage in field‡</td>
<td>63.58 ± 31.42</td>
<td>39.30 ± 13.11</td>
</tr>
<tr>
<td>Eggs placed on foliage in field (1 egg/leaflet, 5 leaflets/plant)</td>
<td>1.47 ± 0.77</td>
<td>29.40 ± 15.39</td>
</tr>
<tr>
<td>Eggs laid on cheese-cloth in lab — taken to field§</td>
<td>0.95 ± 0.87</td>
<td>19.00 ± 17.34</td>
</tr>
<tr>
<td>Eggs laid on wax paper in lab — taken to field§</td>
<td>1.00 ± 0.69</td>
<td>20.00 ± 13.86</td>
</tr>
</tbody>
</table>

* Each evaluation technique was replicated five times.
† Number of eggs laid on foliage in the laboratory ranged from 53 to 90 soybean leaf. Ave. no. of eggs/leaf = 72.4. A leaf represents one experimental unit.
‡ Number of eggs laid on foliage in the field ranged from 32 to 271 soybean leaf. Ave. no. of eggs/leaf = 170.5. A leaf represents one experimental unit.
§ Five eggs/2.54 cm² section of cheese-cloth or wax paper. Each section represents one experimental unit.

Table 2. Comparison of predation on single or grouped *Heliothis zea* eggs during 24 h in a soybean field near Florence, SC (26 August - 8 September 1983).

<table>
<thead>
<tr>
<th>Evaluation technique*</th>
<th>Mean (± SE) no. <em>H. zea</em> eggs missing/24 h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eggs placed on foliage in field (1 egg/leaflet, 5 leaflets)</td>
<td>3.20 ± 0.36 a†</td>
</tr>
<tr>
<td>Eggs placed on foliage in field (5 eggs/leaflet, 1 leaflet)</td>
<td>2.07 ± 0.55 b</td>
</tr>
</tbody>
</table>

* Each evaluation technique was replicated fifteen times.
† Means followed by different letters are significantly (*P* ≤ 0.05) different (t-test).

CONCLUSION

Many techniques have been used to gain insight into the assessment of predation by arthropod predators. Each technique or variation thereof may provide a somewhat different assessment of predation. It is clear from the information published so far, that no single technique will be suitable for all situations. By using a combination of methods, we may come closer to providing more reliable information about the impact of predators on natural populations of pests. For example, Buschman and co-workers (1977) identified predators of velvetbean caterpillar eggs in a soybean field by using a combination of direct observation and radioactive labeling. Recently, Elvin et al. (1983) used a combination of direct observation and mark-release-recapture to quantify predation rates by different species of predators against larvae of the velvetbean caterpillar in soybean.
Many studies indicate that although the total numbers of predatory species are enormous, there often are only a few major species of ‘key’ predators that may have a significant impact on pest populations (Caron and Bradley 1978; Shepard et al. 1974). After these major predators are identified, efforts should be made to develop standardized techniques with which results from different geographical locations can be compared. This will be easier for non-mobile prey such as eggs or pupae. Methodologies for testing predator effectiveness against larvae, however, are in the infantile stages and research is sorely needed here.

It is obvious that no single, simple technique is presently available to accurately quantify predation in the field. In order to incorporate information about predators into the decision-making process associated with pest management, quantitative measurements of the impact of natural enemies on target pests in a crop system are essential, and our techniques must be refined to obtain this information.

ACKNOWLEDGMENTS

Special thanks to C. H. Cobb, R. E. McWhorter, and S. L. Turnipseed for their technical assistance in the preparation of this manuscript. We also thank W. P. DuBose III for critically reviewing an earlier draft of this manuscript.

REFERENCES CITED


111 GRANT and SHEPARD: Techniques for Evaluating Predators


Katanyukul, W., and R. Thurston. 1973 Seasonal parasitism and predation of eggs of the tobacco hornworm on various host plants in Kentucky. Environ. Entomol. 2: 939-945.


