Modeling Population dynamics and dispersion of Codling moth *Cydia pomonella* L. (Lepidoptera, Tortricidae)

Dissertation:

Submitted in fulfillment of the requirements for the degree " Doctor der Agrarwissenschaften"
(Dr. Sc. agr. / Ph.D. in Agricultural Science)

to the

Faculty of Agricultural Science, Hohenheim University

Presented by

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Nov. 2009

This thesis was accepted as a doctoral dissertation in fulfillment of the requirements for the degree Doktor der Agrarwissenschaften by the Faculty of Agricultural Sciences at the University of Hohenheim on 17 Nov. 2009

Date of oral examination: 27 Nov. 2009

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AFFECTIONATELY DEDICATED TO:

THE SOUL OF MY PARENTS

TO DEAR BROTHER

SISTERS

AND

MY WIFE

Declaration

I declare that the thesis hereby submitted for the Ph. D. degree, is my own original research work and has not been previously submitted by me at another University for any degree. Whenever contributions of others are involved, every effort is made to indicate this clearly, with due references to the literature, and acknowledgment of collaborative research and discussions. The work was done under the guidance of Professor Dr. Dr. C. P. W. Zebitz, at the Phytomedicine Institute of Agricultural Faculty of Hohenheim University.

Gholamhossein Gharehkhani

Date: 20.July 2009

Abstract

Modeling Population dynamics and dispersion of Codling moth *Cydia pomonella* (Lepidoptera, Tortricidae)

Abstract:

The study of insect dispersal plays an essential role in estimating the spread of damage caused by a newly invaded pest or the spatial distribution of an insect during the active period in growing season. Moreover concerning dispersal, quantitative information performs a crucial role in the evaluation and implementation of pest control.

Since rearing clean and healthy insects in sufficient numbers is the most important prerequisite for many basic research programs and for developing pest control strategies, mass rearing of the Codling moth on the artificial diet carried out as the first step at optimum conditions. With regard to the fundamental function of feeding and pre-releasing handling on insect biological attributes, we intended to evaluate the individual marking influence on longevity of Codling moths in the next step. For this purpose, one day old adult male and female moths were kept three and five minutes at -20 $^{\circ}C$ to make them motionless, then immediately marked individually with felt tip pens and coded by the different colors, maintained under optimum condition and checked daily for 13 days. The proposed linear model accounted for 89 % of the variations. Numbing and marking process influenced of the moths longevity regardless of their sex while the duration of the anesthetize does not affect the survival of moths meaningfully.

Regarding the obstacles associated with egg and pupa storage of Codling moth, we examined the possibility of adult moth's storage in low temperature in order to evaluate its effect on longevity of moths. Adult 12-24 h old male and female moths were treated separately and maintained in 4 $^{\circ}C$ and (0:24 h, L:D) photoperiod during the entire adult life. The survival rate evaluated with two days interval throughout 27 days. The effects of day and treatment were significant. It seems that the female moths tolerate the cold condition better and further than the male moths and live longer. Additionally the proposed models accounted for 71 % and 57 % of the variations for male and females respectively as verified more affection and debility of the males by the storage condition. Disadvantages of individual marking led us to test the mass marking and it's influence on the survival of the moths. One-day-old moths were marked with fluorescent powder. Mortality of the males and females recorded daily for a 20 days period. Results indicated that the effects of the sex, the replications and interaction of them were significant as well as the effect of the day. The model accounted for 96 % of the variations. This study indicated that male and female moths were influenced by the fluorescent powder. Findings of this study may facilitate the improvement of mark-release experiment results and interpretation more precisely in particular for dispersal studies.

In the field experiments, firstly trade off trap structure in assessing the horizontal and vertical distribution of Codling moth carried out as well as outward and inward dispersal. Three different types of the traps including Delta pheromone traps, Delta Pear ester trap and Cylinder shape Pear ester traps were used in the research station of the Hohenheim University. Ninety six traps were suspended in eight compass directions in order of four traps per direction, at three heights in random arrangement in outward dispersal. In inward dispersal study the traps arrangement and number was the same but dissimilarly the releasing site was from borders of directions SW, NW, W, E, and SE. The traps were checked daily and followed nine days after release. Results demonstrated no significant differences between three types of traps in attracting the marked and feral females ’Fn’. Meanwhile significant dissimilarity in marked and feral male ’Mn’ catches were traced. Reaction of the moths to the traps elevation was not similar in the vertical distribution study. whereas marked female moths exhibited significant differences to different heights, marked and feral male and ’Fn’ moths revealed no difference reaction to traps in different heights.In horizontal distribution study marked female moths ’Fr’ exhibited significant differences. It is revealed that dominant directions for marked and feral moths were different. Concerning inward distribution, both marked male ’Mr’ and female demonstrated significant differences in their direction and distances. In regard to this findings and priceless and effortless manufacturing of the Cylinder traps, utilization of this trap in mark-release-recapture studies of female and male Codling moths is recommended.

Effect of apple cultivar on pheromone and Pear ester trap efficiency studied as the next tread. In this experiment 32 Delta pheromone traps and 32 Cylinder-shape Pear ester traps impartially mounted on different varieties of apple trees. Artificially reared and marked 24 to 26 h old moths were released at 1 m height from a central point. Among the simple effects the most important explanatory variable for the response variables ’Mn’ and ’Fn’ moths was sampling dates of moths, while the variety and distance from the releasing point for ’Mn’ and the variety and trap height for ’Fn’ were the second and third influential variables respectively. Moreover among the nested effects the interaction of distance-height-variety was the most influential one for ’Mn’ likewise the interactions of date, release point, direction and trap height with the variety were the most influential for ’Fn’. For the ‘Mr‘ and ’Fr’ moths releasing date was the most important influential variable, while the trap type and variety for ’Mr’ and variety and trap height for the ’Fr’ were the second and third influential variables respectively. Current study revealed that dispersal of the feral and marked-released male and female Codling moths influenced by host cultivars distinctly and decidedly. Meanwhile, quantifying these relationships and propose distinct model for marked and feral male and female moths are the exclusive characteristics of present findings.

The next stage of present study related to study of climatic factors on dispersal of Codling moth. In this study, Hohenheim station climatic data were used. Several climatic elements including temperature, relative humidity, precipitation, wind speed in two different heights (2.5 m and 10 m), Day Degree, twilight temperature, wind speed and precipitation were utilized in the analysis. Diversity and high number of variables led us to use AIC method for selecting of appropriate regressors and fitted model. The main regressors that influenced the ’Fr’ were flight height, ageing, twilight wind speed (2.5 m heights) and precipitation. For the ’Mr’ the same regressors plus the distance from the releasing point were the best subset. In the case of the feral moths the flight height, relative humidity, Day Degree, twilight temperature and wind speed were the best subset regressors. Comprehensively we concluded that present study provides new knowledge in basic as well as in applied science. Twilight temperature, rainfall, wind speed and Day Degree impress the distribution of the moths in a superior way than the circadian weather data. This knowledge could mitigate confusion which arises from observations of erratic flight patterns and could lead to fewer treatment decision errors in the future. Also may accelerate and strengthen forecasting programs of this key pest as well as the related management tactics.

The combination of mark-release-recapture and diffusion models have been shown to be effective for measuring insect dispersal. We attempted to measure the Codling moth dispersal using traps placed at different distances and heights. Diffusion coefficient calculated for horizontal and vertical dispersal of male and female moths distinctly using direct and indirect methods and resulting models were compared. We fitted the non-linear regression using the iterative process and estimating the parameters accuracy were tested according to the default asymptotic 95 % confidence intervals calculation in non-linear regression. Considering the overall models, suitability of three factors fitted models was more convincible than that of two factors model particularly for male moths. Meanwhile we found great difference in the diffusion coefficient of direct and indirect methods. Regardless of the model type, the R^2 was relatively high in our experiments which evaluate how well the model fits data. We have shown that the diffusion model leads to powerful techniques for the analysis of dispersal data at least for one economically important insect. In conclusion, the present study provides an estimate of population spread by Codling moth using estimated rates of reproduction and dispersal, quantified the association between various key factors and Codling moth movement for the first time using the diffusion model. By including additional parameter to the diffusion model the predictive explanatory potential of this method was improved for dispersal studies at least for a cosmopolitan and critical insect.

Zusammenfassung

Modellierung der Populationsdynamik und der Verbreitung der Apfelwicklers *Cydia pomonella* L. (Lepidoptera: Tortricidae)

Untersuchungen zur Insektenverbreitung sind eine wichtige Grundlage für Voraussagen über das Vordringen eines neu eingewanderten Schädlings auf dem Luftweg oder die räumliche Verteilung eines Insekts während seiner aktiven Periode in der Anbausaison. Darüber hinaus spielen quantitative Aussagen zur Verbreitung eine entscheidende Rolle in der Bewertung und Umsetzung von Pflanzenschutzmaßnahmen. Da die Aufzucht gesunder Insekten in ausreichender Zahl die wichtigste Voraussetzung für viele grundlegende Forschungsvorhaben und für die Entwicklung von Pflanzenschutzstrategien darstellt, war der erste Schritt die Massenzucht des Apfelwicklers auf künstlicher Diät unter optimalen Bedingungen. Aufgrund der erheblichen Auswirkungen von Fütterungs- und Handhabungsbedingungen auf die biologischen Eigenschaften der Insekten beabsichtigten wir, im nächsten Schritt den Einfluß der Markierung auf die Lebensdauer der Apfelwickler zu untersuchen. Dazu wurden einen Tag alte ausgewachsene männliche und weibliche Tiere drei und fünf Minuten einer Temperatur von -20°C ausgesetzt, um sie bewegungsunfähig zu machen, sofort mit verschiedenfarbigen Filzschreibern nach einem Farbschema individuell markiert und dann 13 Tage unter optimalen Bedingungen gehalten und täglich kontrolliert. Das vorgeschlagene lineare Modell deckt 89% der Variationen ab. Der Einfluß des Betäubungs- und Markierungsvorgangs auf die Lebensdauer der Tiere war bei beiden Geschlechtern gleich, dabei hatte die Dauer der Betäubung keine entscheidenden Auswirkungen auf die Überlebensrate der Falter. Angesichts der Schwierigkeiten, Eier und Puppen des Apfelwicklers zu lagern, untersuchten wir die Möglichkeit, adulte Tiere bei niedriger Temperatur zu halten, um mögliche Auswirkungen auf die Lebensdauer der Insekten zu erfassen. Ausgewachsene 12-24 h alte männliche und weibliche Falter wurden getrennt behandelt und während ihrer gesamten Lebensdauer bei 4 °C und einer Photoperiode von (0:24 h, L:D) gehalten. Die Überlebensrate wurde 27 Tage lang jeden zweiten Tag erhoben. Der Zusammenhang von Lebensdauer und Behandlung war signifikant. Es scheint, daß die weiblichen Tiere Kälte besser ertragen als die männlichen und länger leben.

Die vorgeschlagenen Modelle beschreiben jeweils 71% bzw. 57% der Variationen für Männchen und Weibchen und bestätigen höhere Anfälligkeit und Sterblichkeit der Männchen unter Lagerbedingungen. Nachteile der individuellen Markierungsmethode veranlassten uns, Massenkennzeichnungen und ihren Einfluß auf die Überlebensrate der Insekten zu untersuchen. Einen Tag alte Tiere wurden mit fluoreszierendem Puder gekennzeichnet, die Sterblichkeit von Männchen und Weibchen über zwanzig Tage täglich aufgezeichnet. Die Ergebnisse deuten darauf hin, daß der Zusammenhang zwischen Geschlechtszugehörigkeit, den Wiederholungen, ihrem Zusammenwirken und dem Tag der Erhebung signifikant war. Das Modell beschrieb 96% der Variationen. Der Versuch zeigte, daß männliche wie weibliche Falter durch den fluoreszierenden Puder beeinflusst werden. Die Ergebnisse der Untersuchungen können zur Verbesserung von Wiederfang-Versuchen beitragen und helfen, ihre Ergebnisse aussagekräftiger zu machen, insbesondere für Verbreitungsstudien. In den Freilandexperimenten wurde zuerst eine Anordnung von Fallen eingesetzt, um die horizontale und vertikale Verteilung der Apfelwickler sowie ihre Ausbreitungsdynamik zu erfassen. Drei verschiedene Arten von Fallen wurden auf der Versuchsstation der Universität Hohenheim verwendet: delta-Fallen mit Pheromon, delta-Fallen mit Birnenester und Zylinderfallen mit Birnenester. Um die auswärts gerichtete Ausbreitung zu erfassen, wurden sechsundneunzig Fallen in acht Himmelsrichtungen, vier in jeder Richtung, auf drei verschiedene Höhen zufällig verteilt angebracht. Die Anordnung zur Erfassung der einwärtigen Ausbreitung war gleich, aber die Freisetzung erfolgte an den in den Richtungen SW, NW, W, O, und SO gelegenen Grenzen der Versuchsfläche. Die Fallen wurden neun Tage nach der Freisetzung täglich überprüft. Die Ergebnisse zeigten keine signifikanten Unterschiede zwischen den drei Arten von Fallen in ihrer Anziehung auf markierte und wilde Weibchen 'Fn'. Zwischen den Fangraten an markierten und wilden Männchen 'Mn' ließ sich jedoch ein signifikanter Unterschied nachweisen.

Die Reaktion der Falter auf die Höhe der Fallen über dem Boden war unterschiedlich. Während markierte weibliche Tiere signifikante Vorlieben für bestimmte Höhen aufwiesen, war bei markierten und wilden Männchen sowie wilden Weibchen kein Unterschied in der Reaktion auf verschieden hoch angebrachte Fallen zu erkennen. Bezüglich der horizontalen Ausbreitung zeigten markierte weibliche Falter 'Fr' signifikante Unterschiede. Es erwies sich, daß die bevorzugten Richtungen für markierte und wilde Apfelwickler-Motten unterschiedlich waren. Betreffs der migration Ausbreitung wiesen sowohl markierte Männchen 'Mr' als auch Weibchen signifikante Unterschiede in Richtung und Entfernungen auf. Angesichts dieser Ergebnisse sowie der billigen und einfachen Herstellung der zylindrischen Fallen wird ihre Anwendung in Wiederfang-Versuchen mit männlichen und weiblichen Apfelwicklern empfohlen.

Im nächsten Schritt wurde der Einfluß von Wirtstypeen auf die Wirksamkeit der Pheromon- und Birnenester-Fallen studiert. In diesem Versuch wurden 32 delta-Fallen mit Pheromon und 32 Zylinderfallen mit Birnenester zufällig verteilt auf Apfelbäumen verschiedener Sorten angebracht. Im Labor aufgezogene und markierte 24-26 h alte Falter wurden an einem zentralen Punkt in 1 m Höhe freigelassen. Unter den einfachen Zusammenhängen war das Erhebungsdatum die Ausgangsvariable mit dem größten Einfluß auf die Ergebnisvariablen 'Mn' und 'Fn', an zweiter und dritter Stelle kamen Sorte und Entfernung vom Ort der Freilassung für 'Mn' bzw. Sorte und Höhe der Falle für 'Fn'. Unter den Zusammenhängen höherer Ordnung war das Zusammenwirken von Entfernung, Höhe und Sorte am einflußreichsten für 'Mn', dagegen jenes von Datum, Freisetzungtype, Richtung, Fallenhöhe und Sorte am wichtigsten für 'Fn'. Für 'Mr' und 'Fr' war das Freilassungsdatum die bedeutendste beeinflussende Variable, während die Art der Falle und die Sorte für 'Mr' bzw. die Sorte und Fallenhöhe für 'Fr' den zweiten und dritten Rang einnahmen. Die vorliegende Studie zeigte auf, daß die Ausbreitung sowohl von wilden als auch markierten und freigelassenen männlichen wie weiblichen Apfelwicklern entscheidend und deutlich von den Wirtstypeen beeinflusst wird. Diese Verhältnisse werden erstmalig quantitativ beschrieben und ein geeignetes Modell für markierte wie wilde, männliche und weibliche Falter vorgeschlagen. Der nächste Abschnitt der vorliegenden Arbeit beschäftigte sich mit dem Einfluß klimatischer Faktoren auf die Ausbreitung des Apfelwicklers. Zu diesem Zweck wurden Daten der Meteorologischen Station Hohenheim verwendet. Verschiedene Klimafaktoren, wie Temperatur, Rel. Feuchte, Niederschlag, Windgeschwindigkeit in zwei verschiedenen Höhen (2,5 m und 10 m), Gradtage und Dämmerungstemperatur gingen in die Analyse ein. Die Verschiedenheit und Vielzahl der Variablen veranlasste uns, die AIC-Methode zu verwenden, um angemessene Regressoren und ein passendes Modell zu finden. Die Hauptregressoren, welche die Variable 'Fr' beeinflussten, waren Flughöhe, Alter, Windgeschwindigkeit in

der Dämmerung (2,5 m Höhe) und Niederschlag. Bei 'Mr' bildeten dieselben Regressoren und zusätzlich der Abstand vom Ort der Freisetzung die beste Auswahl. Für die wilden Falter stellten Flughöhe, Rel. Feuchte, Gradtag, Dämmerungstemperatur und Windgeschwindigkeit den besten Satz an Regressoren dar. Zusammenfassend ist festzustellen, daß die vorliegende Studie neue Einsichten für die angewandte wie auch die Grundlagenforschung bereithält. Dämmerungstemperatur, Regen, Windgeschwindigkeit und Gradtag bestimmen die Ausbreitung der Apfelwickler sehr viel stärker als das Wetter tagsüber. Diese Erkenntnis könnte die aus der Beobachtung unvorhersagbarer Flugaktivität herrührende Verwirrung verringern und in der Zukunft zu weniger Fehlentscheidungen über Behandlungsmaßnahmen führen. Sie kann außerdem Vorhersagen zum Auftreten dieses wichtigen Schädlings und damit Managementstrategien vereinfachen und absichern. Die Kombination von Wiederfang-Versuchen und Verteilungsmodellen hat sich als effektiv zur Bestimmung der Ausbreitung von Insekten erwiesen. Wir haben versucht, mit Hilfe von in verschiedenen Entfernungen und Höhen angebrachten Fallen die Ausbreitung des Apfelwicklers zu bestimmen. Die Verteilungskoeffizienten, berechnet jeweils für horizontale und vertikale Ausbreitung von weiblichen und männlichen Faltern unter Verwendung von direkten und indirekten Methoden sowie die resultierenden Modelle wurden verglichen. Mittels iterativer Methoden ermittelten wir eine passende nonlineare Regression und schätzten die Genauigkeit der Näherung unter Zugrundelegung eines 95%-Vertrauensintervalls. Im Vergleich war ein auf drei Faktoren beruhendes Modell überzeugender als ein nur zwei Faktoren berücksichtigendes, insbesondere bezüglich männlicher Falter. Allerdings fanden wir große Unterschiede in den Verteilungskoeffizienten zwischen direkten und indirekten Methoden. Unabhängig von der Art des Modells war R^2 in unseren Versuchen, zu ermitteln, wie gut das Modell mit den Daten übereinstimmt, relativ hoch. Wir haben gezeigt, daß das Verteilungsmodell zur Analyse von Ausbreitungsdaten zumindest für ein wirtschaftlich bedeutendes Insekt ein leistungsfähiges Werkzeug darstellt.

Schließlich stellt die vorliegende Studie unter Verwendung geschätzter Vermehrungsraten und Ausbreitungsgeschwindigkeiten eine Abschätzung der Ausbreitung des Apfelwicklers bereit und beschreibt unter Verwendung eines Verteilungsmodells erstmalig quantitativ den Zusammenhang zwischen verschiedenen Schlüsselfaktoren und Mobilität des Apfelwicklers. Durch Einbeziehung zusätzlicher Parameter für das Verteilungsmodell konnte das Potential dieser Methode für Erklärung und Vorhersage im Rahmen von Ausbreitungsstudien zumindest für ein weltweit vorkommendes und wichtiges Insekt verbessert werden.

Acknowledgements

I would like to express my sincere gratitude to my supervisor, Prof. Dr. Dr. Claus P. W. Zebitz, for introducing this fascinating topic to me and whose tireless efforts and patience as my supervisor greatly contributed towards the completion and success of this study at the Institute of Plant protection, Agricultural Faculty of Hohenheim University.

My hearty thanks also go to Prof. Dr. A. Fangmeier for reviewing the work with great care and providing many helpful comments and suggestions that further improved this dissertation.

I really appreciate of Prof. Dr. H. Piepho for his recommendations and orientation in analysing of data as well as the cooperation in the examination committee and for Prof. Jetter for his helps in the mathematical issues and Mrs Muller for her helps in access to climatic data. Special mention must also be made of my colleagues Dr. Schulte, Mmes Stauss and Schmidtke, misses Al-Bitar, Gercken, Goleva, Pudova, Mr. Al-Karrat, Mr. Kryvynets and special gratitude to Mr. M. Hofmeister.

I am grateful to the members of the Entomology Department, Institute of Phytomedicine and Agricultural Faculty of Hohenheim University, for each of them contribution in one way or another towards the success of my research work..

I wish to acknowledge gratefully the financial support from the Ministry of Science, Research and Technology of Iran for sponsoring this Ph. D. study. I am grateful of my iranian colleagues Dr. Gh. Tohidloo, Dr. M. K. Suri, Dr. Kh. Moghtased Azar and Mr. R. Golbon for their endeavor and collaboration in the data collection, analysis and writing process. Last, but not the least, I wish to acknowledge the patience of my wife Nazila and for her helps in the field experiments as well as my family in Iran, particularly of my little sisters Masumeh and Maryam for all their patience, unsparing support and understanding.

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Chapter 1

Introduction

1.1 General Introduction

Codling moth *Cydia pomonella* L. (Lepidoptera: Tortricidae) (also abbreviated as CM) is the most serious pest of apple and pear worldwide. If the fruits are not protected, up to 95 percent injury can occur. Currently the one of the major control tactics is the use of pheromones to disrupt mating behavior. While the cost of using pheromones is declining, the cost cannot yet compare to pesticides if no other reasons, such as insecticide resistance or loss of effective chemicals, are involved. Sanitation methods can help reduce Codling moth densities within an orchard but alone cannot provide satisfactory control [199].

1.1.1 Codling moth ecology

"Codling" is a name given to any of several elongated, greenish English cooking apples. This name was applied to the moth *Cydia pomonella* L. by Wilkes in 1747. Its origin is no doubt Eurasia, but where in this vast area was its center of distribution is hidden by the passage of the time. This pest has generally spread around the world, along with the cultivation of apple and pears, principally in the 18th and 19th centuries (fig.1.1) [11] and [35].

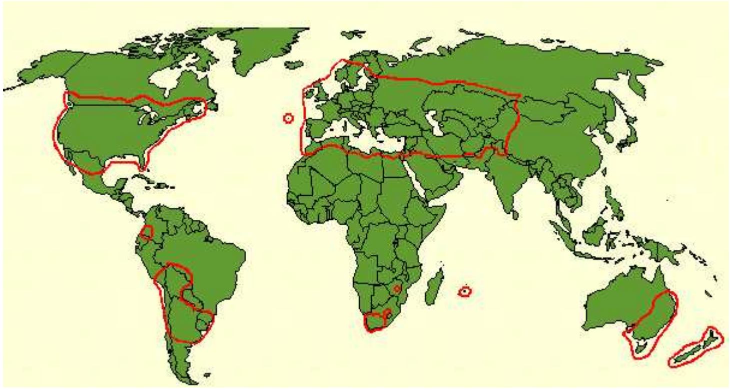

Figure 1.1: World wide distribution of Codling moth.

In the continuum of the concept of r and K life history strategies, the Codling moth may be classified as tending strongly toward a K strategy. Its hosts include apple, pear, English walnut, quince, apricot, plum, peach, nectarine and cherry [11] and [199]. Codling moth close association with the domestic apple, *Malus pumila* Miller, has been investigated in many ways. The outer coating of apple contains E, E -alpha- farnesene and Z, E -alpha- farnesene, which function as kairomones for Codling moth in addition as the determining factor in oviposition as compared with visual stimuli [11].

1.1.2 Life history

Overwintering stage of Codling moth is the mature larvae in silken cocoons under loose bark in protected areas at the base of the tree, fruit bins or orchard trash piles with light pink body, brown head and 12-20 mm at the maturity. Larvae develop to pupal stage when spring temperatures exceed 50 $^{\circ}F$ ($10^{\circ}C$). Pupae are inside the silken cocoons of brownish color of 0.5 inch length. Sexual dimorphism in the Codling moth pupa is determinable. Female pupa has 3 distinguishable segments in its ventral side with a small cleft at the tip of the abdomen. Depending on temperature pupae development take 7-30 days. When the moths begin to emerge the flight period starts. The first flight of Codling moth typically starts sometime from early March to early April and is from the overwintered generation. The flight of the overwintered generation may occur when 600 to 700 Day Degrees (DD) have accumulated from biofix (biofixs is the first moths that is caught in the traps at the starting of each generation) and can last several months. These moths lay eggs that signal the beginning of the first generation. The second flight of moths results when the larvae of the first generation complete their development. The 2^{nd} biofix will be when an increase occurs in trap catches between 800 to 1300 DD from 1^{st} biofix. When the moths in the second flight lay their eggs, this starts the second generation. Codling moth has two to four generations a year regard to the different geographic conditions. Monitoring with traps and accumulating degree-days should continued until the crop is harvested or populations decline to below damaging numbers in September. Adults are mottled gray moths with bands of alternating gray and white on the wings and a bronze to copper spot on the tip of each forewing [199]. Sexual dimorphism between male and females make sexing of them possible. This possibility is described as follow.

1.1.3 Sex and mating determination

For sex and mating determination in female Codling moth the tip of the abdomen inspected carefully. Normal (Fig.1.2, left) and squeezed tip of the abdomen (Fig.1.2, right) of female moth is indicated. Female Codling moth have a hairy "pad" at the tip of the abdomen (Fig.1.2) with a invaginated point at the tip of the abdomen. When the ovaries are squeezed between the fingers (Fig.1.2 right), mating status can be generally determined by the firmness of the ovaries. The ovaries have two round lobes. Hard, enlarged ovaries indicate mated or multiply-mated status. "Flat" ovaries generally indicate non-mated or a female that has had fewer matings [2].

Male Codling moth have "claspers" at the tip of the abdomen. When closed together (Fig.1.3 left) you can sometimes see a line where they come together in a "hook" like manner. When the abdomen is gently squeezed, the claspers will open (Fig.1.3 right) [2]. End of the abdomen of male and female is different. Adult moths remain in the foliage during day and become active at dusk [80]. The locomotion activity of Codling moths occurred mainly during the scotophase and the first

2 h of the photophase, peaking during the dusk period [82]. During oviposition, females lay their eggs singly or sometimes in groups 2-3 on leaves, twigs, calyx of of a fruitlet and later on the young fruits (Davison and Lyon 1987; Carter 1984). Young larvae (L1) bore into the fruits, often entering through the calyx, feed for nearly 3 weeks and pass through 5 instars (L1 to L5). As L5 larvae, they leave the fruit and search on the tree stem for suitable pupation in which they normalcy hibernate [35].

Figure 1.2: Sex and mating determination in female Codling moth, normal tip of the abdomen (left) and squeezed tip of the abdomen (right). (Photo after Lynn Wunderlich, U. C. Cooperative Extension).

Figure 1.3: Sex and mating determination in male Codling moth, normal tip of the abdomen (left) and squeezed tip of the abdomen (right). (photo after Lynn Wunderlich, U. C. Cooperative Extension).

1.1.4 Diapause

Diapause and its induction and termination was studied in various studies for example the light spectrum for breaking diapause in the oak silkworm, *Antheraea pernyi* Guer., and the Codling moth, was from 400 to 700 nm [127]. The results of studies on the dynamics of infestation and emergence from harvest bins by diapausing Codling moth was reported [63]. Computer-linked infrared actographs were used to examine the effect of different constant temperatures on the mobility of adult Codling moths, mass-reared through diapause or standard production protocols [25]. In a separated article Bloem et al.,[24], examined the mobility of diapaused and nondiapaused moths and the effect of mating status and treatment with different doses of gamma radiation [24]. They found that the proportion of recaptured diapaused moths was significantly higher than the proportion of recaptured nondiapaused moths regardless of whether dispersal was measured using nondirected techniques (passive interception traps) that recapture both genders or directed techniques (natural or synthetic pheromone- baited traps) that capture only males. Diapaused females were significantly more mobile than females reared through standard production, whereas no differences were detected in male mobility because of rearing strategy. Mated females were significantly more mobile than virgin females, whereas no difference in mobility because of mating status was detected for males.

1.1.5 Insect rearing

Rearing clean and healthy insects in sufficient numbers is the most important prerequisite for many basic research programs and for developing pest control strategies [13]. Mass rearing and modification of the current diet, oviposition cages, rearing containers, diapause induction and adult handling were described for a rearing colony of Codling moth, maintained at the USDA-ARS facility in Wapato, WA, USA, for over 40 years [59]. Quality control of mass rearing, considered by the process of production and release as a system of interacting components with an interplay of effects and demands [32]. Studies demonstrated that apple leaves provide sufficient stimuli to induce feeding, and that their nutritive value allows larval growth and molting to the second instar [141]. They also showed that Monosodium glutamat (MSG) accelerates feeding behavior and increases leaf consumption. Time- and age dependent effects of MSG on feeding were also studied. In an effort to continue to find ways of improving the quality of laboratory-adapted mass-reared Codling moths, the quality of standard (nondiapaused) and diapaused reared Codling moths treated with two substerilizing doses of gamma radiation (150 and 250 Gy) in large-scale release-recapture experiments compared [23]. Extended researches carried out for chemicals that increase apple leaf consumption by Codling moth neonates, and that may be potentially used for enhancement of pesticides [140].

1.2 Control methods of Codling moth

Malik et al. [114] provided a bibliographic review of investigation about *Cydia pomonella* control, through the entire world [114]. Control methods generally could be categorized as biological control including mating disruption, sterile insect technique, classical biological control, augmentative control, microbial control, cultural control and conservation control, chemical control, Options for organic control and integrated pest management systems. Each method has its advantages and disadvantages [46]. The identification and synthesis of Codling moth pheromone components has made available a potentiality powerful tool with which to combat the pest [189].

Despite positive aspects of mating disruption method such as ease of application and less expensive to use than other methods in areas with low Codling moth density, negative aspects of this method comprise as less effective in orchards with dense Codling moth populations, less effective in small orchards and in areas with untreated surrounding orchards, not effective in orchards that are on steep inclines and a have uneven canopies, has potential to fail catastrophically, and requires excellent mitigation procedures for optimal application [89], [12] and [122].

The effectiveness of Codling moth control by the sterile-insect release method depends on the frequency of effective matings between the released sterile males and the wild females. For an instance the competitiveness of irradiated male Codling moths, from the mass-reared laboratory colony was evaluated against wild males against wild males for wild females [147]. Inherited sterility was used to evaluate alternative pest management tactics or combinations of tactics for Codling moth control, in order to reduce or eliminate organophosphate and carbamate pesticides from use in tree fruit production [20] and [21]. Meanwhile, the use of the sterile male has had very limited success [139]. Regard to the limited time window for biological control agents of Codling moth (egg stage, newly hatched larvae and wintering larvae) attempts to control of Codling moth by classical biological control methods have not been reported being successful [52].

The augmentation of natural enemies has proved an effective tactic in pest management in several crops. It is noticeable that natural enemies influence in reducing the numbers of Codling moth is more important particularly during the egg stage, newly hatched larvae and the hibernating larvae [46]. Additionally tremendous fluctuation in Codling moth population density in different orchards or in the same orchards at the different periods indicates affection by the natural enemies [35]. Effective biocontrol agents of Codling moth including birds, spiders, insect predators and parasitoids, nematodes, bacteria, fungi, protozoa and viruses [46]. Among them the egg parasitoids, *Trichogramma* spp. are the most important control agents which has allocated noticeable studies [153], [115] and [113]. Likewise, microbial control has it's profits and drawbacks too. For example, since CMGV (Codling moth granulosis virus) has a narrow host range, it should be nondisruptive to parasitoids and predators in the orchards. Parameters of efficacy, frequency, and timing of application,and the potential of powdered skim milk as a sunlight screen for field persistence were studied by Vail and et al., [185]. A comparison of the efficiency of the virus with a standard spraying program, demonstrated that under European conditions, in an area where Codling moth is bivoltine, four applications with granulosis virus give adequate protection of fruit against Codling moth damage, even in a particularly hot and sunny season [68]. Despite their advantages as relatively environmentally suitable for use in IPM programs, sensitivity to ultraviolet (UV) radiation, particularly the damaging portion UV-B, range 280-320 nm, and lack of the persistence in the orchards as well as its narrow host range remains major limitations for the commercial development of CpGV [3], [4], [5] and [104]. Extending the persistence of CpGV with spray-dried formulations is possible, although there are still practical limitations to commercial adoption [4].

Maintaining appropriate habitats for natural predators and protecting them from insecticides by using the selective insecticides as well as the field management encompass the conservation control. Assessing the effect of two biological and integrated systems on arboreal spiders indicated that diversity was higher in the biological plot than in the control and the integrated plots [132]. Simon et al., [164] evaluated the effect of Codling moth management on the arthropod community and on the natural enemies of pests within apple orchards. In this study the organic farming orchard presented the highest chard presented the highest number of individuals for both non-pest and beneficial arthropods, but not the richest community.Selective chemical control programs were evaluated in four southern Oregon pear orchards with the goal of maximizing effect of biological control agents for suppression of pear pests by Westigard et al.,[197].

Beside the other control methods, cultural controls relies on sanitation and removal of crop residue to reduce crop damage, despite it's simple principles because of time consuming, is not as effective as other measures. This method is effective in integrating with other methods, since the 96 percent reduction in number of overwintering Codling moth larvae observed in the Wenas valley in 1970 [29]. Several methods of control against *Cydia pomonella*, the apple and pear Codling moth are made available to organic orchard farmers. These methods included use of granulosis viruses and *Bacillus thuringiensis*, mating disruption, sexual disorientation, ploughing, trunk brushing, and strip and peg traps [149].

The final, effective and at the same time the more hazardous method is the chemical control measures. Environmental endangers as well as the pest resistance and consequently, increasing of the economic and health distress resulted the use of the pesticides with more circumspection. Using of the pesticide based on the forecasting and not calendar applications [148], utilizing of the mineral oils out of growing season [146], [48] and study the resistance to pesticides [155], [171] and [123] are the main study fields in relation to pesticides.

1.3 Methods to study dispersal behavior

According to the previous studies such as Southwood (1978) and Audemard (1991), Codling moth population dynamics study can be subdivided into three groups:
I) Trapping methods, by using passive traps, female bated and/or synthetic sexual attractants or light traps for adults and trap bands for mature larvae.
II) Visual assessment of the eggs and various larval stages and damage assessment.
III) Methods based upon the use of manipulated populations.

The last methods include release-recapture of marked adults, release of genetically marked diapausing larvae, emergence cages for adults, oviposition cages, infestation of host material with eggs or young larvae and release of mature larvae marked with radio-elements. Using these methods quantitative and qualitative information on population is provided.

Numerous factors may influence the population and it's fluctuations. Main factors involved in the population dynamics include [7] and [170]:

- Nature of the trophic base (food plant species, ecosystem characteristics)
- Species specific characteristics (flight and displacement, reproductive capacity, voltinism, intraspecific competition for food and cocoon sites)
- Influence of biotic factors (interspecific competition for food and cocoon sites, natural enemies)
- Climatic conditions (day lengths, raining, temperature, relative humidity, wind speed and direction)...

1.3.1 Marking methods

Tracking the movement of insects in their natural habitat is essential for understanding their basic biology, demography, and ethology. A wide variety of markers have been used to assess insect population dynamics, dispersal, territoriality, feeding behavior, trophic-level interactions, and other ecological interactions. The ideal marker should persist without inhibiting the insects normal biology. Furthermore, the marker should be environmentally safe, costeffective, and easy to use. Hundreds if not thousands of studies that required some way to label insects have been conducted, but the search for a universal marker has proven to be challenging. Regard to the overwhelming amount of literature on insect marking, it is virtually impossible to write an all-inclusive review. Unfortunately, most vertebrate-marking techniques are not practical for marking insects because they are cumbersome, heavy, and/or costly [170]. As a result, entomologists are often challenged to develop unique methods for marking insects. The other issue is the marking material, and an ideal marking material is durable, inexpensive, nontoxic (to the insect and the environment), easily applied, and clearly identifiable. Furthermore, the marker should not hinder or irritate the insect or affect its normal behavior, growth, reproduction, or life span. The method of choice for applying markers depends on the insect being marked, the environment that the insect will encounter, and the nature of the experiment [57]. For instances the purpose of Vilarinho et al., (2006) was to evaluate the effect of different oil- soluble dyes on *Spodoptera frugiperda* (J. E. Smith) development, longevity, and fecundity [190]. A technique was described whereby 5th-instar larvae of the Codling moth, which have finished feeding can be tagged externally with cobalt-58 and released on apple trees, where they seek cocooning sites [193]. Broad examples of many of the insect-marking techniques that have been used with overview of the advantages, disadvantages, and limitations of each technique were provided [57].

In a separate experiment, the fluorescent powder applied for marking of adult Codling moths for its effects on longevity and fecundity of Codling moth [120]. Studies was intended as a pilot experiments to primarily investigate the durability of the individually coded tags in the field. The tags were very cheap and easy to produce and the technique has the additional advantage that it can be used in the field, which is not feasible with many other individual marking techniques [134]. Some researchers used coloured felt tip pens, for enabling the coding of different releases in their study of the dispersal of *Epiphyas postvittata* (Walker) [174].

1.3.2 Communication behavior

Study of Codling moth communication behavior constitute a large part of investigations on it. Efficacy of non-pheromone communication disputants of Codling moth as effect of phero mone isomers and of distance between calling females and dispensers was studied [117]. Orientational responses of four species of feral tortricid moths to polyethylene tube dispensers of pheromone were observed in a 0.8 ha apple orchard treated with such pheromone dispensers and in an untreated 0.8 ha orchard [172]. Codling moth single- or multi-component sex pheromone reaction investigated [42] as well as comparison of mating disruption (MD) with the use of the egg parasites, *Trichogramma* spp. to see if these methods would work in allotment gardens and possibility of use in the future [1]. Other studies determined the effects of delayed female mating on population growth of Codling moth and oblique banded leaf roller [77]. They mentioned that two species have different life histories with regards to reproduction; the Codling moth deposits its eggs singly and has a relatively low population growth rate, whereas the oblique banded leafroller deposits eggs in a large mass and has a relatively high population growth rate.

Evidence of Codling moth orientation to host fruit in the field, with assessments of the attractiveness of immature, infested, and ripe apples, as well as ripe pears was reported [106]. Headspace volatiles characterized from the apple tree over the whole season quantitatively, elucidated the response of Codling moth females to volatiles released from fruit-bearing twigs [186]. Additional bioassays were conducted, separately for fruit and for twigs with leaves, in the second part of the season, and selected single compounds were tested for behavioral effects on the Codlingmoth. Volatiles from apple trees that may be used by *C. pomonella* to locate food plant was identified and as well as compared their emission between day and dusk [31]. Influence of plant epicuticular lipids investigated and the accumulating evidence indicated that plant epicuticular lipids play important roles as mediators of insect-plant interactions [41]. Radiello (diffusion sampler) sampling was used to study headspace volatile from apple-bearing twigs which were collected in the field with a Radiello sampler during three different diurnal periods over the complete fruit growing season as well as to investigate study the influence of abiotic factors like rainfall, relative humidity and temperature on volatile emissions from apple trees in situ [187].

Using of Pear ester as an attractive for the male and female Codling moth was objective of different researchers [108], [183], [95], [109], [12]. Arthur et al., (2007) reported on four orchard studies in pome fruit evaluating Pear ester as an insecticidal synergist for CpGV in different cultivars of apple and Bartlett pear [3]. The impact of the Pear ester on the behavior of Codling moth larvae was investigated when in contact with pear ester-treated apple and pear fruits [131]. In particular, they investigated the effects of the Pear ester on newly-hatched larvae searching for the fruits. Knight and Light 2005 reported studies that evaluate The use of pear ester-baited traps as a tool to predict the start of egg hatch of the first summer generation of Codling moth was evaluated [86]. In an other survey the results of monitoring Codling moth with pairs of traps baited with Pear ester or codlemone lures was reported in 102 apple orchards treated with sex pheromone dispensers during a 3-yr period [98]. The effects of (E,Z)-2,4-decadienoic Acid on Codling moth oviposition under laboratory conditions was studied and evaluated its use as a lure to monitor egg laying in apple and walnut orchards as well [85]. In a distinct study, investigations conducted to evaluate the influence of lure loading (0.01 mg to 50.0 mg) on the attractiveness of the Pear ester for Codling moth in apple orchards treated with sex pheromone MD [96]. Codling moth's orientation behaviors was examined and capture in white versus colored traps baited with Pear ester and sex pheromone lure studied [91]. Studies that address the use of pear ester-baited traps to measure the mating status of female Codling moth populations carried out additionally [89].

Comparisons were made of the mating status of female Codling moth caught in pear ester-baited sticky traps, oil-coated interception traps, and UV light traps. The recapture rates of both virgin and mated female Codling moths to a pear ester-baited trap placed overnight in a flight tunnel was evaluated. Also the proportion of virgin females was assessed in a large number of orchards treated with sex pheromone [88], [89] and [90]. The role of the minor sex pheromone components was examined using electrophysiological techniques to quantify the sensory input of the level of male Codling moth's antennae as a preliminary to detailed behavior studies [40]. Some of the scientists even studied the parasitoids pheromone in order to utilize in Codling moth control. Experiments carried out to explore the potential role of *Ascogaster quadridentata* Wesmael, an egg-larval parasitoid of

Codling moth, sex pheromone in pest management of this cosmopolitan fruit pest [176].

Studies accomplished to clear the factors affecting differential capture of male and female Codling moth in traps baited with pear ester [97]. The influence of lure loading on attractiveness of the Pear ester on the number of Codling moths caught, sex ratio and female mating status was evaluated in sex pheromone treated apple orchards [96]. In the other studies in 2005 the effectiveness of codlemone and pear ester-baited traps in predicting the occurrence of fruit injury at several time periods during the season were compared. Action thresholds were developed for the first insecticide spray and for first and second moth flight with data collected from orchard plots not treated with insecticides and not having fruit injury [84]. Studies that address the use of pear ester-baited traps to measure the mating status of female Codling moth populations carried out by Knight 2006. Comparisons were made of the mating status of female Codling moth caught in pear ester-baited sticky traps, oil-coated interception traps, and UV light traps. The recapture rates of both virgin and mated female Codling moths to a pear ester-baited trap placed overnight in a flight tunnel was evaluated. Also the proportion of virgin females was assessed in a large number of orchards treated with sex pheromones. The attractiveness of the Pear ester and codlemone alone versus combinations of Pear ester with codlemone, to Codling moth in apple orchards treated or not treated with sex pheromone MD (mating disruption) was evaluated [92]. Knight 2007 examined the effect of multiple mating of female and male Codling moths on female fecundity and egg fertility under laboratory conditions. Experiments were reported that either evaluated the capture of Codling moths across the interface of adjacent sex pheromone-treated and -untreated orchard blocks or the influence of trap placement within sex pheromone-treated orchards in relation to the orchard's borders on moth catches in distinctive study [83]. In addition, several studies conducted to analyze the use of PI-traps to monitor Codling moth populations in sex pheromone-treated orchards [87]. Knight et al., (Unpublished) evaluated the effectiveness of the Pear ester lure in monitoring Codling moth in sex pheromone- disrupted orchards of four pear cultivars: D́Anjou, Bartlett, Comice and Bosc in three western States in the United States. The goal of Barrett (1995) project was to examine what effect mating disruption dispensers in small orchard blocks had on captures of male Codling moth in traps baited with either synthetic sex pheromone or virgin female moths at different tree heights.

1.3.3 Flight

Timed catches of *Cydia pomonella* males in sex pheromone traps were used to investigate the influence of twilight and climatic parameters on the flight activity of the moths at different latitudes [152]. A special trap design was described to measure the time of day that male moths are captured by the sex-pheromone trap [14]. Some studies provided information on various parameters of trap placement, orientation and density on which insufficient information was available concerning effects on magnitude of moth catch. This information contributed to the standardization of procedures for phenology monitoring and population indexing as well as the optimization of mass-trapping programs [118]. Investigations on the heritability of the flight in Codling moth, addressed the following two questions: First, is flight capacity measured by a flight mill potentially heritable? and second, what are the genetic correlations amongst different flight parameters investigated and between total flight distance and morphological characters? [156]. In other study the flight capacity of *Cydia pomonella* was measured in the laboratory by using computer-linked flight mills [157].

The development of flight capacity in relation to reproductive activities (mating and oviposition) and age after emergence in light brown apple moth was the other research topic [54]. These studies emphasized on the flight behavior and migratory potential of the moth in relation to reproduction [54]. The evaluation of the Sticky-pane trap as a tool to study Codling moth adult flight behavior in the field was other report [194]. The seasonal variations in size of *Epiphyas postvittana* (Walk.) (Tortricidae) individuals that occur in flying populations and causes and adaptive value of these variations were described [33].

Because of the increased response of Codling moth larvae to apple fruit infested with other Codling moth larvae, adult Codling moths may also respond more strongly to the odors of infested apple fruit, compared to un-infested fruit. Experiments were conducted to test this hypothesis, using a flight tunnel assay [144]. Behavioral ecology of pheromone-mediated communication in moths and its importance in the use of pheromone traps studied as well [119]. In a distinct study, behavioral response of male Codling moth to a semiochemocal-based attract-and-kill management strategy was studied [99]. A case study of a pheromone based attract-and-kill management strategy using "Last Call CM" was conducted to examine Codling moth behavioral factors mitigating the possible effectiveness of this strategy. "Last Call CM" is a newly registered attracticide product that combines the primary component of Codling moth sex pheromone with the insecticide permethrin [100]. The overall goal of a additional investigation was to determine whether Codling moth disruption is improved by increasing density and distribution of pheromone release sites [44]. Furthermore, the influence of two spray application techniques on the pattern of deposition of microcapsules and their efficacy in disrupting the sexual communication of Codling moth in apple, examined [93]. Results was reported from field evaluations conducted in apple using grids of both puffers and clusters of dispensers to manage codling moth [88]. The effects of simulated rainfall and the addition of stickers on the retention of microcapsules formulated with codlemone on apple, pear, and walnut foliage studied [94]. Experiments were undertaken in attempt to understand action mode of α-farnesene on the pheromone releasing, attraction and oviposition stimulation of Codling moth females [47]. A method was developed for scalar scoring of various pheromone sources to assess their attractiveness using a selected flight parameter that was found to modulate on changing the quality of the odor source [43].

Effect of plant architecture and hail nets on temperature of Codling moth habitats in apple orchards was another study subject [101]. The influence of the habitat parameters such as plant architecture (traditional standard trees versus commercial dwarf tress) and application of hail nets as well as thermoregulation behavior were examined too [103]. In the other hand the temperature selection behaviour of un-mated adult female and male moths as well as that of ovipositing females was evaluated [102].

The objectives of some study were to determine the seasonal phenology of *C. pomonella* and *A. velutinana* (Walker) in Minnesota apple orchards and to evaluate the effectiveness and specificity of two common types of commercially available pheromone baited traps for monitoring populations of both species in the region [45]. Defining the relationship between pheromone trap catch, emergence and oviposition of Codling moth for the two generation climate in Michigan a basics for a workable forecasting system was the objective of study else [145].

1.3.4 Population modeling

Before the study of Shaffer and Gold [160] there were no previously published models of both numbers of moths and phenology within a season. They presented in their study a generalized model of insect population dynamics, together with details of its parameterization and its evaluation for Codling moth in apple orchards [161]. Unlike the previously published population dynamic models which have been concerned either with the numbers of moths on a time scale of generations or with the phenology of moths within a season, they presented a generalized model of both numbers of moths and phenology within a season [161]. Also The phenology of Codling moth development based on physiological time at both constant and field-simulated temperatures was investigated [66]. Based on a study on the phenology of invertebrate pests, the impact of interpolated daily temperature data on landscape-wide predictions of invertebrate pest phenology was studied [72]. The development and survival of Codling moth in cherry fruit was tested to compare Codling moth development in organic and conventionally produced cherries, and to determine if short-time cold storage reduces survival of early instars of the codling moth [58].

Population dynamics of Codling moth studied by various authors for example different aspects of the population dynamics of Codling moth was discussed [7]. Population dynamics of Codling moth was simulated by using mathematical methods [111] and [110]. The purpose of other study was to report on studies that have been carried out to determine the fecundity and mortality of the various life stages of the Codling moth as an important part of the modeling of the population [49].

Mathematical modeling of dispersal with emphasis on diffusion model was edited in a book [129]. Some appropriate methods for efficient analyzing of data using capture-recapture methods was mentioned by other authors [163]. A new fast algorithmic approach for parameter estimation in Ratcliffs (1978) diffusion model was described [192]. In other study researchers investigated experimental manipulations of specific aspects of the decision process effects on the corresponding parameters in a diffusion model data analysis [191]. The quantitative model of diffusion bioassays also was investigated [8].

1.3.5 Day Degree studies

Included in the research of Neven et al., (2006) were the determinations of the most tolerant infestive stage, most tolerant species, comparative efficacy, and confirmation tests of two CATTS (Controlled Atmosphere Temperature System) treatments against Codling moth and oriental fruit moth in peaches and nectarines [126]. Whereas many tropical and subtropical fruits are treated with hot forced air to kill internal pests, CATTS adds a controlled atmosphere (CA) to the heat treatment. The low-oxygen environment impairs the insects ability to acclimate to the heat treatment, whereas the elevated carbon dioxide levels help shift the internal pH of the insect and maintain spiracle opening, thereby providing additional stress not incurred during a regular heat treatment. Effect of temperature on oviposition behavior, fecundity, and fertility in two Norwegian climatic subzones populations of the Codling moth was the objectives of other study [151]. Studies implemented to determine the longevity of *C. pomonella* and *C. rosaceana* under field conditions in Washington apple orchards. They examined longevity of both sexes on a degree-day (heat unit or physiological time) basis to determine if longevity could be predicted throughout the flight period of both species [76]. Degree-day forecasting of generation time of Codling moth population by using the degree-day in California was investigated [136]. The importance of biofix in Washington apple (*Malus* spp.) orchards for the accuracy of prediction of adult flight and egg hatch, investigated as two key parts of Codling moth integrated pest management (IPM) program. They used a combination of historical weather data and trap data obtained from consultants at different locations throughout Washington apple growing areas, and an intensively collected data specifically geared to examining model accuracy of the PETE (Predictive Extension Timing Estimator) Codling moth model [75]. PETE is an extension phenology modeling system for management of multi-species pest complex.

1.3.6 Dispersion

A noticeable section of the insect management and behavioral control studies allocated to insect dispersal and dispersion behavior. Here, we first presented some instances of non tortricid insects dispersal and flowed by tortricid insect and Codling moth dispersal studies. The influence of atmospheric structure and motions on insect migration was inspected [39]. Study the quantifying dispersal of southern pine beetle withe mark-recapture experiments and a diffusion model carried out in different study [184]. Some authors mentioned the advantages of dispersal study with mark-recapture experiments, as it's ability to predict dispersal, and the null form for diffusion may be amended to account for sex differences and dispersal bias (cardinality) [9]. Other researchers attempted to review and contrast three methods of analyzing data on the dispersal of insects from a point source as well as to illustrate how these methods may be applied to insect recapture data using the example of released mediterranean fruit flies. The other objective of their study was to use the quantitative analysis to compare the results of the that release study with other studies on related species and to draw general conclusions about the nature of the dispersal of released sterile Mediterranean fruit flies [137].

Studies were conducted to establish the validity of an immunoglobulin G (IgG) protein marker for sharp- shooter dispersal studies, to compare the dispersal of *Homalodisca coagulata* (Say) with that of a native sharpshooter *Homalodisca liturata* Ball, and to develop a better understanding of the factors that influence their dispersal [18]. In an other study the reliability of IgG protein markers relative to fluorescent dusts examined and determined how sharpshooter movement differed in this landscape relative to a previous study, and developed a better understanding of the biotic and abiotic factors that could influence sharpshooter dispersal [19]. The consequences of variation in light trap catches caused by daily weather using analyses of 26 years of annual abundance for 133 moth species in the Czech Republic studied as well [65]. validating previous models for predicting Nantucket pine tip moth damage levels by addressing the use of less expensive traps, more generation and site cover was the objectives of other survey [6]. Flight characteristics and dispersal patterns of male fall web worms, *Hyphantria cunea* (Drury), were investigated by a scientific group through three experiments. A flight-mill experiment to estimate potential flight metrics, a wind-tunnel experiment for daily patterns of male activity, and field trials of mark- recapture for estimating dispersal patterns of males in the field [200].

As a part of a wider study on the spatial and temporal patterns of reinfestation by *Triatoma infestans* (Klug) in north western Argentina, simultaneous light trap collections in two neighboring rural villages was conducted during the most likely flight dispersal period, and related the flight activity of *T. infestans* to weather and demographic variables [188]. A simple passive diffusion model was used to analyze the local within-habitat dispersal of twelve species of herbivorous insects using mark-recapture studies in relatively homogeneous habitats [79]. Studies reported on *Teia anartoides* Walker (Lepidoptera: Lymantriidae) male mark- release- recapture, male flight, and trap catch assessed as a function of temperature, along with male survivorship [175]. Differences in life-history traits and hence demographic parameters compared between two genetically differentiated strains of *C. pomonella* in order to elucidate whether and how mobility has fitness consequences in this species [56]. Aphids parasitoid *Aphidius smithi* (Hymenoptera: Aphidiidae) dispersal and its influence on the colony of aphids was studied as well [177]. presented the results of a series of season-long field experiments conducted to examine the degree of control realized by twice per week releases of partially sterile Codling moths or by combining releases of partially sterile Codling moths with commercially available mating disruption [21].

In other research the dispersal and longevity of wild and mass-reared *Anastrepha ludens* Stone and *A. obliqua* (Macquart) (Diptera: Tephritidae) studied [62]. Also, results of a study on adult demography of *Brenthis ino* (Rottemburg) (Lepidoptera: Nymphalidae) in a submontane landscape in western Bohemia, Czech Republic was reported. This study was based on a survey of the distribution of the butterfly in a section of landscape, mark-recapture study of adult demography, and records of adult behaviour and resource use [202]. The spatial distribution of *Helicoverpa* spp. eggs in fresh-market tomato crops was considered and they used this information to construct a sequential sampling plan [36]. Authors else in their survey, provided a brief description of cellular automata and how they used this approach to build spatially explicit transition models to predict gypsy moth outbreaks. The performance of the various models were compared and discussed [201]. The mortality in the immature stages of *Mamestra brassicae* (L.) and dispersal behaviour in young larvae were included in the other study [74]. The goal of a group of researchers in conducting their research was to gain a better understanding of the spatial and temporal patterns of onion maggot adult activity and oviposition in New York onion fields [196]. Studies were conducted to determine the feasibility of using diet-incorporated RbCl and CsCl to mark southwestern corn borer with Rb and Cs was determined in distinct survey [142], meanwhile other studies indicated the effect of Sudan Red 7B and Sudan Blue 670 effects on the biology of southwestern corn borer at the tested rate and the efficacy of these materials in marking adults of the southwestern corn borer [143].

Application of the pheromone traps and mark-recapture methods are not restricted to the field experiments. For an instance Campbel et al., (2002) monitored stored-product pests in food processing plants with pheromone trapping, Contour mapping, and mark-recapture methods [30]. Random dispersal in theoretical populations was the topic of other study [167]. Researchers in their study on local dispersal of overwintered Colorado potato beetle, utilized mark and recapture method [50]. The same method were used in male spruce bud worm (Lepidoptera:Tortricidae) local dispersal [154]. Suitability and calculation method in diffusion model for insect dispersal studied carefully [150]. Dispersal of *Anopplophora glabripennis* (Cerambycidae) studied by others [169]. Effects of climate, host tree, and characteristics of the individual beetle on the propensity to disperse and beetles distance move investigated as well as dispersal distance was also analysed with a diffusion model for *A. glabripennis* [10].

Other group of the researchers conducted experiments to directly examine local dispersal and mating behavior of adult European corn borer in and proximal to irrigated and non-irrigated corn. These data were then compared with the current dispersal model of *Ostrinia nubilalis* Hbn. They used standard diets containing oil-soluble dyes Sudan Blue 670 and Sudan Red 7B dyes to marking of the moths while dyes were tested to ensure they did not appreciably alter insect biology [69]. Study of dispersal of *Ips typographus* L. (Coloptera, Scolytidae) carried out using recapture of dispersing bark beetle in pheromone-baited traps and utilizing regression models [203]. In a distinct research, *Lygus hesperus* (Knight) dispersal distance in row-crops known to be food plants was studied by the combination of capture-mark-recapture and diffusion models which have been shown to be effective for measuring insect dispersal. An advantage of this technique is the ability to predict dispersal (cardinality) [9]. The objectives of other study were to compare two models of simulated dispersal with regard to turning angles in firstly a uniform random distribution and secondly a normal random distribution, and see how the models affect the mean dispersal distance (MDD) and its variation, to find correction factors that would correctly convert the mean square displacement distance of Kareiva and Shigesada (1983) to an MDD [16].

Tortricids dispersal investigated by different authors. Behavioural mechanism and genetic regulation of dispersal in the Codling moth studied [80]. A novel approach was used to investigate the genetic regulation of dispersal capacity in the Codling moth. Experiments consisted of laboratory selection on mobility measured by actograph and a field mark-release-recapture test on the dispersal capacity of the selected strains [82]. In other study authors examined the sex- and age-related circadian patterns of locomotor activity in the Codling moth, and the effects of hormone mimics fenoxycarb and tebufenozide thereon, using an actograph technique [81]. Phenology, movement and within-field distribution of the Grape berry moth, *Endopiza viteana* (Clemens) (Lepidptera: Tortricidae), in New York vineyards studied [64]. Investigation of the genetic basis for determination of flight capacity of *Epiphyas postvittana* (Walker) moths was carried out by means of quantitative genetic analyses [55].

Original objectives of other studis were to document operational sterile:wild (S:W) ratios of Codling moth in several orchards in an effort to determine whether they were falling below the 40:1 target after 1994, and if so, to determine the extent to which inadequate ratios were resulting from large wild populations, thus justifying need for supplemental controls, or were resulting from poor recapture of sterile moths [78]. Geostatistical analysis of *Cydia funebrana* (Treitschke) (Lepidoptera: Tortricidae) Pheromone trap catches accomplished at local and regional scales and, from the determined relationships, knowledge on spatial processes with relevance to pest control was concluded [158]. In an other study distances of marked male and female moths dispersed within orchards was measured as well as the investigation of immigration by feral *Epiphyas postvittana* (Walker) and *Planotortrix octo* Dugdale (Lepidoptera:Tortricidae) moths, and evaluate longevity of released moths carried out [174].

The results of trapping tortricid moths at the margin of three IPM and three abandoned orchards in the Switzerland were presented. Data on emigrant and immigrant tortricids were examined using multivariate analysis and the Mantel test as a whole and for those species that were associated with apple trees [73]. Researchers dealt with the study of larval dispersal and survival of *Lobesia botrana* (Denis and Schiffermueller) on vine inflorescences and their relationship with larval density [181]. The mobility of mass-reared diapaused and nondiapaused Codling moth studied with a focus on understanding the effect of mating status and treatment with gamma radiation as well as the effect of the temperature and lengths of the cold storage while those insects were destined for use in an area-wide program that uses the sterile insect technique (SIT) [24] and [23]. Since the 1950s it is known that insect pests can be controlled or eradicated through a birth control method based on genetic manipulation know as autocidal pest control or the Sterile Insect Technique (SIT). It involves the colonization and mass rearing of the target pest species, sterilization through the use of gamma radiation and releasing them into the field on a sustained basis and in sufficient numbers to achieve appropriate sterile to wild insect over flooding ratios. Here the sterile males find and mate with fertile females, transferring sterile sperm. No offspring results, thereby causing a reduction in the natural pest population. The validity of this method has been demonstrated for many insect pests, including moths, screwworms, tsetse and fruit flies [24], [21], [20].

Some studies focused on the distribution of the Codling moths and has been targeted it's ecological behavior. Since an understanding of the vertical distribution characteristics of insects is necessary for the control of insect pests and for the development of suitable management strategies [128]. Vertical distribution of Codling moth within the canopy was studied using tethered females, a passive trapping technique, and a blacklight observation of released moths. They tested the effects of a synthetic sex pheromone, (E,E)-8,10- dodecadien-l-ol on the moths distribution [195]. According to their results, the response of male Codling moths to pheromone at various heights in an orchard was apparently not constant. Using clear pane traps, they caught greater numbers of males and females at mid-canopy and upper-canopy heights in untreated plots. Presence of pheromone applied to plots in the trapping study did not greatly affect the vertical distribution of males. Maximum response of males to tethered females, measured by mating, was near the top of the orchard canopy (4 m).

Knowledge of the resting behavior of insects is necessary for effective application of insecticides and for other control measures, in order to optimize the contact between the insects and the insecticide-treated surfaces. Consequently methods can be devised which are efficient, economical and less harmful to the environment. Resting behavior of Codling moth has been widely investigated and interesting patterns revealed of the vertical distribution and of the substrates utilized as resting sites. The study of the vertical distribution of insects in response to trapping, with color attractants or odor baits, is concerned in the recent decades [128]. To describe the vertical distribution of insects under any activity, researchers proposed to use a height-dependent aerial density, namely the number of insects per unit height [128]. The vertical and horizontal distribution of grape berry moth, across the vineyard-woods landscape, were studied [27]. Other study results published as assessing and Interpretating the spatial distributions of insect populations [179]. In addition studies was aimed at exemplifying some of the actual approaches to elucidate the spatial dynamics and the underlying mechanisms for insects in the apple ecosystem [38]. Verifying the dispersion patterns of adult male Codling moth populations in the agroecosystems under study, determined the temporal and spatial variation in distribution and abundance of the pest inside and outside the orchards, and evaluated the importance of the presence of several food plants in relation to the observed distribution of adult Codling moth males were the specific objectives of the surveys using Geostatistical techniques [182].

To understand Codling moth behavior more completely, Howell et al., (1990) determined the rate and frequency of male Codling moth response to pheromone lures at various heights within or between trees [67]. In a distinct study the spatial distribution of *Lobesia botrana* (Lepidoptera:

Tortricidae) larvae and their resulting injury and damage characterized using geostatistical techniques [70]. In the present study we evaluated anesthetize, individual and mass marking influence on the survival of adult Codling moth as well as the influence of cold storage on it's longevity. Field experiments started by trade off trap structure in assessing the horizontal and vertical distribution of Codling moth and proceeded with the study of apple cultivar impact on pheromone and Pear ester trap efficiency. Moreover, climatic factors and their influence on dispersal of Codling moth studied as well and completed with the last and main objective of thesis, study of Codling moth dispersal using mark-recapture experiments and diffusion model.

Chapter 2

Material and methods

2.1 Insect rearing

Demanded insects were propagated in the laboratory on an artificial diet. We followed Invaldi-Sender (1974) rearing method with a slightly modification. The materials of our food are included in the table (2.1) [13] and [166]. The product is shared in seven plastic boxes (10*15*3.5 cm.) with 2.2 - 2.5 cm thickness after drying and cooling, the lid of the boxes fixed. Food of each boxes is adequate for feeding 200 larvae. This food could be kept at 4 $°C$ for one month but for longtime storage below zero temperature is recommended. Before using, the food is transferred to the room temperature for some hours.

Mass rearing: In order to mass Codling moth, it's egg clusters were collected from the Codling moth rearing stock culture. Plastic sheets were uprise down in the petri dishes overfilled of formaldehyde (5 %) for 20 minutes, then the same operation done with autoclaved water. Egg sheets moved on drying paper and were dried subtle and carefully and followed by spread on wetted filter paper bedspread petri dishes whereas eggs upward. Afterwards, Petri dishes were girthed with paraffin ribbon and relocated in incubators at optimum condition (24 $°C$, 8:16, D: L and 65-70 % R. H.). After 5-6 days when first instars larvae come out, they were transferred on artificial diet individually by a hair brush. This phase of the breeding process is one of the delicate and sensitive points of it. We used 20*20*5 cm polyethylene boxes for larvae rearing. After transferring the neonate larvae, food boxes were placed under the above mentioned optimum condition and were cleaned and cared during the immature stages. After completing of the larval stages during 15-17 days, 5th. instar larvae were led to the cardboard rings in the inner side of the boxes lied. Development of the pupae take place 7-10 days, later the cardboard was unfolded. Resulting pupae were sexed, counted and kept in segregated boxes in the optimum condition. Daily arrived adults were segregated and displaced in polyethylene cylinders by the size 10 cm diameter and 25 cm long. Inner side and one end of these cylinders were overlaid with a thin layer of sponges. Clear plastic sheets to let the light enter inside and a smooth surface for laying the eggs covered other end of the cylinders. Adults were fed with the autoclaved water in soaked cotton and used in the next generation or experiments.

Whereas artificially reared insects are utilized in nearly all dispersal and distribution studies, undoubtedly flight behavior, fitness and dispersal characteristics of the laboratory produced insects influenced by pre- and post-imaginal process. Pre-imaginal food quality and quantity interfering in adult's body weight and length and consequently in movement potential of the adults. Therefore investigation on the rearing, marking strategies and pre-releasing handling as well as the storage condition which may influence the outcome of movement and dispersal studies, sounds indispensable. Moreover, synchronize the laboratory rearing with the appropriate climatologic conditions is one of the rear-release-recapture studies troubles. At non-favorable climatologic conditions storage of protandrous or harbinger insects sounds of necessity especially for restricted mass production and unstable climate areas. Although Codling moth life traits were studied by several authors, its storage and the influence of the aging and temperature on its life traits has studied infrequently and marking influence on the insect development as well.

Table 2.1: Artificial food composition for Codling moth larvae. Mentioned quantities are suited for growing of 1050 larvae.

Ingredient	Formula
Vitamin C	18g
Benzoic acid	6 g
Methyl4-hydroxybenzoat (Nipagin)	6 g
Agar	60 g
Autoclaved water	2.350 l
Maize meal	150 g
Wheat germ	150g
Yeast	150g
Total diet	2.890g

2.2 Effect of anesthesia and individual marking on the survival of adults

Synchronizing the laboratory rearing with the appropriate climatologic conditions is one of the rear-release-recapture studies dilemma. Regarding this issue, we evaluated the effect of low temperature on adult Codling moths as well as marking on its survival in the laboratory. In order to maintain the adult Codling moths in the appropriate condition before releasing, the effects of low temperature and individual marking were tested on 12-24 h old adults that were mass produced on artificial diet. In this experiment treatments organized as three treatments and a control. 12-24 h old moths were marked using felt-tip pens and coded by the different colors. Treatment I included segregated marked male and females with three minutes numbing temperature, Treatment II segregated marked male and female moths with five minute numbing temperature, Treatment III non marked jointed male and female moths with three minutes of numbing temperature and IV the control without mark and numbing. In order to anesthetizing moths were hold in -20 $^{\circ}C$ to make them motionless and lethargic and then marked individually with felt tip pens. After treating, treatments were transferred to incubators in optimum condition (photoperiod of 16:8 h, L:D, 24 $^{\circ}C$ and 65±5 % R. H.) inside the cylinders and fed by autoclaved water in soaked cotton. Survival rate evaluated daily for thirteen days. Data were analyzed using GLM procedure, SAS software. Significant effects regarded based on alpha equal to 0.05 %. Least square means performed for pair-wise mean comparison. Results are resented in section 3.1.

2.3 Influence of cold storage on the longevity of adult Codling moth

Storage of Codling moth eggs and larvae at low temperatures for piecemeal growing of the embryos not only influences severely the embryo and succeeding stages quality and quantity, but also the anticipated duration of development of the following generation negatively (Author unpublished data). Maintaining of the pupae in low temperature and short photoperiod also bring about the peril of diapauses induction. Therefore, we examined the possibility of adult moth's storage in low temperature in the present experiment in order to evaluate it's effect on longevity of the male and female moths. In this experiment, after sexing the pupae and moths coming out, 12-24h old adult moths were put in 10*14*4 cm plastic lidded boxes. Male and female moths were treated separately, then were maintained in 4 $^{\circ}C$ and (0:24h, L:D) photoperiod during the entirely adult life and fed with 10 % sucrose. The survival rate evaluated with two days interval throughout 27 days and dead insects were removed. Observations repeated three times for each sex group. Data were analyzed using Proc. GLM, SAS software. Treated males and females were compared with the controls that were maintained under room condition. Pair-wise mean comparison performed utilizing LSmean statement and pdiff option. In regard to the moderate left skew survival rates were changed to the square of data.

2.4 Mass marking and its effect on the longevity of adult Codling moth

Despite of some advantages of individual marking of the insects, vulnerability of moths to handling process on one hand and the adverse influence of numbing methods for marking on other hand as well as time and labour consuming of this method led us to test the mass marking and it's influence on the survival of the moths. This experiment aimed to evaluate the effects of the mass marking on the adult's longevity. Moths were arose from sexed and segregated pupae and one-day-old male and female moths were transferred to 18*28 cm plastic pockets separately [173]. A small amount (120 microgram / insect) of fluorescent powder (UV- Elements, Tagesleuchtpigment) were added to the plastic pockets and shook gently for some seconds. Sexes were coded with different colors, accompanied and transferred to the cylinders with the same characteristics of previous experiment and then were kept in the optimum condition (photoperiod of 16:8 h, L:D, 24 $^{\circ}C$ and 65±5 % R. H.). Mortality of the males and females recorded daily for a 21 days period. Observations repeated four times and one of the cylinders treated as control. Proc. GLM and Regression SAS software used for data analyzing and preparing of the charts and diagrams.

2.5 Trade off trap structure in assessing the horizontal and vertical distribution

Preparation of insects Codling moth s mass rearing carried out on artificial diet in the laboratory of plant protection institutes for several generations on optimum condition. To start the experiment 4-5 days old pupae were sexed, segregated and kept in optimum condition in the incubators. Emerged moths were collected and then were transferred to 18*28cm plastic pockets separately. A small amount of fluorescent powder (UV- Elements, Tagesleuchtpigment) were added to the plastic pockets and shook gently for some seconds. Sexes were coded with different colors, and then exhausted to polyethylene cylinders. These cylinders were plated internally with a thin layer of sponges as well as one end and the opposite end plated with clear plastic. Moths were fed with the autoclaved water prior to the field releases. Moths were kept inside incubators at 13C and 16:8h, D: L before carrying to the field. One-day-old adults were transferred to the orchards and released in 1 m height at 18:00-20:00h from a central point.

Site The studies accomplished in three blocks of commercial apple orchards in the research station of Hohenheim University located in the west 2 km of the University campus. This station encompasses around 12 hectares of fruit orchards of different species and varieties including plume, peach, apricot, cherry, pear and more than 17 varieties of apple. Orchards are established and trained as commercial orchards with dwarf tree varieties. The height of apple trees was varying between 1.5 m and 2.6 m. Host trees placed at 2.5 m apart from and the distance between the rows is four meters.

Outward distribution study: Three different types of the traps were used for studying the distribution of natural and artificially reared and released population of Codling moth, in the research station of the Hohenheim University. The first one was the traditional Delta traps (Trifolio-M GmbH)n with red rubber dispensers and containing pheromone. In the second one the same traps were applied with red plastic dispensers which saturated by 50 milligram of the Pear ester in Ethyl acetate. The third type included Cylinder shape traps were made by polyethylene sheets and mounted horizontally with 0.5 ml pipette dispensers and containing the Pear ester as kairomone. Attracting both the male and female is the advantages of the third one. Sticky bed sheets were used in the bottom of traps for catching of the insects. Commercial traps contain sticky beds in 12*26 cm. For the Cylinder traps clear and colorless transparent sheets in the size 21*25 cm were used and a tin layer of adhesive material TEMMEN (Inseken Leim Temmen, Temmen GmbH) used for catching insects. Ninety six traps were suspended in eight compass directions in order of four traps per direction, at three heights (1.2 m, 1.6 m and 2.2 m) in random arrangement. Cylinder-shape traps suspended parallel to the horizon. Distance between the similar traps was 30 m and between the dissimilar 15 m. All the traps were checked daily or at one day intervals. Trap catches were counted until nine days after releases, sexed and divided as marked and feral insects. Indefinite samples were conveyed to the laboratory and then studied precisely by binuclear and UV-lamp to detect the fluorescent powder color in 360 nm. Data were converted to percent per trap per day and all analysis were performed with the SAS program. For all significant factors, List significant differences test was performed to determine the differences between means at 5 % probability level. Proc. GLM and Mean were used for this purposes. Main factors tested included trap type, direction, height and distances.

Study of inward distribution: In this experiment the inward distribution of the female and male Codling moths was studied as well. The traps arrangement and number was similar of the previous experiment but dissimilarly the releasing site was from borders of directions SW, NW, W, E, and SE. The distances of the traps from the releasing points calculated for each releases according to the releasing point. Distances ranged from 5 to 123.5 m. Regarding the non-dominate and unstable wind directions in the research station, releases were carried out from unbiased and random points. Seven releases from five different cardinal points. Nearly all the releases were done during the June to August to cover the main activity period of the second generation. Marking, pre-releasing, releasing and post releasing process and conditions was similar to the previous experiment. Approximately 363-marked moths were released and the traps were checked daily or at one day interval and followed nine days after release. Data were transferred to percent per trap per day and all analysis were performed with the SAS program. For all significant factors, LSD test was performed to determine the differences between means at 5 % probability level. Proc. MEAN and GLM were used for this purposes. Main factors tested included trap type, distance, releasing site, height and direction.

2.6 Effect of apple cultivar on traps efficiency and dispersal of insect

Insects are known to exhibit directed movement in response to preferred food plants [159] and alter their movement behavior in response to canopy complexity [79]. In this experiment Delta traps baited with the pheromone and Cylinder-shape traps with Pear ester and impartially mounted on different varieties of apple trees. 64 traps (32 traps of each type) spaced 15 m and 30 m with the nun similar and similar traps respectively and this order continued up to the borders of the orchards. Traps height were 1.2 m, 1.6 m and 2.2 m which selected objectively for each varieties. The experiment carried out in two hectares of the research station of the University of Hohenheim. In the mentioned site there were 13 varieties of apple including Boskoop, Cmeo, Coxorang, Elstar, Gala, Golden Delicious, Idared, Junagold, Melrose, Pinova, Roter Berlepsch, Rubinette and Topaz. Artificially reared and 24 to 26 h old moths were sexed and marking using fluorescent powder (UV-Elements, Industrieweg, 3. Nordheim-Germany). Then, moths were transferred to the field in internally sponge layered cylinders and released at 1 m height from a central point. Other releases were done from the border sides. The main question was whether the variety of the host may influence the dispersal of the marked-released male and female moths and likewise what is the feral population reaction on these varieties. The results may help to a better understanding of the trap catch interpretation and interpretation of forecasting of invasive populations.

Male dispersal: Data were analyzed using the Generalized model SAS version 9.1, with log link and Poisson dist options. According to the log link option and the zero values of some response variable, the data were set as response variable + 1 using "if" and "then" statement. An important aspect of generalized linear modeling is the selection of explanatory variables in the model. Changes in goodness-of fit statistics are often used to evaluate the contribution of subsets of explanatory variables to a particular model. The deviance, is often used as a measure of goodness of fitting. Based on the (deviance value / degree of freedom) and by including the explanatory variables, fitting the sequence of models and effect of the added variable carried out. Both type I and type III LR statistics included in the analysis and the normality of the residuals were tested using Univariate procedure and QQ plot. Analysis were done for feral and marked male moths separately. With the same method of male moths, data were collected and analyzed for marked-released and feral female moths.

2.7 Influence of climatic factors on dispersal of Codling moth

2.7.1 Marked insects

Under natural conditions, organisms are subject to a combination of environmental factors, both biotic and abiotic. It is this combination that ultimately determines the distribution and abundance of a species [125]. Weather factors play a major role in regulating *C. pomonella* capture by pheromone traps [135]. Regard to the prominent role of the weather factors on dispersal of Codling moth we intended to study the influence of climatic factors on dispersal of male and female moths in detail. For this purpose, Hohenheim weather (latitude 48° 43' N, longitude 09° 13' E and altitude 407 m) climatologic data were used. Several climatologic elements including minimum, maximum and mean temperature, relative humidity, precipitation, wind speed in two different heights (2.5 m and 10 m), Day Degree, twilight temperature, wind speed and precipitation were utilized in the analysis. Night data were calculated from 2100 h up to 0200 h. Day Degree simply was calculated using the following method:

$$(T_{max} + T_{min})/2 - T_{Base} \tag{2.1}$$

Two different types of the traps were used for studying the dispersal of natural and artificially reared and released population of Codling moth, in the research station of the Hohenheim University. The first one was the traditional Delta traps (Trifolio-M GmbH) with red rubber dispensers and containing pheromone. The second one included Cylinder shape traps were made by polyethylene sheets and mounted horizontally with 0.5 ml pipette dispensers and containing the Pear ester as kairomone. Attracting both the male and female is the advantages of the last one. Sticky bed sheets were used in the bottom of traps for catching of the insects. Commercial traps contain sticky beds in 12*26 cm. For the Cylinder traps clear and colorless transparent sheets in the size 21*25 cm were used and a tin layer of adhesive material TEMMEN (Inseken Leim Temmen, Temmen GmbH) used for catching insects. Ninety six traps were suspended in eight compass directions in order of four traps per direction, at three heights (1.2 m, 1.6 m and 2.2 m) in random arrangement. Cylinder-shape traps suspended parallel to the horizon. Distance between the similar traps was 30 m and between the dissimilar 15 m. All the traps were checked daily or at one day intervals. Trap catches were counted until nine days after releases, sexed and divided as marked and feral insects. Indefinite samples were conveyed to the laboratory and then studied precisely by binuclear and UV-lamp to detect the fluorescent powder color in 360 nm. All the climatic variables were calculated for each sampling date and were combined with sample characteristics like height, distance from the releasing point and direction of trap. Diversity and plenty of variables led us to use Akaike's Information Criterion (AIC). Information criteria is a measure of goodness of fit or uncertainty for the range of values of the data. Regard to Bozdogan, (1987) in the context of multiple linear regression, information criteria measures the difference between a given model and the "true" underlying model [28]. Model diagnostics are calculated for each model to help determine which model is "best". These model diagnostics include the root mean square error (RMSE) and the coefficient of determination (R^2). A good linear model will have a low RMSE and a high

R^2 close to 1. However, these model diagnostics alone are insufficient to determine the best model. Among 24 different independent variables thirteen variables were selected for the following analysis.

2.7.2 Descriptive analysis

Variable abbreviations that were used in the following analysis including: FrNr = number of marked female moths h = height, D = day after release, WSLN = wind speed at 2.5 m during twilight, WSHN = wind speed at 10 m during twilight, h = height, PreciN= precipitation of twilight, WS2.5 = wind speed at 2.5 m height, WS10 = wind speed at 10 m height, preci = precipitation (l/m^2), RH = relative humidity, Sun = Sunshine-Duration (h), MeNr = marked-released recaptured male moths number, W1 = twilight wind speed at 2.5 m height, W2 = twilight wind speed at 10 m height, Ws = wind speed at 10 m height, P = precipitation (l/m^2), and PN = twilight precipitation (l/m^2), di = distance from release point (m), Mnat = feral male moth number, TN = twilight temperature, Fnat = number of feral female moths, DD = Day Degree, CumDD = cumulative Day Degree, Tmean = mean temperature.

First of all the correlation of the variables was tested using the Proc. CORR SAS. Based on the correlation values, female moth number (FrNr) was linearly correlated with five of the predictor variables (Day, Tmean, RH, CumDD and TN) further than other predictive variables. Moreover some of the variables were highly correlated which suggested the possibility of multicollinearity problem. For example between variables ws10 and ws25, RH and DD, Tmean and RH, preci, and WS10 and WS25, WSLN and WSHN. Then this probability was tested after selecting the final model using the Variance Inflation Factor (VIF) and Tolerance options.

The first Proc. Reg. calculated AIC for all possible subsets of main effects using an intercept term and by specifying the adjusted R square as selection option. Then the second Proc. Reg. were used to calculate AIC for all possible subsets of main effects without an intercept term by specifying the "noint" option. The output data sets of both test were combined, sorted and printed from smallest AIC to largest. To select the best model by comparing of 266 models, thirteen models with the smallest AIC value were selected and deemed the "best" models, while one of them with smallest AIC and RMSE and highest R^2 was the best one (equation 3.8). Since there was relatively little difference in R^2 and AIC for the selected best subset models we could use other criteria to help in the selection of the best model. Based on using the Cp (Mallows's Criteria) and SBC (Schwarz's Bayesian Criteria) the best selected model presented as the second equation with the R^2 and RMSE equal to the first equation. To select the model based on criteria Cp and SBC the smallest is the best (equation 3.9).

The next step was comparison of AIC results with heuristic methods. For this purpose, thirteen independent variables were regressed against the no intercept dependent variable FrNr (Number of marked female moths) using Forwards election, Backward selection and Stepwise regression. Regard to the moderate right skew in the residuals, we applied a square-root transformation of data. A data set with P independent variables has 2^p possible subset models to consider since each of the p variables is either included or excluded from the model, not counting interaction terms. Thus, finding the best AIC or SIC model by complete enumeration is usually impractical, and we need some shortcuts. One of the possible solutions to this problem is to use the Stepwise selection method with an assumed entry and exit significance level. An entry significance level of 0.15, specified in the slentry = 0.15 option, means a variable must have a p-value < 0.15 in order to enter the model during Forwardselection and Stepwise regression. An exit significance level of 0.15, specified in the slstay = 0.15 option, means a variable must have a p-value > 0.15 in order to leave the model during Backward selection and Stepwise regression. In the present study we used 0.15 as entry option and 0.05 as stay option of variables. The following section examines the AIC results using heuristic Forward, Backward and Stepwise selection.

2.7.3 Heuristic methods for comparison of AIC results

Outcomes of regression analysis using Forward, Backward and Stepwise selection selection hold out in the table (3.25 and 3.26 for female moths). Forward, Backward and Stepwise selection confirmed that model that included variables Day, WSLN and WSHN as predictor variables, was the best subset model meanwhile is not analogous with the conclusion we draw earlier using AIC. The next step was calculation of RMSE (root mean square error) with and without intercept for each possible subset model, then the models were sorted from smallest to largest RMSE and then prints the subset models. The goal of this analysis was to minimize RMSE. Among the subset models the best one with the minimized RMSE and high R^2 represented. The model which included predictor variables dist, Day, Tmean, RH, WSLN, WSHN, DD and PreiN was posited as the best subset model which was not in congruity with the AIC results. According to the correlation of some predictor variables, the final issue of this model selection process was the multicollinearity evaluation. Using the Variable Inflation Factor (VIF) option in the final model revealed that there was a high correlation between variables WSHN and WSLN. As the VIF was higher than 10, and the WSHN was better predictor variable than WSLN, the last one was deleted from the final model and the final model represented in regard to biological and statistical aspects in equation (3.10).

It should be mentioned that the using only AIC as a model selection criteria is probably confusing. To avoid any possible problem we used other model diagnostics like RMSE, Cp and SBC as well as the biological notifications in selecting final model variables. Therfore, our selections are not limited to the degree of R-Square. It is only one the variable selection criteria. Additionally the results of other heuristic methods were controlled and compared withe AIC method. Finally, in contrast withe F test method of model comparison, AIC method is used for selection of the nested and non-nested models, meanwhile never reject any subset model. The last characteristic of the AIC and other similar methods enables the biologist to decide openly and without limitations.

It should be mentioned that the mean speed of wind during the study was 1.212 m/s and 2.124 m/s at 2.5 m and 10 m heights respectively and its maximum speed was 6.3 m/s and 11 m/s for the first and last heights. Moreover, twilight meteorological data calculated using the half an hourly meteorological data from 2100 until the 0200h for each sampling days and then mean of the data were utilized as night data in the regression. Consideration importance of wind and precipitation specific information is given in table (3.27) and the figures (3.18, 3.19 and 3.20).

With the same method of the female moth's model, we constructed a model for male moths dispersal based on AIC, Cp and SBC criteria selection method. The only differences between the methods was log modification of the data regard to the sever right skew of the residuals in male moth's data. Moreover an entry significance level of 0.05, specified as p-value for remaining of the regressor variables and 0.15 in order to enter the model during Forward, Backward and Stepwise regression selection. Results are presented in tables (3.28, 3.29, 3.30, 3.31, 3.32 and 3.33). The pre-final and final resulting models are indicated as equations (3.11) and (3.12) respectively.

2.7.4 Feral Codling moth

Male moths: With the same method of the marked male and female moth's model, we fitted a model for feral male moths using the AIC, Cp and SBC criteria selection method. Log modification of the data accomplished regard to the sever right skew of the residuals. Moreover an entry significance level of 0.05, specified as p-value for remaining of the repressor variables and 0.15 in order to enter the model during Forward, Backward and Stepwise regression selection. Backward and Stepwise selection methods verified the selected model based on the AIC, Cp and SBC criteria, while the Forwardselection method included other regressors. The final model constructed with and without intercept as Equations (3.13 and 3.14) respectively. According to the sever right skew, log transformation of the data carried out. There was little differences between the model which included WSHN and WSLN, thus the model with the smallest AIC, Cp and SBC was the model which included WSHN and selected as best the fitted model. Moreover all the other three methods confirmed the including of WSHN in the model. An entry significance level of 0.15, specified to enter the regressors and of 0.05 to stay in the model during the Forward, Backward and Stepwise selection. Day Degree was calculated based on the method mentioned in previous sections (Eq.2.1) using the climatologic data of Hohenheim station. Results are in the tables (3.34, 3.35, 3.36, 3.37, 3.38 and 3.39).

Female moths: All the process for the feral male moths model accomplished for the feral females. There was incongruity amongst the outputs of Forward, Backward and Stepwise regression of this analysis. Results of AIC method and testing for the collinearity presented here (Eqs.3.15 and 3.16). The multicolinearity possibility was tested using the VIF option which revealed some correlation between the regressors. Then some of the regressors left the model in regard of the R^2 and VIF value.

2.8 Study of Codling moth dispersal with mark-recapture experiments and diffusion models

Because of the abundance and high mobility of insect as compared to animals of similar size, insects are suitable for study of dispersal. A dispersal experiment consists of releasing a great number of insects from a give source and of observing the spatial distribution at various subsequent times [129]. Moreover according to the wolfenbarger definition, the smaller the organism, the more it is subject to the effect of environmental turbulence. Thus, the diffusion of small animals should be considered as partly passive and partly active [130]. The combination of mark-release-recapture and diffusion models have been shown to be effective for measuring insect dispersal [184]. Since the three-dimensional dispersal is difficult to observe, we attempted to measure the two dimensional distribution of dispersal by the use of traps placed at different distances and heights. The study of insect dispersal plays an essential role in estimating the aerial spread of damage caused by a newly invaded pest or the spatial distribution of a insect during the active period in spring subsequent to the emergence from hibernation spots [129]. Moreover quantitative information concerning dispersal plays an essential role in the evaluation of pest control. In the present study mark-release-recapture experiments were used to measure the rates of dispersal male and female Codling moths and examine the factors that govern dispersal. Mass rearing of the Codling moths accomplished in the laboratory using artificial food and on optimum condition. Resulted pupae sexed and coming moths marked and coded using a few milligrams of fluorescent powder. Releases performed from a central point at the evening 18:00-20:00 h in three blocks of apple orchards at the research station of the Hohenheim University. Ninety six traps of two different types were used in this study. Commercial Delta traps were baited with pheromone to attract the male moths and Cylinder-shape traps with Pear ester for sampling of both male and female moths. Traps were displaced alternatively as the distance of the synonym traps was 30 m and antonyms 15 m. and organized in eight cardinal directions and three different heights in a random arrangement. Trap catches were counted daily after releases, sexed and divided as marked and feral insects.

2.8.1 Descriptive data analysis and D calculation using indirect method

As the first method, we used statistical testing with a general linear model SAS software to determine variables influencing movement. The influence of distance that each marked moths traveled, flight height, direction and the day since release were tested for male and female moths distinctly. Quantitative analysis of male and female moths dispersal as the second method were used with the flowing further description.

The dispersal models applied to estimate dispersal are based on the well-known diffusion model (Equation 2.2) [129]. This equation has been tested in numerous studies [169], [10], [9] and [184]) while it is a robust approximation for ecological studies using the mass mark-recapture technique. Moreover the diffusion model predicts the statistical distribution of individuals that move in a "random walk". It provides a probability distribution of individuals that move as a function of time and position using the following assumptions:

- (a) Marking does not affect the insects in movement or mortality. This assumption was tested by pilot experiments and the marker quantity and method adjusted as well as possible.
- (b) An additional assumption is that the insects do not move preferentially in one direction from the release point, also called cardinality.
- (c) Finally, the standard model assumes a random walk in a uniform field, which is always violated to some degree but some of these digressions in the experiments are unavoidable.

$$\frac{\partial n}{\partial t} = D\left(\frac{\partial^2 n}{\partial x^2} + \frac{\partial^2 n}{\partial y^2} \right) - Ky = D\left(\frac{\partial^2 n}{\partial r^2} + \frac{\partial n}{r\partial r} \right) - Ky \qquad (2.2)$$

where n is the density of moths, t is time, D is the diffusion coefficient, x and y are spatial coordinates, and r is the radial distance from the release point and $r = \sqrt{x2 + y2}$. In order to obtain an analytical formula to fit the data, we need to specify the initial and boundary conditions and solve the equation (2.2). At the beginning of the mark-release experiment (t = 0), y_0 marked moths were released at the origin of the coordinate system, this was at (x,y) = (0,0). Moths will spread in all directions uniformly. Utilizing the resulting circular system, Equation (2.2) can be simplified by rewriting in polar coordinates as the right part of this equation. We were interested in the diffusion coefficient, which determines the rate at which moths move. The key assumption of this equation is homogeneous movement across the landscape. The term -Ky produces a decreases in the number of individuals proportional to the number of individuals remaining, with proportionality constant K. Ordinarily, we might suppose that:

$$K = k_m + K_e \tag{2.3}$$

where k_m, is the mortality rate and k_e, is an emigration rate. We assume that, if an individual emigrates, it does not return to the system. Furthermore, we assume that there is no way for new individuals to enter the area under study. The solution of equation (2.2) for one-dimensions diffusion is:

$$y_{(x,t)} = y_0 \frac{e^{-k*t} e^{-x^2/(4D*t)}}{2\sqrt{(\pi * D * t)}} \tag{2.4}$$

We now turn to the question of how to analyze dispersal data using the diffusion model. We suppose that we have measured the population density at time t after having released y_0 individuals and that we have several pairs of numbers y_i as a function of the x_i the distances from the release point, at which the population counts were taken. We applied a straightForwardnonlinear least squares technique to determine the coefficients A and B in the next equation (2.5) and A, B and C in the equation (2.9).

$$y_i = A\ e^{-B(x_i)^2} \tag{2.5}$$

Then we can calculate r^2 to evaluate how well the model fits data. A good fit (high r^2) does not necessarily prove that the individuals move independently and at random. The least squares value for B in the previous equation yields the diffusion coefficient directly:

$$D = 1/4B * t \tag{2.6}$$

Given the value of D from equation (2.6) and the least squares coefficient A, we can determine the value of the emigration/mortality coefficient K for one dimensional diffusion as in:

$$K = -ln(2A\sqrt{(\pi * D * t)/y_0})/t \tag{2.7}$$

Abundance calculation

Once k has been determined, an estimate of the total population y (t) left in the sampling area at the time the sample was taken can be found from equation (2.8).

$$y_t = y_0\ e^{-k*t} \tag{2.8}$$

Finally it should be mentioned that determining A and B provides the probability distribution of the insects. One can use this function to obtain other information about the distribution of the insects. The integral of the distribution function between limits (a) and (b) yields the number of insects remaining between spatial positions (a) and (b).

2.8.2 Evaluating the influence of flight distance and height on dispersal parameters

After utilization of the diffusion model for study of one dimensional dispersal of Codling moth, we were interested in evaluation of a more complex model, which was based on the diffusion model but we modified it to include the height of flight effect in the model. The suggested model constructed by adding an extra factor in the right hand of the equation (2.5), presenting the equation below (h = height):

$$y_i = A\ e^{-B(x_i)^2 - C*h} \tag{2.9}$$

Data analysis were carried out by including a new term in the non-linear regression model. A, B and C parameters were estimated and used to calculate the diffusion coefficient (D), emigration/mortality coefficient (K) and overall population (Y) at the time t presented. The results are indicated in the tables 3.42 and 3.43.

2.8.3 Calculation of diffusion coefficient using the direct method

This method is based on the same well known diffusion model [10] and [169]. The calculation of the Diffusion coefficient (D) for two-dimensional case is:

$$D = X^2/4t \tag{2.10}$$

where x is the distance from the releasing point and t is days since release. From this calculation, the median distance,

$$R_a = \sqrt{4D * t} \tag{2.11}$$

and the radius encompass 98 % of dispersing moths is

$$R_{98} = 2\sqrt{4D * t} \tag{2.12}$$

This is a well-described and accurate method for most recapture studies, but when more than 10 % of the organisms move beyond the most distant capture annulus, the method is not annulled and a correction may be needed [79]. One of the advantages of this method is the population rate of spread calculation. It could be reliably calculated using diffusion coefficient and intrinsic rate of increase. In regard to Okubo (1980) the appropriate rate for our analysis may be estimated as

$$C = 2\sqrt{r * D_{an}}, \tag{2.13}$$

where D_{an} is the annualized diffusion coefficient and "r" is the annual intrinsic rate of increase [167]and [129].

To calculate the spread of Codling moth, we used estimates of the longevity, s = 15.13 days for male and s = 18.26 days for female moths based on our pilot laboratory experiments and previous studies [56], [116] and intrinsic rate of increase, r = 0.118584, from previous studies [56]. The last authors reported different rates of "r" and "s" for sedentary and mobile strains and in regard to the possible presence of both strains in our experiments we used the average of to strains. From these estimates, the annualized diffusion coefficient was calculated as:

$$D_{an} = D * s \tag{2.14}$$

Finally, the intrinsic rate of increase for *C. pomonella* was used to calculate speed of population spread for male and female moths using equation (2.13). All the results are presented in table (3.44).

As a final step we intended to evaluate of the fitted models and comparison of models discussed in this section.

2.8.4 Comparison of models

To comparison of the models, magnitudes of diffussion coefficient (D), correlation coefficient (R^2), mortality and migration (K) and asymptotic correlation matrix of the estimated parameters were treated. Models that included flight distance (two factor model) and flight distance and hight (three factor model) were compared as well as for the male and female moths (Tables 3.40, 3.41, 3.42, 3.43, and 3.45).

Tight-fitting of female moth models when included only the flight distance in comparison when included flight distance and height, encouraged us to attempt more investigation on the variables influence on the female moths population using the AIC and GLM procedure. The question is whether flight height could participate in the female dispersal model? When the answer is positive, then which levels of this variable will influence the model? To answer these questions we used AIC variable subset method for selecting the best fitted model, that resulted the equation (3.21). GLM procedure results were presented in the table (3.46). To compare the variable levels Pdiff option were used in Lsmean statement and the results were displayed in table (3.47). Inverse conversion of data accomplished since the sever right skew of the primary data.

Chapter 3

Results

3.1 Effect of anesthesia and individual marking on survival of adults

Analysis of data with Proc. GLM revealed that the proposed model accounted for 89 % of the variations (R^2= 0.89). Numbing and marking process influence of the moths longevity regardless of their sex (F = 0.17 ; and P = 0.8411), while the difference between the treatments was significant (F = 6.4; and P = 0.0004) as well as the age (days) (F = 152.82; and P < 0.0001) (Table 3.1). Detailed study of the differences between the levels of the variables was feasible through the including of the "Pdiff" option to the least square mean comparison. In regard to that, despite non significance of sexes effect, the differences in the survival of segregated male and female with the jointed male-female group was significant.

Table 3.1: Analysis of variance for anesthesia and individual marking.

Sorce	DF	Type I SS	MS	F	P
treatment	3	2579.1890	859.7297	6.40	0.0004
sex	2	46.5199	23.2600	0.17	0.8411
days	12	246203.3928	20516.9494	152.82	<0.0001
		R^2=0.90			

Treatment effects were significant in the overall model, while pair wise mean comparison revealed that difference between treatment I and II was not significant as well as treatment III and IV (see table 3.2). The same comparison carried out for the variable day. According to the result of the analysis no significant differences at the first three days detected. Moreover in the majority of the remaining days the survival differences between successive days was not meaningful. In other word significant differences revealed with one day intervals.

Normally in general linear models (GLM), the dependent variables do not necessarily have normal distribution. But the error term in the model should have a standard normal distribution (Guangbin Peng, Eli Lilly and Company, Indianapolis, Indiana 46285 U.S.A.) (personal communication). Since residuals after model fitting approximate the actual errors, we should check the normality of the residuals to assure the validity of statistical tests using the GLM. For this purpose we utilized Univariate procedure of SAS. QQ plot of the residual normal distribution indicated in Fig. (3.4). In the case of Kolmogorov-Smirnov test, the D was equal to 0.06288 and non-significant at alpha = 0.01 (P value = 0.028). The attractive feature of this test is that the distribution of the K-S does not depend on the underlying distribution function being tested, therefore it is considered as non-parametric and distribution free.

To propose a model for the relation of anesthetize and individual marking with the survival of the Codling moth, regression analysis were used. Figures (3.1, 3.2 and 3.3) pointed out this relations as well as equations (3.1, 3.2 and 3.3) for male, female and male-female correspondingly. Proposed models accounted for 86%, 89 % and 83% of the variations for male, female and male-female respectively (Fig. 3.2 and 3.1).

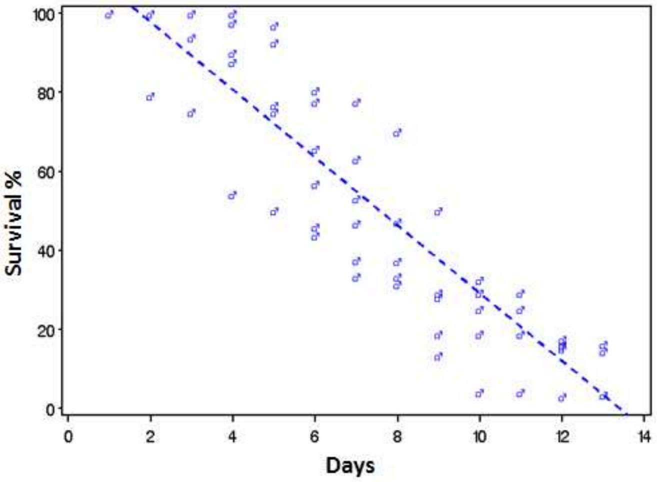

Figure 3.1: Effect of anesthesia and individual marking on the survival of male moths.

$$Survival_M\% = 114.95 - 8.58(days) \tag{3.1}$$

$$Survival_F\% = 118.95 - 9.06(days) \tag{3.2}$$

$$Survival_{MF}\% = 112.93 - 8.77(days) \tag{3.3}$$

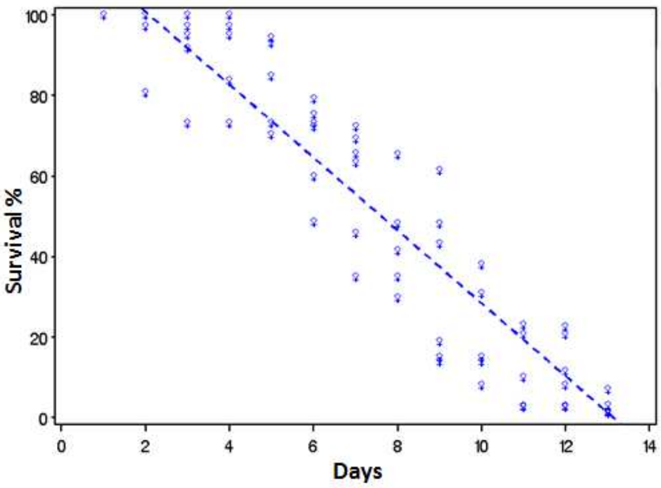

Figure 3.2: Effect of anesthesia and individual marking on the survival of female moths.

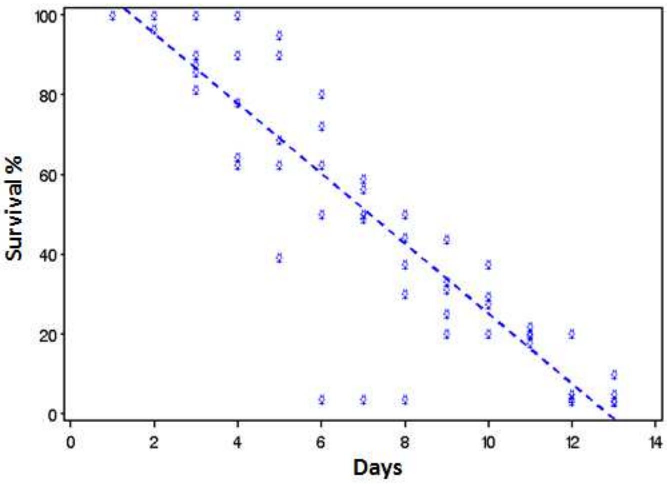

Figure 3.3: Effect of anesthesia and individual marking on the survival of both sexes (male-female) moths.

Table 3.2: Pair-wise mean differences of treatments in numbing and individual marking study. Treatment I marked male and females 3 minutes in numbing temperature, II marked male and female moths 5 minute in numbing temperature, III non marked male-female moths 3 minutes of numbing temperature and IV the control without mark and numbing.

Treatment	I	II	III	IV
I		0.3487	0.0005	0.0002
II	0.3487		<0.0001	<0.0001
III	0.0005	<0.0001		0.8543
IV	0.0002	<0.0001	0.8543	

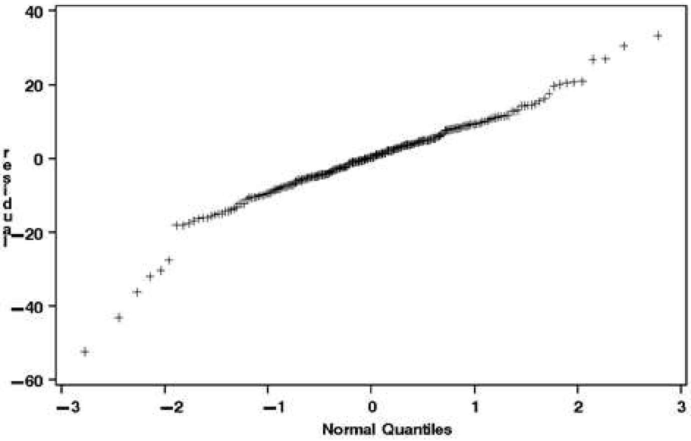

Figure 3.4: Normality distribution of the residuals in anesthesia and individual marking experiments.

3.2 Influence of cold storage on the longevity of adult Codling moth

In regard to the analysis, the effects of time and treatment were significant at alpha = 0.01 (Table 3.3). We used categorical variable for the sex and numerical variable for times and treatments. Overall model was accounted for 88 % of the variations. Mean comparison carried out using the LSmean and "pdiff" option. Both male and female longevity significantly differentiated in comparison with the control. The differences of the male and female moths longevity was significant at alpha = 1 %, as well as the differences of treatments and the times. Results revealed that the capability of male and female moths to tolerate cold was significantly different and female moths tolerate the cold condition further than the male moths and live longer. Moreover the differences between the treatments and times were significant too. Meanwhile the survival of the treatment II (treated female moths) was approximately two times of the control female moths (treatment IV), and the same condition for the male moths (treatment I) with the control (treatment III) (Tables 3.3 and 3.4).

Table 3.3: Overall analysis of variance for cold storage of male and female Codling moths.

Sorce	DF	Type I SS	MS	F	P
treatment	3	367217716	122405905	84.09	0.0001
time	8	1200685891	150085736	103.11	<0.0001
		R^2 =0.88			

Table 3.4: Least square mean comparison of treatments in cold storing experiment of Codling moth.

I	II	III	IV
I	0.0521	<.0001	<.0001
II	0.0521	<.0001	<.0001
III	<.0001	<.0001	0.6012
IV	<.0001	<.0001	0.6012

There was no significant difference in the survival of the moths until the sixth day, which means that under this experiment condition, moths could be stored without considerable changes in their survival up to six days (Table 3.5 and Fig.3.5). Since residuals after fitting the model approximate the actual errors then we should check the normality of the residuals to assure the validity of statistical tests using the GLM. For this purpose at first we checked the residual distribution and according to the non normality of them as well as the moderate left skew, the square transformation was performed on the response variable and then the analysis carried out. Using univariate procedure of SAS and QQ plot (Fig. 3.6) and histogram indicated that distribution of the residuals was normal.

Kolmogorov-Smirnov (K-S) test is based on the empirical distribution function (EDF). To test normality, the K-S statistic is computed using the sample data against a normal distribution with mean and variance equal to the sample mean and variance (SAS Institute, 1999). In order to propose a simple model for utilization in the future experiments, regression model was exploited. Regression analysis pointed out the influence of cold storage on male and female moths over the time (Fig. 3.7 and 3.8). The suggested model (equations 3.4 and 3.5) indicants fitting of data by 71 % and 57 % for male and female moths respectively.

$$Survival_M\% = 102.78 - 4.85(T) \tag{3.4}$$

$$Survival_F\% = 101.58 - 3.93(T) \tag{3.5}$$

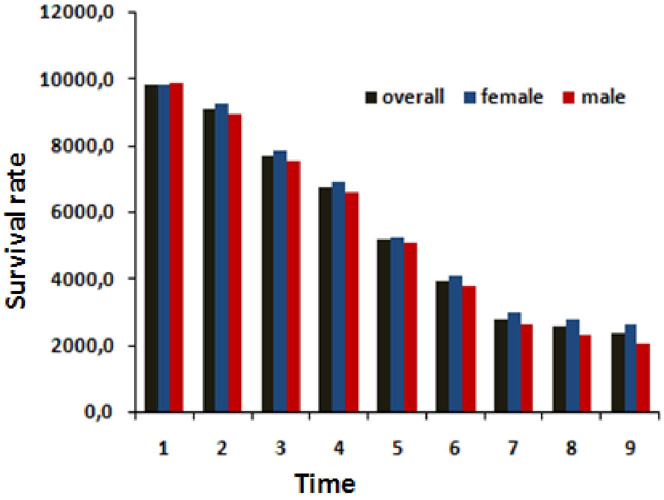

Figure 3.5: Influence of cold storage period on survival of Codling moth (data were modified as square of data in regard to the moderate right skew).

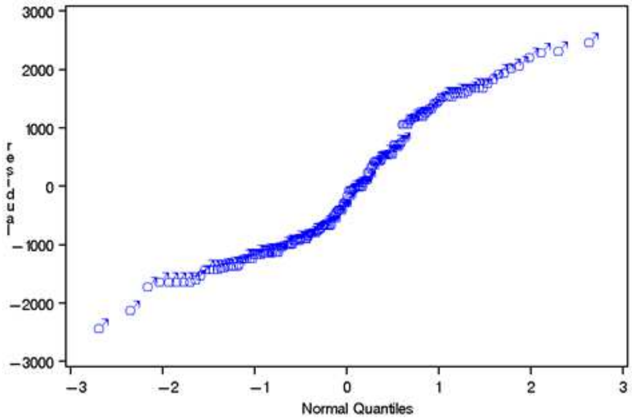

Figure 3.6: Normality distribution of the residuals in cold storage of male and female moths (data were modified as square of data in regard to the moderate right skew).

Table 3.5: Pair-wise mean comparison of the Codling moth survival during the storage under cold condition. Numbers of the first column and the row indicates the time (days).

Time	3	6	9	12	15	18	21	24	27
3		0.0662	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
6	0.0662		0.0006	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
9	<0.0001	0.0006		0.0175	0.0001	<.0001	<.0001	<.0001	<.0001
12	<.0001	<.0001	0.0175		0.0001	<.0001	<.0001	<.0001	<.0001
15	<.0001	<.0001	0.0001	0.0152		0.0028	<.0001	<.0001	<.0001
18	<.0001	<.0001	<.0001	<.0001	0.0028		0.0054	0.0008	0.0001
21	<.0001	<.0001	<.0001	<.0001	<.0001	0.0054		0.5487	0.2702
24	<.0001	<.0001	<.0001	<.0001	<.0001	0.0014	0.5487		0.6138
27	<.0001	<.0001	<.0001	<.0001	<.0001	0.0001	0.2702	0.6138	

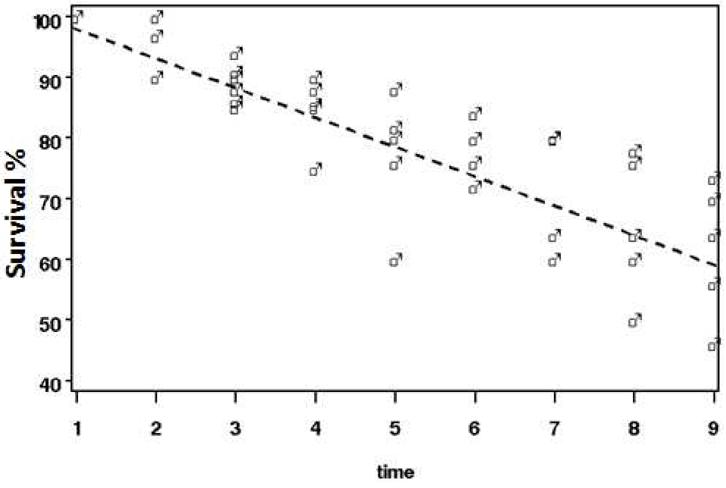

Figure 3.7: Proposed regression model for influence of the cold storage on the survival of male moths (each number of the x axis represents three days).

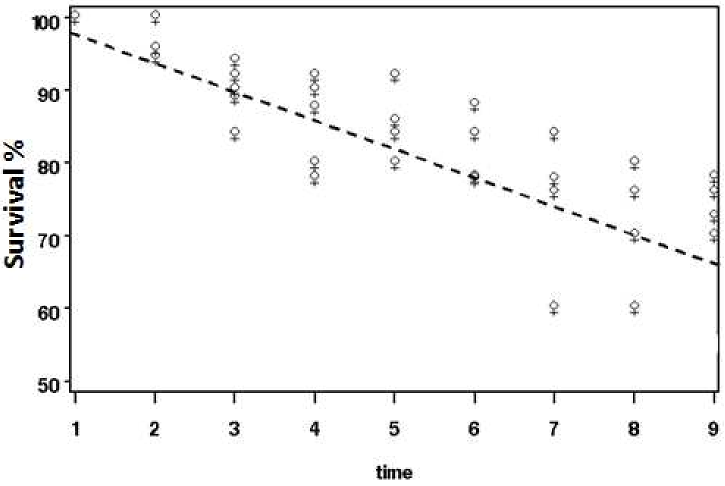

Figure 3.8: Proposed regression model for influence of cold storage on survival of female moths (each number of the x axis represents three days).

3.3 Mass marking and its effect on the longevity of adult Codling moth

Due to the labour and time consuming method of individual marking and likewise vulnerability of Codling moth, mass marking was evaluated using fluorescent powder. As much as 355 moths including 191 males and 164 females were used in the present study. Analysis of data using the GLM presence that the effects of sex (F = 13.97; and P = 0.0003), the cylinders (F = 43.51; and P< 0.0001) and interaction of the sex and Cylinder (F = 2.6; and P = 0.0376) were significant as well as the effect of the age (Table 3.6). We used numerical variables for all the factors. These variables interpreted 96 % of the variations ($R^2 = 0.96$). Least square mean comparison with the pdiff option facilitates the mean comparison among the different levels of the variables. As a result, the significant mortality of the moths started after 5 days moreover in the most cases the differences of successive days were not significant.

Pair-wise comparison of the cylinders indicated significant differences between all the cylinders with the control. Furthermore, daily mortality comparison indicated that the mortality of the both sexes at the first half of the period, was similar but at the second half of life, mortality of the female moths was additional as well as quick (Fig.3.9). Using QQ plot and histogram as well as Kolmogorov-Smirnov test indicated non-significant of residuals (alpha = 0.1 and P value = 0.02).

$$M_m = -6.61 + 1.96D \tag{3.6}$$

$$M_f = -6 + 1.84D \tag{3.7}$$

Where M_m and M_f are the mortality of male and female moths respectively with 72 % goodness of fitting for both of the sexes and D is the time (days).

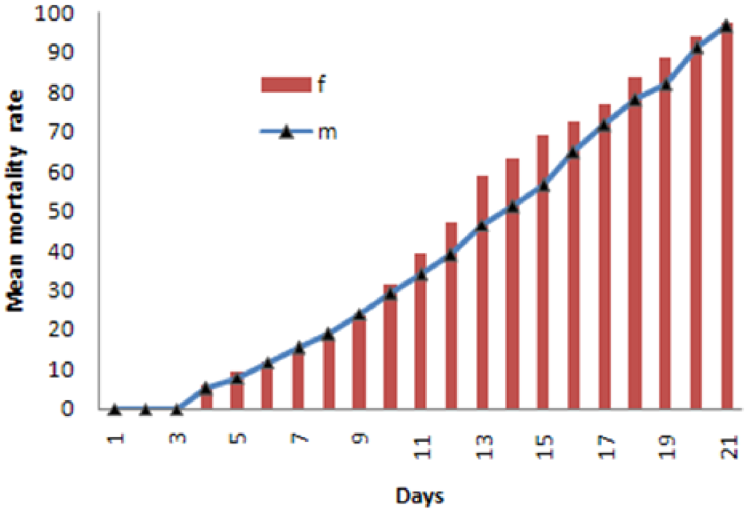

Figure 3.9: Mean comparison of daily mortality of male and female moths influenced by fluorescent powder in mass marking.

Table 3.6: Analysis of variance for influence of the mass marking on the mortality of male and female Codling moths.

Sorce	DF	Type I SS	MS	F	P
Cylinder	4	9769.7774	2442.4444	43.51	<.0001
sex	1	783.9932	783.9932	13.97	0.0003
Day	20	215556.4680	10777.8234	191.98	<.0001
Cylinder*sex	4	584.5382	146.1345	2.60	0.0376
		R^2= 0.96			

3.4 Trade off trap structure in assessing the horizontal and vertical distribution

3.4.1 Evaluation of the trap structure in outward distribution study

Approximately 1370 marked Codling moth adults were released and a total of 695 marked moths were recaptured ($\simeq$ 50.07 %).

Trap type

Analysis of the data demonstrated no significant differences between the three types of traps in attracting the released and feral females as well as for total moths. (marked female: $F = 0.19$; df $= 1$; $P = 0.66$, Feral female: $F = 3.47$; df $= 1$; $P < 0.64$), total: $F = 1.33$; df $= 2$; $P = 0.26$). Meanwhile significant dissimilarity in marked and feral male catches were traced (for marked male see Table 3.7 and for feral male: $F = 39.38$; df $= 2$; $P < 0.0001$). Mean comparison results for moths percent caught per trap per day ± standard deviation using t test are presented in table (3.8). In this table the traps catching significantly ($P < 0.0001$) ranked as D (Delta pheromone traps) > S (Cylinder traps)> DP (Delta Pear ester traps) for marked and feral male and S > DP for marked and feral female moths. Likewise, the numerical catches of Cylinder traps for feral and marked females were higher than in Pear ester baited Delta traps as well as for total moths. Additional to moth's reaction to the various traps, released and feral moths exhibited different reaction to trap heights, distances and orientation (Table 3.7 and 3.8).

Table 3.7: Analysis of variance for marked male and female moths vertical and horizontal distribution using three different trap. Fr = marked-released female and Mr = marked-released male moths, Dis = distance from the releasing point, Dir = direction, H = height of the trap.

	Source	DF	Type I SS	MS	F	P
	Dis	3	1.3320	0.4440	11.56	<0.0001
	Dir*H	22	4.8407	0.2200	5.73	<0.0001
Fr	Dir*Dis	12	1.3380	0.1115	2.90	0.0011
	Ttype	1	0.0101	0.0101	0.26	0.6079
	Site	2	0.2106	0.1053	2.74	0.0673
	H	2	0.3457	0.1728	3.04	0.0491
	Dis	3	0.2702	0.0901	1.59	0.1927
Mr	Dir	7	0.6566	0.0938	1.65	0.1204
	Ttype	2	2.9575	1.4787	26.04	<0.0001
	Dir*Dis*H*Ttype	108	12.7525	0.1181	2.08	<0.0001
	Site	2	0.03268	0.0163	0.29	0.7502

Table 3.8: Mean ± standard deviation of catch per trap per day of marked and feral female and male in different trap types using Proc. Mean and t test to compare different trap efficiency in catching different group moths (Mr = marked-released male, Mn = feral male, Fr = marked-released female and Fn = feral female, D = Delta trap with pheromone, DP = Pear ester baited Delta trap, S = Cylinder trap, Ttype = trap type).

Ttype	N.Obs	Variable	Mean±Sd	SE	t-Value	Pr>t
D	224	Mr	0.423±0.747	0.050	8.47	<0.0001
		Mn	0.587±0.666	0.044	13.20	<0.0001
		Fr	0.211±0.238	0.027	7.93	<0.0001
DP	80	Mr	0.126±0.176	0.020	6.43	<0.0001
		Fn	0.076±0.169	0.019	4.02	0.0001
		Mn	0.097±0.197	0.022	4.41	<0.0001
		Fr	0.229 ±0.276	0.024	9.41	<0.0001
S	128	Mr	0.135±0.182	0.016	8.41	<0.0001
		Fn	0.142±0.172	0.015	9.32	<0.0001
		Mn	0.099±0.144	0.013	7.81	<0.0001

Vertical distribution

Reaction of the moths to trap height was not similar, whereas marked female moths exhibited significant differences to different heights (F = 10.16; df = 2; P < 0.0001), marked and feral male and feral female moths revealed no difference reaction to traps in different heights (marked male:F = 2.59; df = 2; P = 0.076, feral male: F = 2.62; df = 2; P = 0.074, and feral female: F = 0.83; df = 2; P = 0.43). Furthermore the dominant distribution height was 1.6 m for marked and feral insects while the 2.2 m was the last choice, although there was no preference for feral female moths, the marked female moths were caught significantly in higher number in 1.6 m rather than 1.2 m and 2.2 m heights (0.308 ± 0.317, P<0.0001) (Fig. 3.10 and Table 3.10).

Horizontal distribution

Marked female moths exhibited significant differences (F = 8.42, df = 3 and P < 0.0001). Also marked female mean catch percent per trap per day in 30 m and 45 m distances were more than 15 m and 60 m (0.334 ± 0.316, 0.270 ± 0.259 vs. 0.148 ± 0.235, and 0.142 ± 0.163 respectively (p<0.0001, see table (3.9)). In contrast, distribution of marked male and feral male and female moths in different distances was not expressive. Moreover, non-significant effect of distance factor analyzing feral male and female moths distribution, undoubtedly does not imply that they have equable distribution through out distances 15 - 60 m. For example for feral female moths the maximum catches related to traps distanced 30 m and minimum in 15 m, unlikely maximum male moths were caught in 60 m distanced traps and minimum in 45 m (Fig. 3.11 and Table 3.9).

Table 3.9: Mean ± standard deviation of marked insect cumulative caught percent per trap per day, in distances nine days after release using Proc. Mean and t test to compare different trap catches in different heights (D = Delta trap with pheromone, DP = Pear ester baited Delta trap, S = Cylinder trap, Dis = Distance (m)).

			marked male			marked female		
Trap	dis	N	Mean ± Sd	t	P	Mean ± Sd	t	P
	15	57	0.547±0.889	4.64	<0.0001	- -	-	-
D	30	59	0.362±0.789	3.52	0.0008	- -	-	-
	45	54	0.309±0.375	6.05	<0.0001	- -	-	-
	60	54	0.473±0.810	4.29	<0.0001	- -	-	-
	15	25	0.137±0.188	3.65	0.0013	0.206±0.280	3.69	0.0012
DP	30	15	0.158±0.170	3.61	0.0029	0.203±0.216	3.64	0.0027
	45	25	0.079±0.164	2.40	0.0247	0.218±0.251	4.34	0.0002
	60	15	0.155±0.179	3.35	0.0048	0.218±0.177	4.75	0.0003
	15	37	0.136±0.185	4.46	<0.0001	0.108±0.193	3.42	0.0016
S	30	32	0.144±0.150	5.42	<0.0001	0.395±0.339	6.60	<0.0001
	45	32	0.135±0.198	3.85	0.0006	0.312±0.262	6.73	<0.0001
	60	27	0.125±0.201	3.23	0.0034	0.100±0.141	3.67	0.0011

Dispersal direction

Distribution of the moths in cardinal directions was a little more complicated and bear no common trend at all. Unlike the non-significant directional dispersal of feral and marked males, (F = 1.62; df = 7, P = 0.12, and F = 1.27; df = 7, P = 0.26, catch percent per trap per day for feral and marked male respectively) feral and marked female moths dispersal at directions possess significant differences (F = 2.76; df = 7, P = 0.009 and F = 12.15; df = 7, and P<0.0001 respectively). In addition, while the SW, NW, W and SE were respectively dominant dispersal directions of the marked females (Fig. 3.12 a), dissimilarly main catches of the feral insects were at SE, NE, NW and SW directions respectively (Fig. 3.12 b and 3.13 d). Interaction of direction and distances was significant for marked female (Table 3.7) and feral female moths (F = 3.96; df = 8, P = 0.0003) as well as the counter effect of direction and flight height for marked male and female moths (Table 3.7) and feral female (F = 1.83; df = 13, P = 0.043). These significant counter effects together with previous analysing, which revealed that dominant directions for marked and feral moths were different, motivated us to enquire them further through analysing of data using Proc. Mean. Our newborn question was whether there was a correlation between distance and directions. For instance, whether moth's density decreases by increasing the distances in distinctive directions?

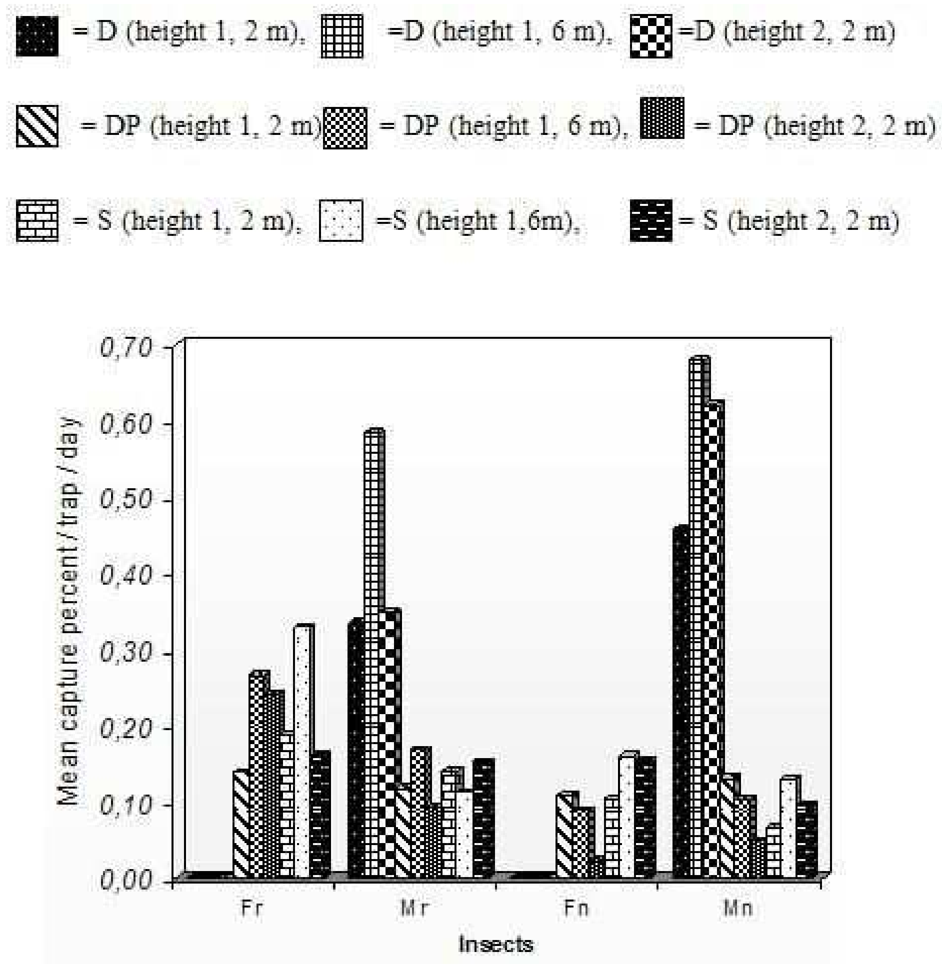

Figure 3.10: Vertical dispersal of marked and feral male and female Codling moth (Fr and Mr = released female and male, Fn and Mn = feral insects, D = Delta pheromone traps, DP = Delta Pear ester traps and S = Cylinder traps).

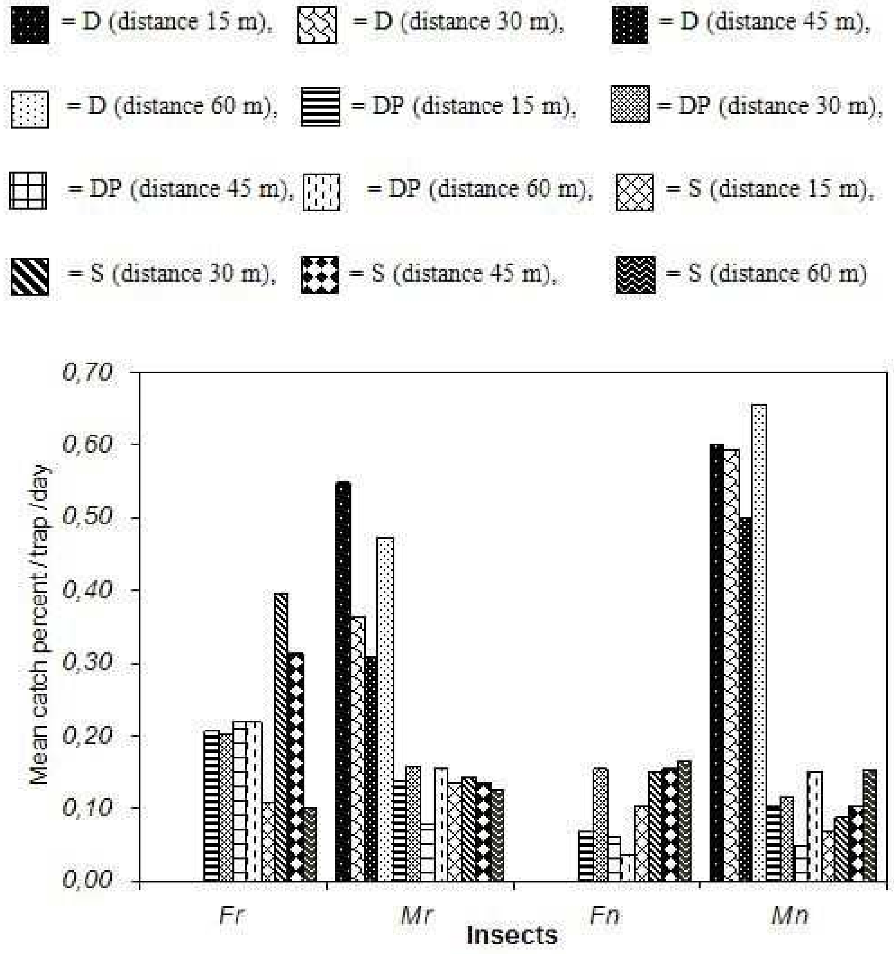

Figure 3.11: Horizontal dispersal of marked and feral male and female Codling moth (Fr and Mr = released female and male, Fn and Mn = feral insects, D = Delta pheromone traps, DP = Delta Pear ester traps and S = Cylinder traps).

Table 3.10: Mean ± standard deviation of marked insect cumulative caught percent per trap per day, nine days after release using Proc. Mean and t test to compare the mean catches of traps at separate heights(D = Delta trap with pheromone, DP = Pear ester baited Delta trap, S = Cylinder trap, H = height (m)).

			marked male			marked female		
Trap	H	N	Mean ± Sd	t	P	Mean± Sd	t	P
	1.2	73	0.336±0.613	4.68	<0.0001	- -	-	-
D	1.6	74	0.585±1.008	4.99	<0.0001	- -	-	-
	2.2	77	0.350±0.517	5.94	<0.0001	- -	-	-
	1.2	30	0.119±0.168	3.87	0.0006	0.140±0.165	4.65	<0.0001
DP	1.6	25	0.168±0.186	4.53	0.0001	0.267±0.290	4.61	0.0001
	2.2	25	0.094±0.173	2.70	0.0126	0.241±0.244	4.94	<0.0001
	1.2	40	0.141±0.189	4.70	<0.0001	0.189±0.246	4.87	<0.0001
S	1.6	45	0.113±0.139	5.44	<0.0001	0.330±0.333	6.65	<0.0001
	2.2	43	0.153±0.214	4.71	<0.0001	0.161±0.201	5.25	<0.0001

Simultaneous mean analysis for cardinal directions and distances provided useful information about the dispersal of moths. Analysis pointed out that trap catches per trap per day for marked female moths in SW, NW and S directions confirmed our assumption, in which there was a negative correlation between distance from a central point and moth's density. The same result and situation was fitted exactly for feral female moths in NE, NW, S and SW directions. Simultaneous distance and cardinal directions mean comparison disclosed inverse results. Therefore the highest density of feral male moths was in farthest distance (60 m) in SE, SW, W, N, and NW directions as well as for marked male moths in NE, NW and SE directions.

Recent resolution may propel us toward other deduction that high density of feral male moths at further distances and near the border of the orchards may originated of the outside orchard resources and migrated moths. Regarding to the study site situation and it's habitual management and periodic maintenance activities which normally promote decrease of feral moths density, in addition to the surrounding abandoned scattered apple trees and orchards, and finally beyond the high density of attractant and traps in our study site and capability of overestimation at such situation all together confirmed such conclusion, meanwhile motivated us to ponder it more in our next study on the inward dispersal of Codling moth.

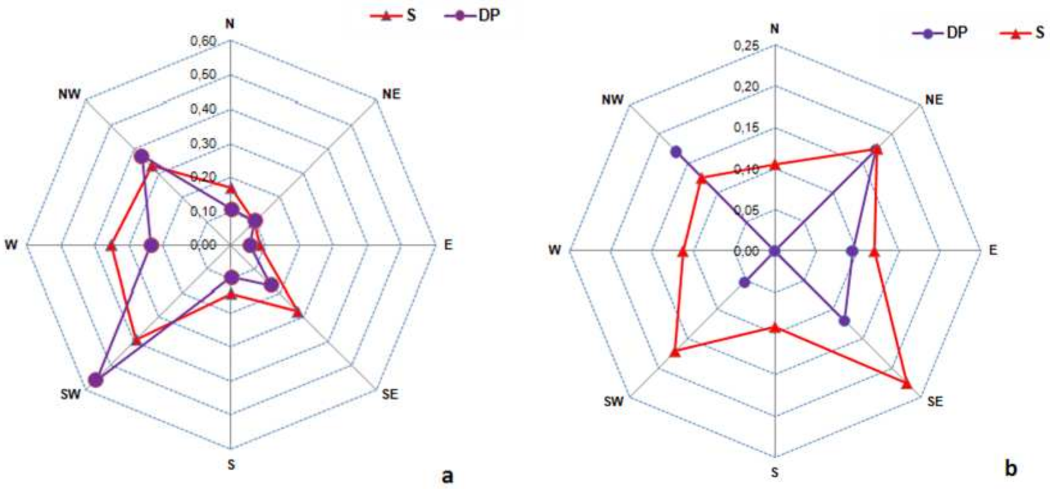

Figure 3.12: Dispersal of marked (a), and feral female (b) moths in different directions using Delta Pear ester traps and Cylinder-shape traps.

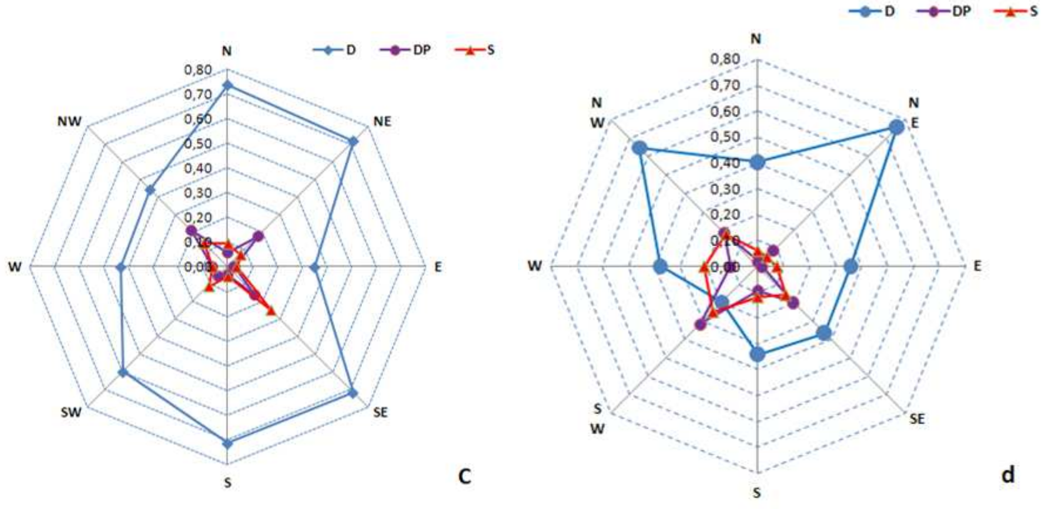

Figure 3.13: Dispersal of feral (c) and marked male (d) moths in different directions in Delta pheromone traps, Delta Pear ester traps and Cylinder-shape traps.

3.4.2 Inward distribution

According to the data analysis with Proc. GLM, SAS software, both marked male and female demonstrated significant differences in their direction and distances. Unlikely trap catches in different heights were non-significant for the both marked sexes as well as at the releasing date. Although numerically, female catches in 1.2 m height was the highest in contrast with the male, which caught in higher number in 2.2 m height. In addition neither trap type nor releasing site were significant for the male but correspondingly significant for females, as the female catches in the Cylinder traps with Pear ester dispensers was significantly more than Delta traps with the same dispenser. When we started analysing the data first with trap type as variable for the marked female, despite the significance of the traps effect, trap type accounted for only 7 % of the variations. In other word R^2 = 0.07 (F = 7.21, and P = 0.0086), by continuing the analysis and adding the distance factor to the analysis, meanwhile both the trap type and distances were significant, R^2 increased to 0.85, thus indicated that distance was an exterminating factor in present inward dispersal of the female moths.

Including height in the analysis had no reasonable effect on the R^2 and then did not contributed in the interpretation of the variances as well as the releasing site. We continued analyzing to find direction counter effect with distance, significance of this effect demonstrated as like as direction and distance counter effect. Regarding the counter effect of direction and releasing site of the moths indicated its significance. Therefore, the releasing site influenced the directional catches of traps. According to significance effect of these factors by adding them to the analysis, R^2 improved and 98 % of the variations could be interpreted. Therefore, the main factors in this experiment were distance and direction respectively. The nearest trap had 5 m distance with the releasing point and the farthest trap 123.5 m. The most remote trap which caught marked females were at 93.4 m, in other word the deepest penetration of the marked female moths was 94 m. Simultaneous direction and distance mean analyzing revealed that maximum catches of the female moths were in traps located at 5 m and North West direction, while W and SW, S and N were the next directions located in 66.8, 94.6, 94.3 and 53 m respectively and the minimum in 87.6 m and North direction (Fig.3.14). The same process for marked male indicated that for marked male moths there were no advances of the traps (F = 0.58; df = 2 and P = 0.57). The distances effect was significant about 90 % and thus a majority of the variations in trap catches of marked males could interpreted. The releasing site and the direction counter effect was not significant, therefore trap catches at special directions could not interpreted by the effect of the releasing site. Simultaneously direction and distance mean analyzing revealed that maximum catches of the marked male moths were at 120 m and minimum at 61.6 m at SE and NE respectively. Nearly in all directions maximum catches of marked male moths took place at distances further than 67 m and minimum catches at distances lesser than 39 m (Fig. 3.14 and 3.15). These findings confirm that moths were more interested in dispersing inside rather than outside to migrate, in other words while the overestimating probability and immigration of moths was confirmed, our assumed conclusion in the prior experiments was verified.

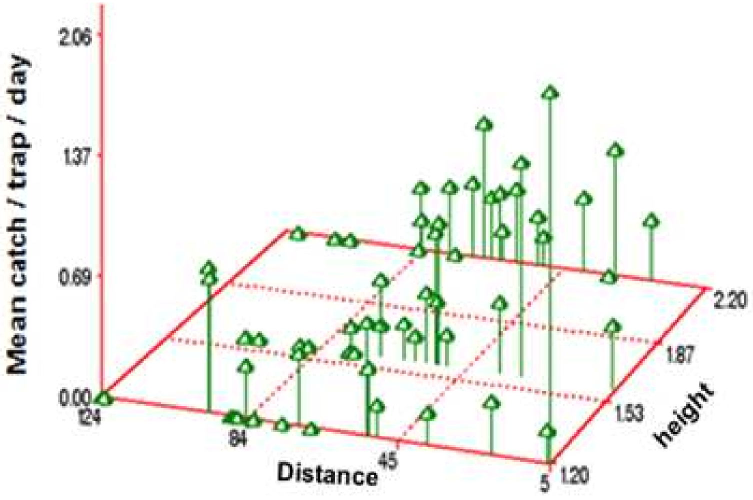

Figure 3.14: Vertical and horizontal distribution of marked female in inward distribution experiment. (X = distance that differed from 5 m to 124 m, Y = height (12 m; 1.6 m and 2.2 m); Z = mean catch percent per trap per day).

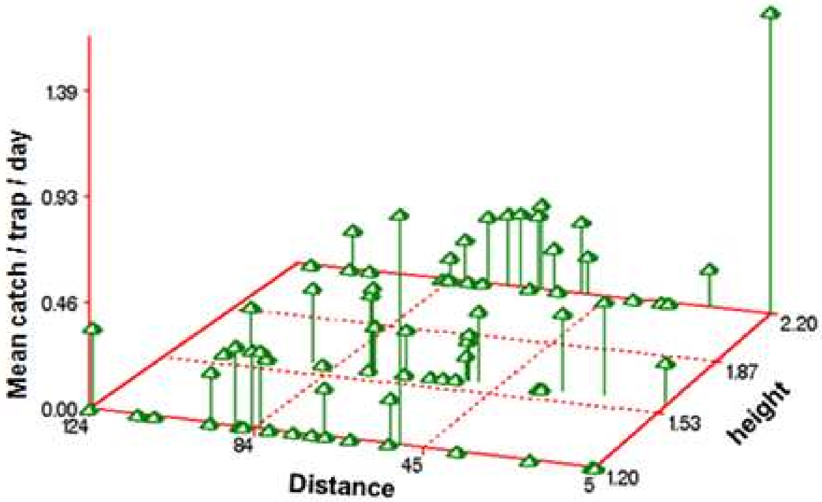

Figure 3.15: Vertical and horizontal distribution of marked male in inward distribution experiment. (X = distance that differed from 5 m to 124 m, Y = height (12 m; 1.6 m and 2.2 m); Z = mean catch percent per trap per day).

3.5 Effect of apple cultivar on traps efficiency and dispersal of insect

Male dispersal: Data were analyzed using the Generalized model SAS version 9.1, with log link and Poisson dist options. According to the log link option and the zero values of some response variable, the data were set as response variable+1 using 'if' and 'then' statement. An important aspect of generalized linear modeling is the selection of explanatory variables in the model. Changes in goodness-of-fit statistics are often used to evaluate the contribution of subsets of explanatory variables to a particular model. The deviance, is often used as a measure of goodness of fitting. Fitting the sequence of models and effect of the added variable carried out based on the (deviation value) / (degree of freedom) (V/df) and by calculation of probability value (P value). Both type I and type III LR statistics included in the analysis and the normality of the residuals were tested using Univariate procedure and QQ plot. Among the simple effects the most important explanatory variable for the response variable 'Mn' (feral male moth) was sampling dates of the male insects in different dates with V/df equal to 0.2850, while the variety and distance from the releasing point were the second and third influential variables with V/df equal to 0.4018 and 0.4129 respectively. Moreover among the nested effects the interaction of distance-height-variety was the most influential one ($V/df = 0.2339$). Every sequence of the variable selection followed by calculation of probability value (P value) by using the deviance value and degree of freedom to evaluate the significant effect of the included variable. Unnecessary and non-significant effects were removed from the model. The final suited explanatory variables were presented in table 3.11. The final deviance V/df was equal to 0.1717 with df = 234 and the calculated P value for overall model equal to 1, that indicate the suitability of the fitted model. The influence of the variety, released groups and direction were strongly significant as well as the interaction of the distance, height and variety.

Table 3.11: Genmod type I analysis of variance for feral male moths. dist in this analysis refers to the distance from the releasing point.

Source	Dev.	DF	F	Pr>F	χ^2	Pr> χ^2
Intercept	125.9182					
Direction	123.0141	7	2.50	0.0169	17.52	0.0143
Date	70.4726	18	17.61	<0.0001	316.93	<0.0001
variety	58.3125	12	6.11	<0.0001	73.35	<0.0001
dist*height*variety	40.1846	48	2.28	<0.0001	109.35	<0.0001
$Dev./DF$= 0.1717						

Testing the normality of the Pearson residuals indicated non-significant statistics for the Shapiro-Wilk test (W = 0.992628 and P = 0.1155) as well as the QQ plot (Fig.3.16). Rechi (χ^2 residuals) was used for this purpose. Least square means used as the additional statement on the model with "Pdiff" option to evaluate pair-wise mean comparisons and the results were presented in the table 3.13. Parameters were estimated with 95 % confidence limit and χ^2 used to evaluate of differences.

Differences of the directions accounted for N, NW, NE, and SW in the analaysis table. Twelve out of nineteen different sampling dates were significant. Individual effects of varieties had connection with significant effects of Bosk, Cmeo, Golden Delicious, Idared, Jonagold and Roter Berlepsch, Rubinete and Melrose varieties (Tables 3.12 and 3.13). To test the goodness of fit, P value was calculated based on calculation of P value using the deviance value and degree of freedom. As a whole if the test V/df in the "Criteria for assessing Goodness of fit" is not significant then the fit is adequate.

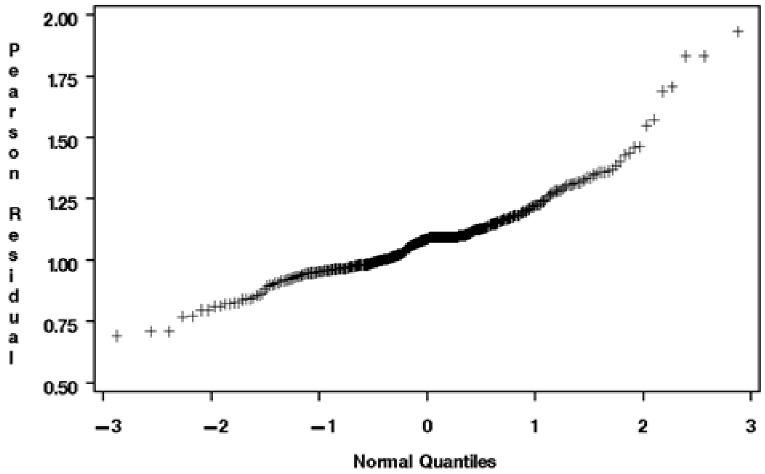

Figure 3.16: Normality distribution of the residuals in the study of apple cultivar impact on distribution of feral male moths.

With the same methods the influence of the host tree on distribution of marked male moths was studied. As regards to the right skew in the residual normality plot, data were transformed as 1 / Mr plus 1 to avoid zero values and provided log link option. Generalized model SAS version 9.1 was utilized for analyzing of data, with log link and Poisson dist options. Among the simple effects the most important explanatory variable for the response variable 'Mr' (marked male moths) was releasing date of the male moths with V/df equal to 0.2750, while the trap type and variety were the second and third influential variables with V/df equal to 0.2751 and 0.2822 respectively. The simple effects of the distance from the releasing point, releasing point (outward or inward) and height of the traps were not significant and then removed from the overall model.

Meanwhile among the nested effects the interactions of distance, height and trap type with the variety were the most influential one (Table 3.14). Every sequence of the variable selection followed by calculation of probability value (P value) by using the deviance value and degree of freedom to evaluate the significant effect of the included variable. All non significant effects removed from the model. The final suited explanatory variables extracted and presented in table (3.14). Least squire and Significant pair-wise mean differences of traps catches were presented in tables (3.15 and 3.16). The final V/df was equal to 0.0312 with 252 degree of freedom and the calculated P value for overall model was equal to 1, that indicated the suitability of the fitted model. The influence of the release date, variety and interaction of height-variety, distance-variety and trap type-variety were strongly significant. Normality of the Pearson residuals tested using the QQ plot (Fig.3.17) which revealed normal distribution of the residuals.

Table 3.12: Least square mean for traps catches of feral male moths on different varieties. Only the significant differences were presented in this table.

Effect	variety	Estimate	SE	DF	χ^2	Pr> χ^2
variety	Bosk	-0.4197	0.1852	1	5.13	0.0235
variety	Cmeo	-0.8292	0.1663	1	24.87	<0.0001
variety	Golden	-0.8776	0.1345	1	42.57	<0.0001
variety	Idared	-0.3209	0.1347	1	5.67	0.0172
variety	Jonag	-0.4920	0.1074	1	20.98	<0.0001
variety	Roterb	-1.1605	0.2358	1	24.22	<0.0001
variety	Rubin	-0.4781	0.0948	1	25.44	<0.0001
variety	Melro	-0.4549	0.1562	1	8.48	0.0036

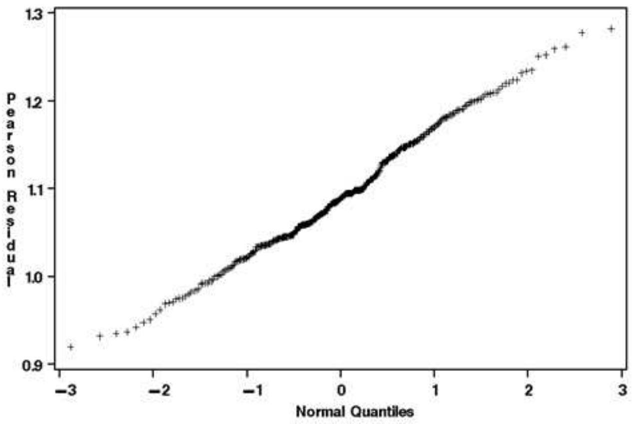

Figure 3.17: Normality distribution of the residuals in the study of apple cultivar impact on distribution of marked-released male moths.

Table 3.13: Significant pair-wise mean differences of traps catches of feral male moths on different varieties. Only the significant differences out of 169 pair-wise comparison were presented in this table.

Effect	variety	-variety	Estimate	SE	DF	χ^2	Pr> χ^2
variety	Bosk	Roterb	0.7409	0.3656	1	4.11	0.0427
variety	Cmeo	Gala	-0.5871	0.2740	1	4.59	0.0321
variety	Cmeo	Idared	-0.5083	0.1701	1	8.93	0.0028
variety	Cmeo	Jonag	-0.3372	0.1185	1	8.10	0.0044
variety	Cmeo	Pinova	-0.5609	0.2751	1	4.16	0.0414
variety	Cmeo	Roterb	0.3313	0.1143	1	8.41	0.0037
variety	Cmeo	Topaz	-0.7843	0.2177	1	12.98	0.0003
variety	Elstar	Golden	0.5906	0.2632	1	5.03	0.0249
variety	Elstar	Roterb	0.8735	0.3641	1	5.76	0.0164
variety	Gala	Golden	0.6356	0.2803	1	5.14	0.0233
variety	Gala	Roterb	0.9185	0.3205	1	8.21	0.0042
variety	Gala	Rubin	0.2360	0.1192	1	3.92	0.0476
variety	Golden	Idared	-0.5567	0.1606	1	2.02	0.0005
variety	Golden	Jonag	-0.3856	0.1279	1	9.09	0.0026
variety	Golden	Pinova	-0.6093	0.2834	1	4.62	0.0315
variety	Golden	Rubin	-0.3995	0.1920	1	4.33	0.0374
variety	Golden	Topaz	-0.8328	0.1288	1	41.78	<0.0001
variety	Golden	Coxo	-0.7477	0.3224	1	5.38	0.0204
variety	Golden	Melro	-0.4227	0.1984	1	4.54	0.0331
variety	Idared	Jonag	0.1711	0.0868	1	3.89	0.0486
variety	Idared	Roterb	0.8396	0.2530	1	11.02	0.0009
variety	Jonag	Roterb	0.6685	0.2012	1	11.05	0.0009
variety	Jonag	Topaz	-0.4471	0.1428	1	9.80	0.0017
variety	Pinova	Roterb	0.8922	0.3209	1	7.73	0.0054
variety	Roterb	Rubin	-0.6824	0.2399	1	8.09	0.0044
variety	Roterb	Topaz	-1.1157	0.2879	1	15.02	0.0001
variety	Roterb	Coxo	-1.0306	0.4012	1	6.60	0.0102
variety	Roterb	Melro	-0.7056	0.2866	1	6.06	0.0138
variety	Rubin	Topaz	-0.4332	0.2058	1	4.43	0.0352
variety	Topaz	Melro	0.4101	0.2074	1	3.91	0.0480

Table 3.14: Genmod type I analysis of variance for marked-released male moths. dist refers to the distance from releasing point and Dev. = Deviance.

Source	Dev.	DF	F	Pr>F	χ^2	Pr> χ^2
Intercept	14.0148					
date	12.7358	8	5.09	<0.0001	40.76	<0.0001
variety	11.8976	12	2.23	0.0111	26.71	0.0085
variety*height	10.1311	20	2.81	<0.0001	56.29	<0.0001
variety*Ttype	9.1548	8	3.89	0.0002	31.11	0.0001
variety*dist	7.8513	19	2.19	0.0036	41.54	0.0020
$Dev./DF = 0.0312$						

Table 3.15: Least square means for traps catches of marked-released male moths on different varieties. Only the significant differences were presented in this table.

Effect	variety	Estimate	SE	DF	χ^2	Pr> χ^2
variety	Bosk	-0.4171	0.0562	1	55.08	<0.0001
variety	Cmeo	-0.4268	0.0498	1	73.44	<0.0001
variety	Elstar	-0.5688	0.0606	1	88.01	<0.0001
variety	Gala	-0.5618	0.0835	1	45.29	<0.0001
variety	Golden	-0.3457	0.0487	1	50.32	<0.0001
variety	Idared	-0.2926	0.0699	1	17.54	<0.0001
variety	Jonag	-0.4457	0.0343	1	168.80	<0.0001
variety	Pinova	-0.4823	0.0738	1	42.72	<0.0001
variety	Roterb	-0.5935	0.1063	1	31.17	<0.0001
variety	Rubin	-0.4746	0.0436	1	118.62	<0.0001
variety	Topaz	-0.5106	0.1102	1	21.48	<0.0001
variety	Coxo	-0.5427	0.0509	1	113.59	<0.0001
variety	Melro	-0.5202	0.0376	1	191.36	<0.0001

Table 3.16: Significant pair-wise mean differences of traps catches of marked-released male moths on different varieties. Only the significant differences out of 169 pair-wise comparison were presented in this table.

Effect	variety	-variety	Estimate	SE	DF	χ^2	Pr> χ^2
variety	Elstar	Golden	-0.2231	0.0778	1	8.22	0.0041
variety	Elstar	Idared	-0.2762	0.0925	1	8.92	0.0028
variety	Gala	Golden	-0.2161	0.0967	1	5.00	0.0254
variety	Gala	Idared	-0.2692	0.1088	1	6.12	0.0134
variety	Golden	Roterb	0.2478	0.1170	1	4.49	0.0341
variety	Golden	Rubin	0.1288	0.0654	1	3.88	0.0487
variety	Golden	Coxo	0.1970	0.0705	1	7.81	0.0052
variety	Golden	Melro	0.1745	0.0616	1	8.03	0.0046
variety	Idared	Jonag	0.1531	0.0778	1	3.87	0.0491
variety	Idared	Roterb	0.3010	0.1272	1	5.60	0.0180
variety	Idared	Rubin	0.1820	0.0823	1	4.89	0.0271
variety	Idared	Coxo	0.2502	0.0864	1	8.37	0.0038
variety	Idared	Melro	0.2276	0.0793	1	8.23	0.0041

Female dispersal: Likewise the previous analyzing, selection of the suitable explanatory variables implicated evaluation of more than 52 different subsets of models. Generalized model SAS version 9.1 was utilized for analyzing of data, with log link and Poisson dist options. Both type (I) and type (III) LR statistics included in the analysis and the normality of the residuals were tested using QQ plot. Among the simple effects the most important explanatory variable for the response variable 'Fr' (marked-released female) was sampling date of female moths with V/df equal to 0.2087, while the Variety and trap height were the second and third influential variables with V/df equal to 0.2158 and 0.2399 respectively. The simple effects of the distance from the releasing point, releasing point (outward inward) and direction of the traps were not significant and then removed from the overall model. In the final overall model the effects of variety, trap height, releasing group were seriously significant as well as the interaction effects of variety-release date and variety-release point (Table 3.17).

Moreover among the nested effects in the subset models, the interactions of date, release point, direction and trap height with the variety were the most influential. Every sequence of the variable selection followed by calculation of probability value (P value) by using the deviance value and degree of freedom to evaluate the significant effect of the included variable. All the non significant effects removed from the model. The final suited explanatory variables extracted and presented in table (3.17). The final V/df was 0.1519 with 106 degree of freedom and the calculated P value for overall model was equal to 1, that indicated the suitability of the fitted model. The effect of the sampling date, variety, height and interaction of variety-date, variety-outin were strongly significant (Table 3.17). Normality of the Pearson residuals tested using the QQ plot.Parameter analyzes accomplished with 106 parameters. As regard to the great table of this analyzes only the parameters with significant effect are listed in the table (3.20).

Table 3.17: Genmod type I analysis of variance for marked-released female moths. Outin refer to dispersal route (inward or outward).

Source	Dev.	DF	F	Pr>F	χ^2	Pr> χ^2
Intercept	44.2058					
variety	35.6010	10	5.96	<0.0001	59.57	<0.0001
height	33.2819	2	8.03	0.0006	16.06	0.0003
Date	18.8015	4	3.09	0.0189	12.37	0.0148
variety*date	20.5877	48	1.83	0.0052	87.88	0.0004
variety*outin	16.0980	5	3.74	0.0037	18.72	0.0022
Dev./DF= 0.1519						

Table 3.18: Least square means for traps catches of marked-released female moths on different varieties. Only the significant differences were presented in this table.

Effect	variety	Estimate	SE	DF	χ^2	Pr> χ^2
variety	Cmeo	-0.3957	0.1198	1	10.91	0.0010
variety	Golden	-0.5223	0.1563	1	11.17	0.0008
variety	Jonag	-0.3174	0.0997	1	10.13	0.0015
variety	Rubin	-0.7608	0.1404	1	29.35	<0.0001
variety	Melro	-0.5137	0.1100	1	21.80	<0.0001

In accord to the unbalanced data of varieties, evaluation of the least square means and pair-wise comparison for all the varieties in the overall model is not possible, there so we studied the varieties least square means and pair-wise comparison in an extra analysis. Among eleven varieties the simple effect of variety Cmeo, Golden Delicious, Jonagold, Rubinette and Melrose was significant. Interaction effects are presented in the table (3.19). All the effects other than these effects were non-significant.

Analasis were continued with the feral female moths interactions. The explanatory variable selection carried out likewise previous sections, meanwhile evaluation of 57 subset models resulted the final model. The most important explanatory variable for the response variable ‘Fn‘ (feral female moth) was the date of sampling with V/df equal to 0.2786, while the Variety was the second influential simple variable with V/df equal to 0.4280. The simple effects of the distance from the releasing point, trap height and direction of the traps were not significant and then removed from the overall model. In the final overall model the effects of variety and date were seriously significant as well as the nested effect of variety-date (Table 3.21).

Table 3.19: Significant pair-wise mean differences of traps catches of marked-released female moths on different varieties. Only the significant differences out of 169 pair-wise comparisons were presented in this table.

Effect	variety	-variety	Estimate	SE	DF	χ^2	Pr> χ^2
variety	Bosk	Rubin	0.6304	0.1974	1	10.19	0.0014
variety	Bosk	Melro	0.3833	0.1771	1	4.68	0.0304
variety	Cmeo	Gala	-0.3957	0.1992	1	3.94	0.0470
variety	Cmeo	Rubin	0.3652	0.1846	1	3.91	0.0479
variety	Cmeo	Coxo	-0.4737	0.1593	1	8.84	0.0029
variety	Elstar	Golden	0.4735	0.2053	1	5.32	0.0211
variety	Elstar	Rubin	0.7120	0.1936	1	13.53	0.0002
variety	Elstar	Melro	0.4649	0.1728	1	7.24	0.0071
variety	Gala	Golden	0.5223	0.2231	1	5.48	0.0192
variety	Gala	Rubin	0.7608	0.2123	1	12.84	0.0003
variety	Gala	Melro	0.5137	0.1935	1	7.05	0.0079
variety	Golden	Roterb	-0.5223	0.2311	1	5.11	0.0238
variety	Golden	Coxo	-0.6003	0.1883	1	10.17	0.0014
variety	Jonag	Rubin	0.4435	0.1723	1	6.63	0.0100
variety	Jonag	Coxo	-0.3954	0.1448	1	7.45	0.0063
variety	Pinova	Rubin	0.6196	0.2304	1	7.23	0.0072
variety	Roterb	Rubin	0.7608	0.2207	1	11.89	0.0006
variety	Roterb	Melro	0.5137	0.2027	1	6.43	0.0112
variety	Rubin	Coxo	-0.8388	0.1754	1	22.88	<0.0001
variety	Coxo	Melro	0.5917	0.1521	1	15.13	0.0001

Every sequence of the variable selection followed by calculation of probability value (P value) by using the deviance value and degree of freedom to evaluate the significant effect of the included variable. All the non significant effects excluded. The final suited explanatory variables extracted and presented in table (3.21). The final V/df was equal to 0.1587 with 98 degree of freedom and the calculated P value for overall model was equal to 1, that indicate the suitability of the fitted model. Parameter estimation analysis revealed that only five parameters than 110 parameters significantly influenced the model (Table 3.22). Normality of the Pearson residuals tested using the QQ plot. For the reason mentioned in previous analysis, least square means of the varieties for non marked female moths calculated and pair-wise comparisons carried out (Table 3.24). As a whole if the test V/df in the " Criteria for assessing Goodness of fit" is not significant then the fit is adequate. Although the minor quantity of the V/df may not guarantee better fitting of a model, firstly it is used to evaluates the included variable effect in the model and secondly calculated P value based on the deviance and degree of freedom indicates the adequacy of fitting as well. In other word V/df is not a model selection criteria solely but has an essential function in variable selection and model formation process.

Table 3.20: Simple and nested parameters estimation in traps catches of marked-released female moths on different varieties. Only the significant effects were presented in this table. Bosk = Boskoop, Coxo = Cox Orange, Golden = Golden Delicious, Rubin = Rubinette, Outin = outward or inward options, inw = inward dispersal, 95 perc. CL. = 95 % confidence limit.

parameter			DF	Estimate	SE	95 perc.	CL.	χ^2	Pr> χ^2
Intercept			1	-1.7216	0.5899	-2.8777	-0.5654	8.52	0.0035
variety	Bosk		1	1.6516	0.6353	0.4065	2.8968	6.76	0.0093
variety	Elstar		1	1.5205	0.6452	0.2559	2.7852	5.55	0.0184
variety	Gala		1	1.7216	0.6482	0.4511	2.9920	7.05	0.0079
variety	Jonag		1	0.9206	0.3079	0.3171	1.5241	8.94	0.0028
variety	Pinova		1	2.0823	0.6637	0.7814	3.3831	9.84	0.0017
variety	Rubin		1	-2.3939	1.1252	-4.5993	-0.1885	4.53	0.0334
variety	Coxo		1	1.7432	0.6265	0.5153	2.9710	7.74	0.0054
hight	1.6		1	-0.3607	0.1107	-0.5776	-0.1438	10.62	0.0011
variety*date	Cmeo	26.juni	1	1.3198	0.6384	0.0685	2.5710	4.27	0.0387
variety*date	Golden	14.aug	1	1.4989	0.6699	0.1860	2.8118	5.01	0.0252
variety*date	Rubin	14.aug	1	3.8073	1.2613	1.3352	6.2795	9.11	0.0025
variety*date	Rubin	2.juni	1	1.8482	0.6908	0.4944	3.2021	7.16	0.0075
variety*date	Rubin	24.juni	1	2.6758	1.3489	0.0320	5.3196	3.93	0.0473
variety*date	Rubin	6.juli	1	3.7249	1.2650	1.2455	6.2043	8.67	0.0032
variety*date	Melrose	14.aug	1	1.4755	0.6386	0.2239	2.7271	5.34	0.0209
variety*date	Melrose	24.juni	1	1.3865	0.6425	0.1272	2.6458	4.66	0.0309
variety*date	Melrose	6.juli	1	1.3466	0.6444	0.0836	2.6096	4.37	0.0366
variety*outin	Rubin	inw	1	2.4314	1.0381	0.3968	4.4660	5.49	0.0192

Table 3.21: Genmod type I analysis of variance for feral female moths on different varieties.

Source	Dev.	DF	F	Pr>F	χ^2	Pr> χ^2
Intercept	103.6107					
date	46.5249	8	44.26	<0.0001	354.07	<0.0001
variety	35.7304	10	6.70	<0.0001	66.95	<.0001
variety*date	22.1563	40	2.10	0.0016	84.19	<.0001
Dev./DF= 0.1587						

Table 3.22: Simple and nested parameters estimation in traps catches of feral female moths on different varieties. Only the significant effects were presented in this table. Roterb = Roter Berlepsch, Bosk = Boskoop, Coxo = Cox Orange, Golden = Golden Delicious, Rubin = Rubinette and Outin = outward or inward options, 95 perc.CL = 95 % confidence limit.

parameter			DF	Estimate	SE	95 perc.	CL	χ^2	Pr> χ^2
Intercept			1	-1.1637	0.3781	-1.9049	-0.4226	9.47	0.0021
date	18.aug		1	1.2647	0.4469	0.3888	2.1407	8.01	0.0047
variety	Roterb		1	1.1637	0.5516	0.0827	2.2448	4.45	0.0349
variety*date	Pinova	18.aug	1	0.9163	0.3965	0.1392	1.6934	5.34	0.0208
variety*date	Rubin	6.juli	1	1.5955	0.8040	0.0196	3.1713	3.94	0.0472
dist*variety	45	Bosk	1	-0.8354	0.2544	-1.3340	-0.3369	10.79	0.0010

Table 3.23: Least square means for traps catches of feral female moths on different varieties. Only the significant differences were presented in this table.

Effect	variety	Estimate	SE	DF	χ^2	Pr> χ^2
variety	Bosk	0.5108	0.1658	1	9.49	0.0021
variety	Cmeo	-0.4545	0.2031	1	5.01	0.0253
variety	Golden	-1.0634	0.3373	1	9.94	0.0016
variety	Jonag	-0.5364	0.1833	1	8.57	0.0034
variety	Pinova	0.7415	0.1935	1	14.69	0.0001
variety	Melro	-0.6160	0.1907	1	10.43	0.0012

Table 3.24: Significant pair-wise mean differences of traps catches of feral female moths on different varieties. Only the significant differences out of 169 pair-wise comparisons were presented in this table.

Effect	variety	-variety	Estimate	SE	DF	χ^2	Pr> χ^2
variety	Bosk	Cmeo	0.9653	0.2622	1	13.55	0.0002
variety	Bosk	Elstar	0.5969	0.2783	1	4.60	0.0320
variety	Bosk	Golden	1.5742	0.3759	1	17.54	<0.0001
variety	Bosk	Jonag	1.0472	0.2472	1	17.95	<0.0001
variety	Bosk	Melro	1.1268	0.2527	1	19.88	<0.0001
variety	Cmeo	Pinova	-1.1960	0.2805	1	18.18	<0.0001
variety	Cmeo	Rubin	-0.5834	0.2515	1	5.38	0.0204
variety	Cmeo	Coxo	-0.6006	0.2631	1	5.21	0.0224
variety	Elstar	Golden	0.9773	0.4047	1	5.83	0.0157
variety	Elstar	Pinova	-0.8276	0.2956	1	7.84	0.0051
variety	Gala	Golden	0.9881	0.4335	1	5.20	0.0226
variety	Gala	Pinova	-0.8168	0.3340	1	5.98	0.0145
variety	Golden	Pinova	-1.8049	0.3889	1	21.54	<0.0001
variety	Golden	Roterb	-0.9631	0.4480	1	4.62	0.0316
variety	Golden	Rubin	-1.1923	0.3685	1	10.47	0.0012
variety	Golden	Coxo	-1.2095	0.3765	1	10.32	0.0013
variety	Jonag	Pinova	-1.2779	0.2665	1	22.99	<0.0001
variety	Jonag	Rubin	-0.6653	0.2357	1	7.96	0.0048
variety	Jonag	Coxo	-0.6825	0.2481	1	7.57	0.0059
variety	Pinova	Roterb	0.8418	0.3526	1	5.70	0.0170
variety	Pinova	Rubin	0.6127	0.2437	1	6.32	0.0120
variety	Pinova	Coxo	0.5954	0.2557	1	5.42	0.0199
variety	Pinova	Melro	1.3575	0.2717	1	24.97	<0.0001
variety	Rubin	Melro	0.7449	0.2416	1	9.51	0.0020
variety	Coxo	Melro	0.7621	0.2536	1	9.03	0.0027

3.6 Influence of climatic factors on dispersal of Codling moth

3.6.1 Climatic factors and dispersal of marked moth

Marked female: Based on the climatologic data of Hohenheim station and calculation of Day Degree (based on equation 2.1), cumulative Day Degree, and twilight data, analysis accomplished. The first regression analysis using AIC for all possible subsets resulted the best fitted model as:

$$FrNr = 0.065(h) + 0.034(D) - 0.851(WSLN) + 0.453(WSHN) \tag{3.8}$$

Where the R^2 was 0.24 and the RMSE was equal to 0.457. FrNr = number of marked female moths h = height, D = day after release, WSLN = wind speed at 2.5 m during twilight, WSHN = wind speed at 10 m during twilight.

Since there was relatively little difference in R^2 and AIC for the selected best subset models we could use other criteria to help in the selection of the best model. Based on using the Cp and SBC criteria the best selected model presented as the second equation with the R square and RMSE equal to the first equation. To select of the model based on criteria Cp and SBC the smallest is the best.

$$\begin{aligned} FrNr &= 0.049(h) + 0.036(D) - 0.572(WSLN) \\ &\quad + 0.315(WSHN) - 2.967(PerciN) \end{aligned} \tag{3.9}$$

Where FrNr = number of marked female moths h = height, D = day after release, WSLN= wind speed at 2.5 m during twilight, WSHN = wind speed at 10 m during twilight and PreciN= precipitation of twilight.

SAS confirmed the minimum AIC for all possible subsets of variables while the smallest AIC was -1082.18 with the response variables included height, days after release, twilight wind speed and precipitation in the model.

3.6.2 Heuristic methods for comparison of AIC results

Following tables (3.25 and 3.26) hold out results of regression analysis using Forward, Backward and Stepwise selection for female moths. Forward, Backward and Stepwise selection was originated in model that included Day, WSLN and WSHN as predictor variables, and attributed as the best subset model meanwhile was not analogous with the out put of earlier mentioned AIC. Estimation of models using RMSE (root mean square error) resulted sorted models with and without intercept. Among the subset models the best one with the minimized RMSE and high R^2 was represented. The model which included predictor variables dist, Day, Tmean, RH, WSLN, WSHN, DD and PreiN was posited as the best subset model which was not in congruity with the AIC results. Regard to the aforementioned methods, all four heuristic methods include variables Day, WSLN and WSHN, which approved the using of AIC selection method. While a heuristic method is an approximate method that does not guarantee convergence to the optimal model.

Table 3.25: Regression analysis of meteorological data for female moths using Forward, Backward and Stepwise selection.

Source	Df	SS	MS	F	P
Model	3	33.168	11.056	65.98	<0.0001
Error	605	101.381	0.167		
Uncorrected total	608	134.549			
R^2= 0.25, RMSE = 0.409					

Table 3.26: Regression analysis and parameter estimation of meteorological data for female moths using Forward, Backward and Stepwise selection.

Variable	DF	Estimate	SE	t-Value	P	TypeIISS
Day	1	0.02981	0.00656	4.55	<0.0001	3.46339
WSLN	1	-0.39472	0.23163	-1.70	0.0889	0.48661
WSHN	1	0.24992	0.12389	2.02	0.0441	0.68191

Using information criteria for multivariate model selection has been shown to be superior to heuristic methods such as Forwards election, Backward elimination, Stepwise regression and minimizing RMSE using simulated data with a known underlying model.Using the Variable Inflation Factor (VIF) option in the final model revealed that there was a high correlation between variables WSHN and WSLN. As the VIF was higher than 10, and the WSHN was better predictor variable than WSLN, the last one was deleted from the final model and the final fitted model represented as:

$$FrNr = 0.049(h) + 0.036(D) + 0.315(WSLN) - 2.967(PreciN) \tag{3.10}$$

Where h = height of the trap, D = days after release, WSLN = twilight wind speed at 2.5 m height, PreciN = twilight precipitation (l/m^2).

Table 3.27: Mean, standard deviation and maximum wind speed and precipitation for overall study period and twilight. WS2.5 = wind speed at 2.5 m height, WS10 = wind speed at 10 m height, preci = precipitation (l/m^2).

Period	Variable	N	Mean (Sd)	Maximum
Overall	WS2.5	8784	1.212(0.857)	6.300
	WS10	8784	2.124(1.494)	11.000
	Preci	4392	0.103(0.720)	25.500
Twilight	WS2.5	2196	0.821(0.657)	3.800
(2100-0200h)	WS10	2196	1.605(1.605)	7.100
	Preci	1098	0.085(0.530)	11.100

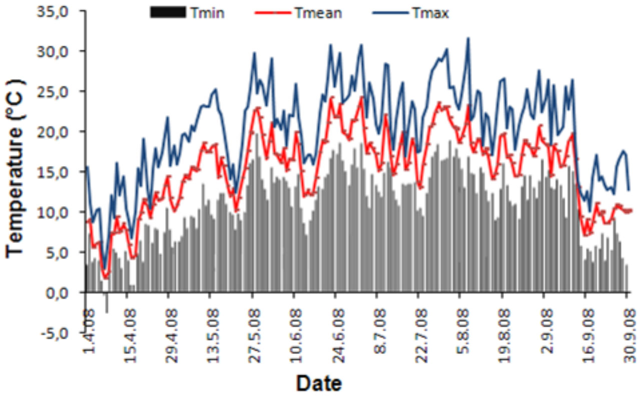

Figure 3.18: Maximum, minimum and mean temperature during the season in Hohenheim station.

Marked male: Table 3.28 indicates the overall model for marked male moths based on Stepwise election. Based on the AIC model selection method and in regard to the overall aspects and expectations, following model was selected amongst 222 models.

$$\begin{aligned} Ln(MrNr) &= 0.130h + 0.049D + 0.003RH + 0.295W1 + 0.315W2 \\ &\quad - 0.123WS - 0.007PN + 0.012P \end{aligned} \tag{3.11}$$

Where MrNr = marked-released recaptured male moths number, h = height of the trap, D = days after release, RH = relative humidity, W1 = twilight wind speed at 2.5 m height, W2 = twilight wind speed at 10 m height, Ws = wind speed at 10 m height, P = precipitation (l/m^2), and PN = twilight precipitation (l/m^2).

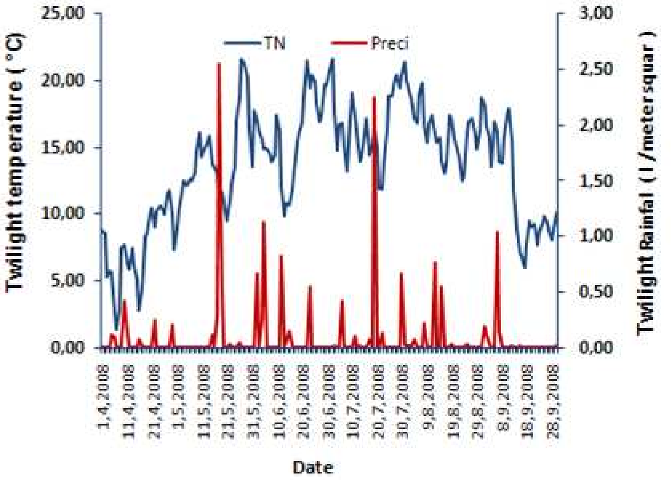

Figure 3.19: Twilight temperature and rainfall during the season in Hohenheim station.

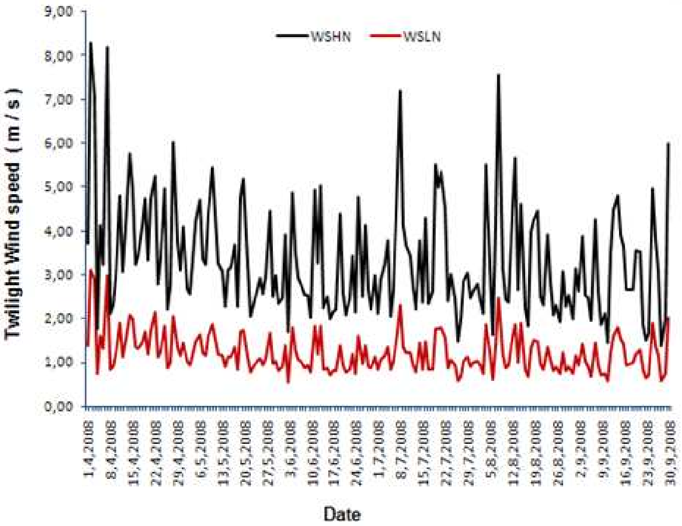

Figure 3.20: Twilight wind speed at 2.5 m (WSLN) and 10 m (WSHN) during the season in Hohenheim station.

Evaluation of the selected model for multicolinearity, revealed that the VIF was further than 10, there so for deleting one or some regressors of the model, correlation between the regressors, t-Value and regressors influence on the VIF value were used as index for stay or removing the variables. The finale model with VIF <10 represented as equations (3.12).

$$Ln(MrNr) = 0.130h + 0.049D - 0.007di + 0.295W1 - 0.007PN \tag{3.12}$$

Where MrNr = marked-released recaptured male moths number, h = height of the trap, D = days after release, di = distance from release point (m), W1 = twilight wind speed at 2.5 m height, and PN = twilight precipitation (l/m^2).

Table 3.28: Stepwise regression analysis of variance for marked-released male moths.

Source	DF	N	SS	MS	F	P
Model	7	307.77063	43.96723	101.81	<0.0001	
Error	761	328.62794	0.43184			
Uncorrected Total	768	636.39857				
$R^2 = 0.48$						

Table 3.29: Parameter estimation using the Stepwise regression for marked-released male moths. Rh = relative humidity, WS10 = wind speed at height 10 m, WS25 = wind speed at height 2.5 m, WSLN = twilight wind speed at 2.5 m, PreciN = twilight precipitation (l/m^2).

Variable	DF	Estimate	SE	t Value	Pr>t	Type II SS
distance	1	-0.00679	0.00142	-4.78	<0.0001	9.85715
height	1	0.14258	0.05573	2.56	0.0107	2.82638
RH	1	0.00504	0.00175	2.88	0.0041	3.57082
WS10	1	-0.60183	0.12428	-4.84	<0.0001	10.12590
Ws25	1	0.98274	0.23798	4.13	<0.0001	7.36383
WSLN	1	0.28903	0.07712	3.75	0.0002	6.06514
preciN	1	-0.65000	0.28792	-2.26	0.0243	2.20088

Regressors included to the final model accounted for 50 % of the variations (R square= 0.50). Testing for the normality using the univariate procedure indicated that the residuals have the normal distribution (Fig.3.21).

Table 3.30: Forward selection regression analysis of variance for marked-released male moths.

Source	DF	SS	MS	F	P
Model	9	36.67742	4.07527	9.44	<0.0001
Error	758	327.13402	0.43158		
Uncorrected Total	767	363.81145			
		$R^2 = 0.10$			

Table 3.31: Parameter estimation using the Forward selection regression for marked-released male moths. RH = relative humidity, WS10 = wind speed at height 10 m, WS25 = wind speed at height 2.5 m, WSLN = twilight wind speed at 2.5 m, Preci = precipitation (l/m^2), Sun = Sunshine-Duration (h), PreciN = twilight precipitation (l/m^2).

Variable	DF	Estimate	SE	t Value	Pr>t	Type II SS
Intercept	1	0.31303	0.50221	0.62	0.5333	0.16767
distance	1	-0.00692	0.00147	-4.70	<0.0001	9.54315
height	1	0.13614	0.05910	2.30	0.0215	2.28983
RH	1	0.00129	0.00585	0.22	0.8260	0.02086
Preci	1	0.00840	0.00459	1.83	0.0678	1.44319
sun	1	-0.00492	0.01130	-0.44	0.6632	0.08191
WS10	1	-0.56442	0.15275	-3.70	0.0002	5.89257
Ws25	1	0.82854	0.29364	2.82	0.0049	3.43596
WSLN	1	0.34583	0.09361	3.69	0.0002	5.89012
preciN	1	-0.53345	0.29616	-1.80	0.0721	1.40016

3.6.3 Climatic factors and dispersal of feral moth

Feral male moths: With the same method of the marked male and female moth's model, we fitted a model for feral male moths using the AIC, Cp and SBC criteria selection method. The equations 3.13 and 3.14 represent the fitted models with and without intercepts respectively. R^2 was 0.11 for the first one and 0.56 for the last one.

$$Ln(Mnat) = 0.259h + 0.110TN + 0.119W1 - 1.162 \tag{3.13}$$

$$Ln(Mnat) = 0.219h - 0.010RH + 0.001CD + 0.085TN + 0.112W1 \tag{3.14}$$

Where Mnat = feral male moth number, h = height, RH = relative humidity, CD = cumulative Day Degrees, TN = twilight temperature, W1 = twilight wind speed at 2.5 m height.

Table 3.32: Backward selection regression analysis of variance for marked-released male moths.

Source	DF	SS	MS	F	P
Model	7	307.77063	43.96723	101.81	<0.0001
Error	761	328.62794	0.43184		
Uncorrected Total	768	636.39857			
$R^2 = 0.48$					

Table 3.33: Parameter estimation using the Backward selection regression for marked-released male moths. Rh = relative humidity, WS10 = wind speed at height 10 m, WS25 = wind speed at height 2.5 m, WSLN = twilight wind speed at 2.5 m, Preci = precipitation (l/m^2), Sun = Sunshine-Duration (h), PreciN = twilight precipitation (l/m^2).

Variable	DF	Estimate	SE	t Value	Pr>t	Type II SS
distance	1	-0.007	0.001	-4.78	<0.0001	9.857
height	1	0.142	0.056	2.56	0.0107	2.826
RH	1	0.005	0.002	2.88	0.0041	3.571
WS10	1	-0.602	0.124	-4.84	<0.0001	10.126
WS25	1	0.983	0.238	4.13	<0.0001	7.364
WSLN	1	0.289	0.077	3.75	0.0002	6.065
preciN	1	-0.650	0.288	-2.26	0.0243	2.201

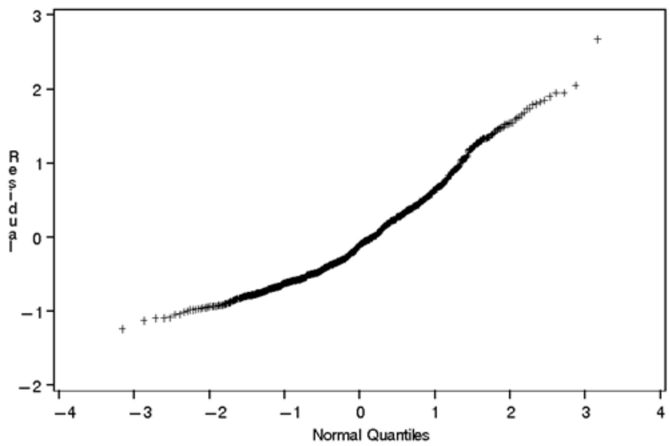

Figure 3.21: Normal distribution of residual distribution of marked male moth in analysis of climate factors influence on dispersal. Data were modified as log data.

Selected model was evaluated for multicolinearity, and revealed that the VIF was not further than 10, there so the model fixed and fitted without further modification. Normality of the rsiduals was inspected using Proc. Univariate and the normal quantaile and residuals plotting showed normal distribution of the residuals.

Table 3.34: Forward selection regression analysis of variance for selecting model of feral male moths.

Source	DF	SS	MS	F	P
Model	5	3465.49747	693.09949	605.11	<0.0001
Error	2408	2758.13984	1.14541		
Uncorrected Total	2413	6223.63730			
$R^2 = 0.56$					

Table 3.35: Parameter estimation using the Forwards election regression for feral male moths. (RH = relative humidity, WSHN = twilight wind speed at 10 m).

Variable	DF	Estimate	SE	t Value	Pr>t	Type II SS
hight	1	0.233	0.052	4.51	<0.0001	23.267
RH	1	-0.010	0.001	-6.85	<0.0001	53.719
DD	1	-0.016	0.010	-1.64	0.1007	3.088
TN	1	0.097	0.007	14.52	<0.0001	241.434
WSHN	1	0.107	0.031	3.44	0.0006	13.538

Table 3.36: Backward selection regression analysis of variance for selecting model of feral male moths.

Source	DF	SS	MS	F	P
Model	4	3462.409	865.602	755.18	<0.0001
Error	2409	2761.228	1.146		
Uncorrected Total	2413	6223.637			
$R^2 = 0.56$					

Feral female moths: The best fitted models amongst 126 models were selected and presented as with and without intercepts in equations (3.15 and 3.16) respectively.

Table 3.37: Parameter estimation using the Backward selection regression for feral male moths. (Rh = relative humidity, WSHN = twilight wind speed at 10 m).

Variable	DF	Estimate	SE	t Value	Pr>t	Type II SS
height	1	0.216	0.051	4.26	<0.0001	20.846
RH	1	-0.010	0.001	-6.79	<0.0001	52.813
TN	1	0.091	0.005	16.85	<0.0001	325.607
WSHN	1	0.101	0.031	3.26	0.0011	12.177

$$Ln(Fnat) = 0.403 + 0.045h - 0.005RH + 0.03TN + 0.02DD - 0.026WSHN \tag{3.15}$$

$$Ln(Fnat) = 0.051h - 0.002RH + 0.032TN + 0.01DD - 0.023WSHN \tag{3.16}$$

Where Fnat = number of feral female moths, h = height, RH = relative humidity, TN = twilight temperature, DD = Day Degree and WSHN = twilight wind speed at 10 m height.

AIC was -2473.28 for the first model and -2472.64 for the lat one. These regressors accounted for 27 % of the the variations. Final models variance inflammation test revealed the VIF value lower than 10, thus the stability of the regressors verified. Furthermore, the normality of the residuals inspection pointed out the normal distribution of the residuals.

It should be mentioned that the using only AIC as a model selection criteria is probably confusing. To avoid any possible problem we used other model diagnostics like RMSE, Cp and SBC as well as the biological notifications in selecting final model variables. Therfore, our selections are not limited to the degree of R-Square. It is only one of the variable selection criteria. Additionally the results of other heuristic methods were controlled and compared withe AIC method. Finally, in contrast withe F test method of model comparison, AIC method is used for selection of the nested and non-nested models, meanwhile never reject any subset model. The last characteristic of the AIC and other similar methods enables the biologist to decide openly and without limitations.

Table 3.38: Stepwise selection regression analysis of variance for selecting model of feral male moths.

Source	DF	SS	MS	F	P
Model	4	3462.409	865.602	755.18	<0.0001
Error	2409	2761.228	1.146		
Uncorrected Total	2413	6223.637			
$R^2 = 0.56$					

Table 3.39: Parameter estimation using the Stepwise selection regression for feral male moths. (RH = relative humidity, WSLN = twilight wind speed at 2.5 m).

Variable	DF	Estimate	SE	t Value	Pr>t	Type II SS
hight	1	0.216	0.051	4.26	<0.0001	20.846
RH	1	-0.010	0.001	-6.79	<0.0001	52.813
TN	1	0.091	0.005	16.85	<0.0001	325.607
WSLN	1	0.101	0.031	3.26	0.0011	12.177

3.7 Study of Codling moth dispersal using mark-recapture and diffusion models

We fitted the non-linear regression using the iterative process and Lvenberg-Marquardt method specification. This method is appropriate in fitting the models that parameters are highly correlated. Estimating the parameters accuracy were tested according to the default asymptotic 95 % confidence intervals calculation in non-linear regression. To perform a two-side hypothesis test about the parameters, at the 5 % probability level, it should be checked if the hypothesized value is inside or outside of confidence bounds. If it is inside the intervals, null hypothesis (estimated parameter value is inside the intervals) fail to reject, otherwise it is rejected.

3.7.1 Indirect method of diffusion coefficient calculation

Base on the equations (2.2), (2.5), (2.6), (2.7) and (2.8) numerical values of A, B, D, K and finally the total population left in the sampling area calculated for male and female separately and presented in the tables (3.40, 3.41, 3.42 and 3.43). All the calculations carried out as daily and for overall. Users of the linear regression models are accustomed to expressing the quality of fit a model in terms of the coefficient of determination, also known asR^2. In non linear regression such a measure unfortunately, not readily defined. One of the problems with the R^2 definition is that it requires the presence of an intercept, which most nonlinear models do not have. A measure, relatively closely corresponding to R^2 in the nonlinear case is pseudo R^2 = 1- SS (residual) / SS (total corrected). We used the same pseudo R^2 in our analysis.

Table 3.40: Diffusion coefficient calculation using indirect method or least square method for male moths by including dispersal distance in the model.

Time	A	B	D	Y0	R^2	K	Y
1	0.8162	0.00418	59.8086	478	0.92	3.06187	22.37
2	0.7870	0.00119	105.0420	478	0.97	1.23506	40.43
3	0.7449	0.00022	378.7879	478	0.85	0.56035	88.99
4	0.7435	0.00235	26.5957	478	0.83	0.71680	27.18
5	0.7064	0.00134	37.3134	478	0.81	0.52751	34.20
6	0.7065	0.00240	17.3611	478	0.81	0.48813	25.55
7	0.7053	0.00356	10.0321	478	0.87	0.44680	20.95
8	0.7201	0.00495	6.3131	478	0.80	0.40896	18.14
9	0.7145	0.00529	5.2510	478	0.79	0.36808	17.41
9(Overall)	0.7376	0.00125	22.2222	478	0.83	0.28439	36.97

According to the mentioned data and equation (2.5) overall dispersal of male and female moths using the diffusion model resulted as:

$$MrNr = 0.00125\ e^{-22.2222(Dist)^2} \tag{3.17}$$

$$FrNr = 0.3861\ e^{-0.00754(Dist)^2} \tag{3.18}$$

Where MrNr and FrNr are the number of the Mark-release-recaptured male and female moths respectively, Dist is the distance from the release point.

3.7.2 Evaluation the influence of the flight distance and height on dispersal parameters

Including of the flight height effect in diffusion model, and utilizing the equation (2.9) resulted the following models:

$$MrNr = 0.7768\ e^{-0.0019(Dist)^2 - 14.6198*h} \tag{3.19}$$

$$FrNr = 0.9840\ e^{-0.00779(Dist)^2 - 0.059*h} \tag{3.20}$$

Where MrNr, FrNr and Dist are the same as previous mentioned and h is the height of traps.

Table 3.41: Diffusion coefficient calculation using indirect method or least square method for female moths by including dispersal distance in the model.

Time	A	B	D	Y0	R^2	K	Y
1	0.951	0.00215	116.2791	348	0.96	2.25919	36.34
2	0.8425	0.00191	65.4450	348	0.93	1.16057	34.16
3	0.8373	0.00057	147.4926	348	0.92	0.57277	62.42
4	0.3983	0.00080	78.3208	348	0.91	0.65848	24.98
5	0.8272	0.00410	12.1951	348	0.91	0.54428	22.89
6	0.8597	0.00813	5.1251	348	0.89	0.50419	16.90
7	0.8741	0.01550	2.3041	348	0.89	0.47588	12.44
8	0.9425	0.01920	1.6276	348	0.88	0.42036	12.05
9	0.974	0.02350	1.1820	348	0.88	0.38123	11.26
9(Overall)	0.3861	0.00754	3.6841	348	0.91	0.42089	7.88

Table 3.42: Diffusion coefficient calculation using indirect method or least square method for male moths by including dispersal distance and height of flight in the model.

Time	A	B	C	D	Y0	R^2	K	Y
1	0.8645	0.00346	0.0443	72.2543	478	0.92	2.90986	26.04
2	0.8756	0.00123	-0.0015	101.6260	478	0.88	1.18998	44.24
3	0.7624	0.00058	0.0118	143.6781	478	0.85	0.71418	56.09
4	0.7280	0.00209	-0.0106	29.9043	478	0.83	0.70741	28.21
5	0.7188	0.00157	0.0087	31.8471	478	0.81	0.53986	32.14
6	0.7840	0.00374	0.0522	11.1408	478	0.81	0.50775	22.71
7	0.7814	0.00489	0.0514	7.3035	478	0.80	0.45484	19.80
8	0.7932	0.00609	0.0493	5.1313	478	0.80	0.40982	18.01
9	0.7939	0.00649	0.0541	4.2800	478	0.79	0.36772	17.46
9(Overall)	0.7768	0.00190	14.6198	14.6198	478	0.83	0.3019	31.57

3.7.3 Calculation of Diffusion coefficient using direct method

Equations (2.10, 2.11, 2.12, 2.13 and 2.14) were used to calculate the table (3.44) items. Using the last method, forecasting of the population spread between the adjacent cultivations and local migration of the population is conceivable as well as the substantiation and estimation of new infestations and invasions.

Table 3.43: Diffusion coefficient calculation using indirect method or least square method for female moths by including dispersal distance and height of flight in the model.

Time	A	B	C	D	Y0	R^2	K	Y
1	0.9855	0.00230	0.0203	108.6956	348	0.96	2.25727	36.41
2	0.9275	0.00161	0.0554	77.6397	348	0.93	1.06979	40.96
3	0.9529	0.00085	0.0746	97.5800	348	0.92	0.59851	57.78
4	0.9308	0.00109	0.0686	57.3394	348	0.91	0.48525	49.95
5	0.9718	0.00441	0.0711	11.3378	348	0.90	0.51935	25.93
6	1.0190	0.00845	0.0896	4.9309	348	0.89	0.47907	19.64
7	1.0296	0.01580	0.0612	2.2603	348	0.88	0.45386	14.51
8	0.9918	0.01930	0.0298	1.6191	348	0.87	0.41431	12.65
9	1.0725	0.02350	0.0571	1.1820	348	0.87	0.37052	12.39
9(Overall)	0.9840	0.00779	0.0590	3.5658	348	0.90	0.31875	19.75

3.7.4 Comparison of fitted Models

Comparison of the asymptotic correlation matrix revealed that the asymptotic parameter correlation between parameters A and B has decreased severely when the model included the flight height. There for the estimated parameters in the model with flight height are more reliable and indicates the model expressed adequately for both male and female moths. In the overall model of male moths the correlation matrix of the A and B decreased from 0.96 % in the two factors model to 0.73 % in the three factor model and at the same case of the female moths the reduction was from 0.96 % to 0.67 % (table 3.45). There was no reasonable differences in asymptotic correlations of male and female moths at case of two factors overall models, while differences between three factors models was obvious, which emphasis again on the reliability of the last group models.

3.7.5 Diffusion coefficient for models

Models included flight distance: Determined values of D for mentioned models were not the same. Values of D was fluctuating between 378.7879 and 5.2510 during the nine sampling days in two factors model. While the highest value calculated for the 3^{rd} day and the lowest for the 9^{th} day. Moreover for the overall model it took the value equal to 22.2222 (Fig. 3.22 and Table 3.40).

In the same case of the female moths, meanwhile it was lower than that of the male moths, varying among 147.4926 and 1.1820 as well as 3.6841 for the overall model.The last one was seven times smaller than that of the males (Fig.3.22 and Table 3.41). Pay attention to the R^2 of mentioned models showed that although R^2 for both models is relatively high, female model possess superior R^2.

Models included flight distance and height: In accord with Fig.3.23, Fig.3.24 and Table 3.42, diffusion coefficient of male moths was waving between 143.6781 and 4.2800 during the sampling period (nine days), whilst the overall model D was equal to 14.6198. Correspondingly, for

Table 3.44: Diffusion coefficient calculation using direct method for male and female moths. Where D_{ist} = dispersal distance from the central point (m), R_a = Median distance of dispersal (m/d), R_{98} = radius encompass 98 % of dispersing moths (m/d), D_{anm} = annualized diffusion coefficient for male, S_m = male longevity (day), C_m = male population rate of spread (m/year), D_{anf} = annualized diffusion coefficient for female, S_f = female longevity (day) and C_f = Female population rate of spread (m/year).

T(Day)	D_{ist}	D	R_a	R_{98}	D_{anm}	S_m	C_m	D_{anf}	S_f	C_f
9	15	6.25	15	30	94.56	15.13	6.70	114.13	18.26	7.36
9	30	25.00	30	60	378.25	15.13	13.39	456.50	18.26	14.72
9	45	56.25	45	90	851.06	15.13	20.09	1027.13	18.26	22.07
9	60	100.00	60	120	1513.00	15.13	26.79	1826.00	18.26	29.43
9*	36.03	452.91	127.69	255.38	6852.59	15.13	57.01	8270.21	18.26	62.63

*overall model constructed with calculation of mean displacement of the moths using GLM.

female moths, the maximum and minimum values of D was equal to 108.6956 and 1.1820 respectively. Meanwhile it was 3.5658 in the overall model. The same condition of R^2 for previous models were stabilized for these models as well.

Models of for male and female moths: Pointing out of similarities and differences of male and female moths diffusion coefficient indicated that first of all, nearly in all models the main fluctuations in diffusion coefficient was related to the days one to five, while moths had uniform distribution during days sex to nine (see Fig. 3.22 and 3.23). Furthermore differences between male moth models was overall more robust than female moth models (Fig.3.24). Dispersal of the male and female moths was totaly opposite at the first two days. While diffusion coefficient of male moths possessed escalation trend as well as with lower starting point, female moths diffusion coefficient was declined at first two days, in addition started superior than the male moths. Maximum diffusion coefficient for both sexes was on third day and then continued whit a sharp declining for male and a little slightly for female on fourth day, whereas a slight decrease tendency take place up to the end of the experiment period for both. meanwhile numerical rate of male diffusion coefficient was higher than female at the rest over period of the dispersal next to fifth day.

Tight-fitting of female moth models when included only the flight distance in comparison when included flight distance and height, encouraged us to attempt more investigation on the variables influence on the moths population using the GLM procedure. The model with the smallest AIC deemed to be the best fitted model and resulted the following equation.

$$(FrNr) = 1.054 + 0.014T - 0.055D - 0.041h - 0.021d \tag{3.21}$$

Where FrNr is the number of female moths, T is the trap, D is distance from the releasing point, h is flight height and d is the day since release.

Table 3.45: Comparison of the asymptotic correlation matrix for male and female moths.

Approximate correlation matrix for models with two factors

		Female		Male	
Day		A	B	A	B
1	A	1.0000000	0.9632630	1.0000000	0.9596431
	B	0.9632630	1.0000000	0.9596431	1.0000000
2	A	1.0000000	0.9628594	1.0000000	0.9605277
	B	0.9628594	1.0000000	0.9605277	1.0000000
3	A	1.0000000	0.9628594	1.0000000	0.9600083
	B	0.9628594	1.0000000	0.9600083	1.0000000
4	A	1.0000000	0.9618288	1.0000000	0.9599359
	B	0.9618288	1.0000000	0.9599359	1.0000000
5	A	1.0000000	0.9620486	1.0000000	0.9592233
	B	0.9620486	1.0000000	0.9592233	1.0000000
6	A	1.0000000	0.9618177	1.0000000	0.9583712
	B	0.9618177	1.0000000	0.9583712	1.0000000
7	A	1.0000000	0.9615653	1.0000000	0.9568727
	B	0.9615653	1.0000000	0.9568727	1.0000000
8	A	1.0000000	0.9609697	1.0000000	0.9561544
	B	0.9609697	1.0000000	0.9561544	1.0000000
9	A	1.0000000	0.9608965	1.0000000	0.9553614
	B	0.9608965	1.0000000	0.9553614	1.0000000
Overall	A	1.0000000	0.9620342	1.0000000	0.9584954
	B	0.9620342	1.0000000	0.9584954	1.0000000

Using AIC to choose the best model and variable subset, indicated that there was negative correlation between the trap capture and the flight height for female moths, moreover the height was one of the best fitted model variables in the AIC analysis. R^2 for this analysis was 0.12 and 0.89 with and without intercept respectively. Results of utilizing the GLM procedure SAS software were subtracted in the tables (3.46 and 3.47).

Aforementioned results demonstrated that, days since release, flight height, distance and direction significantly influence the dispersal of the male and female moths ($P<0.0001$). However heights 1.6 m was significantly different than the other two heights while influence of heights 1.2 m and 2.2 m were not significantly different than each other. It could be concluded that probably 1.6 m height is the best height for our study condition. Furthermore the interactions of the height levels were not identical for male and female moths (See table 3.47).

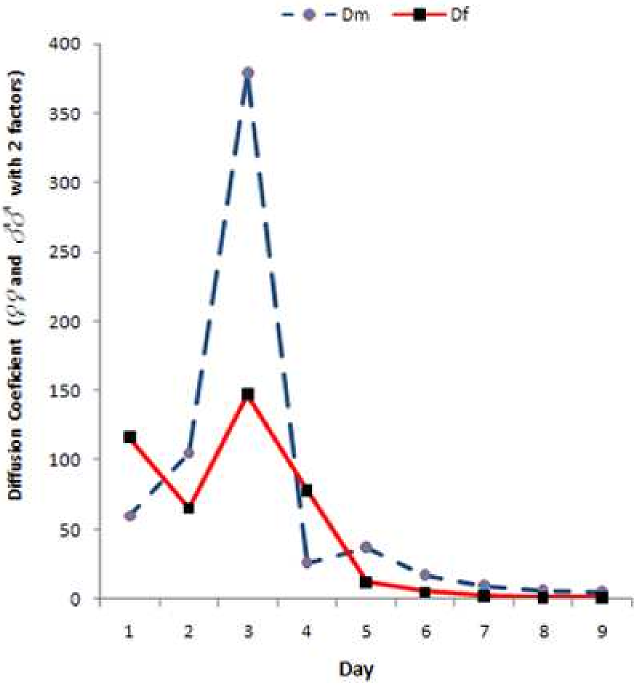

Figure 3.22: Diffusion coefficient of male and female moths using the model which included dispersal distance, Dm and Df refer to Diffusion coefficient of male and female respectively.

3.7.6 Direct and indirect fitted models attributes

Generally, diffusion coefficient of direct model (452.91) was more higher in contrast with indirect model (22.2222 and 14.6198 for male in two and three factors model respectively, 3.6841, 3.5658 the same for female). Diffusion coefficient showed increasing trend parallel to the escalation of the distance from releasing point in the direct model (3.44). Based on this model and annual diffusion coefficient calculation mechanism equation (2.14) not only (D_{anm} and D_{anf}) increased along with distance escalation, but also consequently the annual diffusion coefficient of the female moths were further than male. Nearly all of indirect models estimated the diffusion coefficient of male moths further than the female moths while direct models calculated the annual diffusion coefficient of female moths higher than that of male moths. Population rate of spread (C_m and C_f) gave the impression of reliability while computed equal to 26.79 and 29.43 meter per year for male and female respectively. Additionally the radius that encompassed 98 % of dispersing moths each day was two times of each distances from the releasing point in direct model.

3.7.7 Mortality and emigration

Estimation of mortality (k_m)and emigration rate (k_e) based on the equation (2.3), revealed resembling results regardless of model type and moth's gender (See tables3.40, 3.41, 3.42, and 3.43).

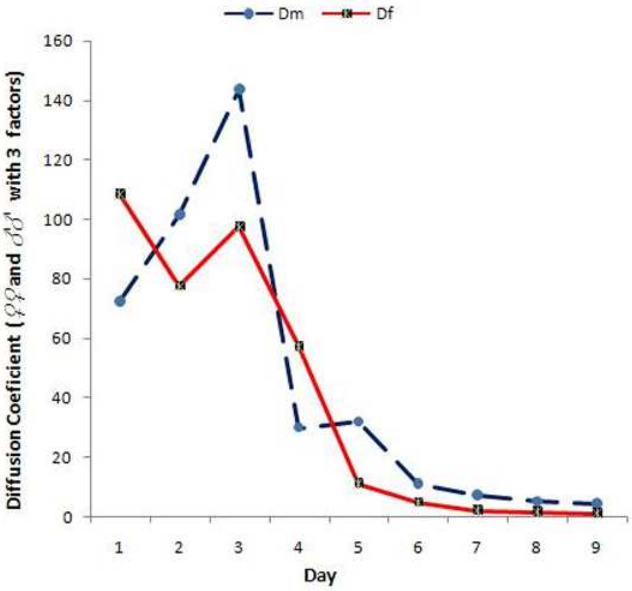

Figure 3.23: Diffusion coefficient of male and female moths using the model which included dispersal distance and flight height, Dm and Df refer to Diffusion coefficient of male and female respectively.

Table 3.46: Analysis of variance for female and male moths dispersal.

Sex	Source	DF	Type1SS	MS	F	Pr > F
Female	Day	8	0.42041060	0.05255133	9.12	<0.0001
	height	2	0.06974060	0.03487030	6.05	0.0024
	Direc*dist	21	2.76976539	0.11540689	20.03	<0.0001
Male	Day	8	924.110989	115.513874	10.53	<0.0001
	dist	3	361.538879	120.512960	10.98	<0.0001
	height	2	292.926383	146.463192	13.35	<0.0001
	Direction	7	2015.973629	287.996233	26.25	<0.0001
	Direc*dist	21	6166.100188	293.623818	26.76	<0.0001
	R^2= 0.37(female)		R^2= 0.27(male)			

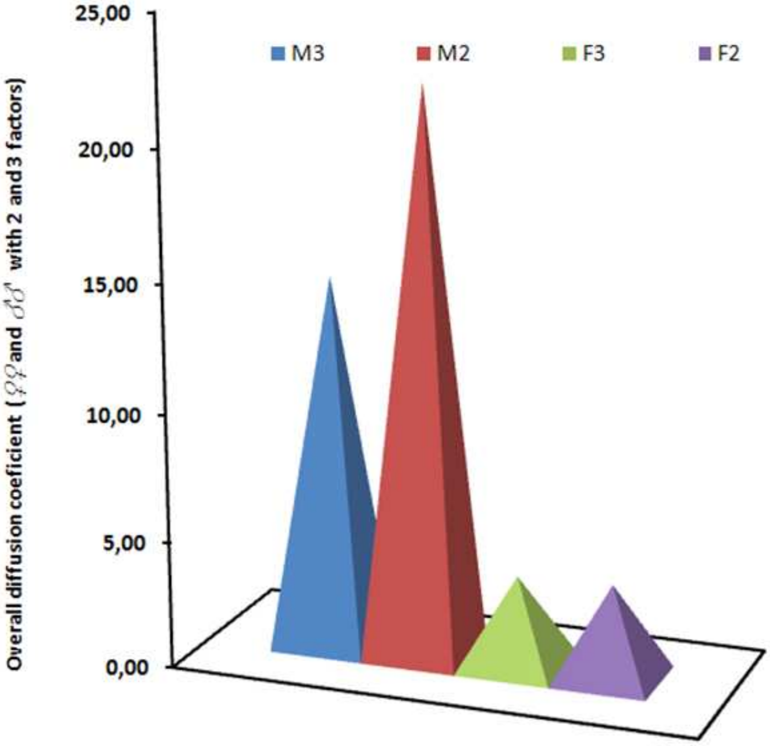

Figure 3.24: Overall Diffusion coefficient of male and female moths using the models which included dispersal distance and dispersal distance and flight height. (M3 and F3 = Male and female moth D in the model with three factors respectively, M2 and F2 = Male and female moth D in the model with two factors respectively).

Table 3.47: Least square mean comparison of flight height for male and female moths.

Sex	Variable level	1.2	1.6	2.2
Female	1.2		<.0001	0.8728
	1.6	<0.0001		<0.0001
	2.2	0.8728	<0.0001	
Male	1.2		<0.0001	0.8520
	1.6	<0.0001		<0.0001
	2.2	0.8520	<0.0001	

Chapter 4

Discussion

Tracking the movement of insects in their natural habitat is essential for understanding their basic biology, demography, and ethology. A wide variety of markers have been used to assess insect population dynamics, dispersal, territoriality, feeding behavior, trophic-level interactions, and other ecological interactions. An ideal marking material is durable, inexpensive, nontoxic to the insect and the environment, easily applied, and clearly identifiable. Furthermore, the marker should not hinder or irritate the insect or affect its normal behavior, growth, reproduction, or life span [57].

4.1 Effect of anesthesia and marking on survival of adult Codling moth

Individual marking: For individual marking, paints and inks are appropriate materials [170]. The major advantages of using paint or ink to mark individual insects are that these techniques are inexpensive and the specimens can be nondestructively sampled and re-sampled over the course of a long-term study [57] and [60]. The major disadvantages of using paints and inks for marking individual insects are that the application of the marker is often tedious and time-consuming. Also, the marker or the solvent is often toxic to insects [57].

According to the vulnerability of the Codling moths as well as problematic handling of it, individual marking implies anesthetizing or numbing of the moths prior marking. Treatment effects was significant in the overall model, while pair wise mean comparison revealed that there was no significant difference between treatment I and II as well as treatment III and IV. The first section hints that duration of the anesthetize does not affect the survival of moths meaningfully and the last section indicate that the anesthetize does not influence the moth's survival and the differences is only related to the marking process.

Mean comparison indicated that mean survival of the coupled genders (non marked numbed treatment) was further than the segregated treatment I and II. This differences pointed out that marking influenced the moths significantly. While, non differences between treatment III and IV indicated ineffectiveness of the numbing temperature. Although we used felt-tip pens for the marking of hind wing margin of the moths, probably marking mal influence on the survival related to its solvent. Despite feasibility and inexpensive traits of this method, Southwood, 1978 has mentioned toxic solvents of the paints as disadvantages of method.

Presented information firstly implies focusing on other appropriate methods of the marking and secondly when nominated as a marking method, may assist proper interpretation of Mark-release-recaptured population characteristics based on this marking method. Furthermore, marking arisen mortality and disappearance of the released insects may explain slightly clear.

Mass marking: Mass-marking techniques are an important element of many dispersal studies [100], [154], [120]. Dusts also known as powders have been used to mark insects for more than 75 years [57]. To date, they are probably the most commonly used materials for externally marking a variety of insects [57]. Various kinds of dusts have been used to label insects [138], [178], [173], [170] and [9]. An invisible green fluorescent dust used in crime detection was among the first dusts used to mark insects [138] and [178]. in contrast to the Day-Glo, fluorescent dust is not comfortably visible with naked eye. Dust application does not possess disadvantages of the individual markings.

Most studies using the marked insects pre-evaluate the influence of the marking agent on longevity and to a more limited degree, reproductive biology [170]. Our aforementioned aimed study indicated that male and female moths influenced by the perviously mentioned amount of the fluorescent powder. Differences in the replicates (Cylinder in the Analysis of variance table) hints that variations originated partially of experimental material. Meanwhile suggested linear model for the male and female moths may be useful for the coming researches distortion interpretation, we have modified the quantity of the fluorescent powder in the main release recapture studies up to the 50 percent. Regard to the utilization of the UV-lamp to detect the fluorescent powder color in 360 nm, small amount of it could be adequately distinguished. Most of the aforementioned studies except Moffitt and Albano 1972, did not revealed the quantity of the powder. Our finding were in congruity with the Mofitt and Albano 1972 results. These findings may facilitate the improvement of mark-release experiment results and interpretation of them more precisely. Particularly considering of the mortality and disappearance rate, as well as its functionality in estimation of the mortality and disappearance in dispersal studies.

4.2 Effect of cold storage on the longevity of adult Codling moth

Efforts to storage and maintaining of the insect for desired times has been performed for long times [37], [120] and [165]. Most of the studies on interaction of low temperature and Codling moth are related to the control tactics of this pest [121]. For example Moffitt et al. [120] reported 133 days survival for diapausing larvae, 30 days for non-diapausing mature larvae at standard cold of apple storage and 60 days for pupae. Whilst in the mass production and storage process the quality and quantity of the stored insect is crucial, high mortality, perpetual diapause, short longevity and altered sex ratio actually may influence coming experiments [120]. Singh and Ashby 1986 reported two years storing of the diapausing larvae where longevity of them strongly decreased after one year. Our finding indicated that keeping the adult Codling moths at $4°C$ increased the longevity of male and female moths, while the female moths lasted distinctly further than males. One explanation of this differences may be related to the innate characteristics of the male and female moths. Under the optimum condition longevity of the females is higher than that of males [56] and [116]. Body size and continent as well as the less mobility and non productivity (male and female were segregated in this study) probably are other reasons. In the proposed models, cold storing explained 71 % of the male variations in contrast to 57% of the females which verify more affection and debility of the males by the storage condition than by females (Fig. 3.7, 3.8). Stability of the survival of both male and female moths up to the first six days imply on utilization of at least six days old stored moths in the mark-release-recapture researches without noticeable considerations. Meanwhile by utilizing of the presented model, calculation of an index and including it in the coming studies (e. g. calculation of mortality and or disappearance in dispersal studies) appear to be feasible. In the unstable climatic conditions similar Germany climate, the most important obstacle of field researches is weather condition. Therefore appropriate storage method with the slightest influence on the biology of the organism could be panacea to rescue from this instability.

4.3 Influence of climatic factors on dispersal of Codling moth

Weather factors play a major role in regulating *C. pomonella* capture by pheromone traps [135]. Since activity by Codling moths particularly by males is primarily crepuscular, with peak flight occurring shortly after sunset, [15] and [198], because of regulation of iris pigment in the compound eye and its migration between its two extremes [152], we focused more on the twilight weather conditions. May this study bring up appropriate knowledge on meteorological factors and Codling moth dispersal interactions. In June-July in Central Europe ($50°N$, e. g in Prague and Bonn) nautical twilight begins one hour after sunset and astronomical twilight about two hours after sunset [152]. The results presented in this study clearly demonstrate the effects of weather factors on dispersal of the Codling moth. While over circadian factors were included in the models simultaneously with twilight climatic data, twilight temperature, twilight wind speed, and precipitation were the dominant regressors in the models and impressive factors on dispersal of Codling moth.

Despite the similarity of proposed models for marked male and female moths, male moth's model accounted for 50 percent of the variations while 25 percent of the variations explained by marked female moth's model. Nearly the same result was obtained for feral moths in which the feral male model interpreted 56 percent and feral female model 27 percent of the variations. Furthermore, the variables which governing the marked and feral male and female moths were not the same (Eq. 3.12, 3.9, 3.14 and 3.16). Probably this non similarity hints the further affection of weather factors on male moths. One explanation for this could be the differences in the activity of the male and female moths as well as calling and foraging behavior of the male and female moths. Normally female moths release the pheromone and that is the male moths which should attempt to find the couple. Positive effect of twilight wind speed in the models may refer to this actuality. Application of the Pear ester traps which is attractive for both male and female moths in addition to the captivity of the female moths in this traps, meanwhile may fortify the calling behavior of the females [15], increase the male searching efforts through the decreasing of the available females. Pitcairn et al., (1990) emphasized on the influence of the climatic factors on male moths too. Another reason to support the idea of more mobility of male moths and consequently further affection by weather factors is the emission of majority of host volatile during the dusk since male moths show a response equal to or higher than females to nearly all compounds [31]. Mean distances traveled by released males was significantly higher than by females in Bloem et al., (1998) studies which is another testimony for more mobility of male moths.

Negative influence of dusk precipitation on the marked male and female moth dispersal on one hand related to the physical effect of the rainfall which restrict the activity of the moths, on the other hand has connection with volatile emissions of the host tree. Vallat et al. [187] revealed that rainfall was associated consistently with an increase in the late afternoon in terpene and aldehyde volatiles with a known repellent effect on the Codling moth. Although the interaction of the pheromone and kiremone with secondary metabolites of food plant may require further investigation. In regard to the relation of precipitation and relative humidity, the negative influence of relative humidity in dispersal of feral moths (Eq. 3.14 and 3.16) probably could be explain in reference to the rainfall direct and indirect impacts. Moreover, effect of relative humidity (RH) above 50 percent (average 73.89 percent) in this study corresponds well with the findings of Saethre and Hofsvang, [152]. RH is directly connected to temperature, and an increase in RH in the evening is an effect of the temperature decreasing during the evenings. In this study feral moths model linked with positive effects of dusk temperature and Day Degree. Since the minimum, mean and maximum temperature in this study at twilight was 1.40, 13.71 and 21.53 respectively during the study season (Fig. 3.20), Batiste et al., (1973) reported further that low temperatures were a limiting factor for the daily flight during the early season, while high temperatures often delayed initiation of daily flight during the latter half of the season. Our "by date option" analysis also verified that the influence of the weather factors did not followed steady flow during the growing season. Meanwhile, Saethre and Hofsvang [152] emphasized on the temperature impact and mentioned that temperature, and not light conditions is the main factor limiting flight and oviposition activity to continue throughout the night, Kuehrt et al. [102] refer to mating condition of the moths. Based on their findings unmated adults were negatively thermotactic after their nocturnal activity period and prefer to settle at the low-temperature ends of the temperature gradients. Relative humidity did not influenced the thermal response in unmated females, whereas unmated males showed a less distinct temperature selection under high humidity. By contrast to unmated moths, ovipositing females appear to be markedly thermophilous because they deposit the highest proportions of their eggs at the highest temperatures in the gradients offered and also settle in warm areas [103]. This findings are partially in congruity with our findings in which the feral females model allocated tall indexes for twilight temperature and Day Degrees as well as feral male moths (Eq. 3.14 and 3.16). Immense work load and repeated daily samplings as well as maintaining the rearing colony at the same time demanded extensive labour and time build up to ignorance of the mating condition of the moths in this study. Meanwhile, beside the aerial temperature, the microclimate temperature such as different sides of the tree trunk and apple fruit temperature may influence the development and oviposition behavior of the Codling moth differently [103].

The influence of wind on the flight activity of the moths is not very easy to measure, because wind speed is rarely constant over time, but often changes from one second to another. The 30 minutes mean values on wind speed obtained in this study. Mean an maximum wind speed for overall period was 6.30 m/s (at 2.5 m) and 11.00 m/s (at 10 m) and for twilights 3.80 m/s (at 2.5 m) and 7.10 m/s (at 10 m) respectively (Table 3.27). The interesting aspect of wind speed impact on the moths distribution joined with different effects of wind speed at 2.5 m height and 10 m height. Whereas marked male and female and feral male positively influenced by low elevation wind speed, feral female moths influenced negatively by high elevation wind speed. In regard to the higher speed of the wind in upper levels on top of host canopy, the negative effect of the wind speed at 10 m elevation on feral female moths is reasonable. This phenomena is in congruity with Pitcairn et al. [135]. They concluded that moth capture with light traps was reduced at wind speeds above 8-13 m/s and was completely inhibited above 21-31 m/s [135]. Positive effect of the proportionally low speeded wind with the marked and feral moths is reasonable since the emissions carry over upwind. Then accelerate finding of couple, suited host or luring trap. This findings criticized Batiste et al., (1973) results. They reported that wind did not appear to be a major flight limiting factor in their studies, but they were not able to measure the wind conditions at the actual time of catch [152]. It should remember that normally number of the dispersed organism decreases by the time thus hints the negative correlation of the time with the density. The positive effect of the time (Day) in the present models was accounted for daily cumulative data. Likewise the effect of the height may be born of dwarf varieties in our study site in which the upper parts of the canopy was the appropriate flight heights.

We can conclude that present study provides new knowledge in basic as well as in applied science. Twilight temperature, rainfall, wind speed and Day Degree impress the distribution of the moths in a superior way than the circadian weather data. Furthermore, relating weather to *C. pomonella* male and female capture in pheromone traps can offer behavioral insight to individual monitoring their flight patterns for commercial purposes. This knowledge could mitigate confusion which arises from observations of erratic flight patterns and could lead to fewer treatment decision errors in the future. At last, concurrently integration of the Day Degree and other climatic factors with distribution of Codling moth in present study, may accelerate and strengthen forecasting programs of this key pest as well as the related management tactics.

4.4 Trade off trap structure in assessing the horizontal and vertical distribution of Codling moth

Pear ester has proven to be a promising attractant for Codling moth in apple orchards in several fruit growing regions [86], [96], [98] and [92]. Studies reported here suggested that a variety of factors can influence the effectiveness of Pear ester and pheromone traps in differentially capture each sex, and consequently the interpretation of horizontal and vertical distribution influenced. For example, Cylinder -Pear ester baited traps versus Delta- Pear ester baited catch further marked and feral male and female moths, whereas delta-pheromone baited traps catch more marked and feral males rather than prior traps. Also traps placed at mid height (1.6 m) versus low (1.2 m) and high (2.2 m) heights in the canopy, caught more marked and feral insects (Fig.3.14 and 3.15). In addition, traps placed on 15 m distances of releasing point caught more marked male, while on 30 m distances caught more marked and feral females rather than traps placed other distances. The high numbers and proportions of female moths caught in our field studies with Pear ester baited Cylinder-shape trap suggest that the Cylinder-shaped trap is an effective monitoring tool for female Codling moths. This result is in congruity with the results of Knight and Fisher [91]. They comprised Pear ester baited Delta traps with the clear interception traps and concluded that the low numbers and proportions of female moths caught in field and flight tunnel studies indicates the non effectiveness of delta-shaped trap as a monitoring tool for female Codling moths.

Action thresholds for Codling moth that trigger a recommendation to apply insecticides in orchards treated with sex pheromones are based on relatively low cumulative moth catches (1-4 moths / trap / time period) in white delta-shaped traps baited with either sex pheromone or Pear ester [92]. Therefore, switching to a different trap / lure combination that could achieve even small increases in moth catches could significantly impact growers' pest management decision-making. Our data show that replacing Cylinder-shape with Delta traps to monitor Codling moth will likely require a reassessment of action thresholds for this important pest.

Attracting both male and female moths is the advantages of the Pear ester traps while the pheromone traps attract only male moths. In the first experiment, male caught more than three folds in pheromone traps than other traps. Differences in our results with other studies in catching the male and female may originated from trap density and distance, site and orchard condition and the attractant potency as well as the different releases and the weather and the last but not least traps checking intervals. For example in a study by Knight and Light [96] reported 0.75 0.37 and 0.60 0.15 caught per trap per day of males and females respectively with the same loading of the Pear ester (50 mg), which are lesser than our trap caught. One of the misleading in the counting of trap catches is the role of predators which feed on the tethered moths. Foe an instances Earwigs feed on the captive moths voraciously and in long term sampling intervals distinguish of the moths (Marked or feral or the sex) remnants and even detection of the traces of them on sticky bottoms is impossible (personal unpublished observations). Therefore, appropriate sampling interval could be one of the deterministic factors of the trap catches. Other kind of differences may develop by the varieties of the trees in the sampling site. Divorce varieties influence on the Pear ester trap caught unequally ([96] and [98]). In our experiment site, a mixture of more than 13 different varieties of apple trees could influence trap caught. We applied different colors of fluorescent powder for coding of each release, which could differently affect dispersal capabilities of moths.

The response of male Codling moths to pheromone at various heights and distances in an orchard is apparently not constant. The variation in capture of the moths with height and or distances may be a response to the canopy height, fruit distribution or virgin female distribution and attraction of males. Our vertical distribution results for marked male moths confirmed the results of Thwaite and Madsen [180], they found no statistical difference in the number of males caught in pheromone-baited traps placed low and high in the canopy. While the results for the marked female dispersion contrasting their study because attraction of the females at different height were significantly different. These results were consistent with those of Riedl et al. [145], Howell et al. [67], McNally and Barnes [118] suggesting that traps for monitoring Codling moths be placed in the upper canopy because of the preference for mating near the canopy top. Results presented here strongly suggest that for optimal disruption of Codling moth mating, Pear ester dispensers be placed in the upper part (in this study 1.6 m height of canopy).

Vertical distribution of male and females in this experiment was more or less complicated. For example while the overall catching percent of males in delta-shape traps was about three and five folds respectively for marked and feral males further than other two traps, distribution of the catches in different distances was non similar (Table, 3.9 and Fig. 3.11). In other word, the radius attraction of Delta Pear ester bated traps and the Cylinder-shape traps for their top catches was greater than Delta pheromone traps. For instance, feral female catches in the Cylinder-shape traps two and sex times more than the catches of Delta Pear ester baited traps for 45 m and 60 m distances respectively (Table 3.9 and Fig. 3.11). According to non-significant catches between Delta Pear ester baited traps and Cylinder-shape traps, it could be concluded that the only differences of mentioned traps with Delta pheromone one is their attractant material. Suckling et al. [174] when found the similarity in the distance dispersal of male *Epiphyas postvittana* (Walk.) and *Planotortrix octo*

(Lepidoptera: Tortricidae) suggested that the differences in trap efficiency between species comes from other sources such as attractiveness of the lure, etc. Other factor, which may influence the dispersal distances and consequently trap catches may lie in body weight, length and therefore wing loading. Danthanarayana [33] in his study on *Epiphyas postvittana* (Walk.) showed that adult body length, and therefore wing loading was dependent on larval host plant, and he argued that smaller moths from hosts such as white clover would be more likely to disperse further than larger moths, which had fed as larvae on plants such as curled dock. We used laboratory-propagated insects in our experiments in which the larvae were reared on precisely supply recipe. Hence, variation in body weight and length of the marked population in our experiments sounds less significance. Regard to foregoing discussion, it is estimated that if Cylinder-shape traps bated with pheromone, not only would catch as much as the Delta pheromone traps but also because of its further catches in farther distances and distanced efficiency, the number of demanded traps could reduce. Finally, Cylinder-shape traps could recommend for both male and female moths population studies. This recommendation sounds more reliable when assume that there is no differences in flight potential of male and female moths. Schumacher et al. [156] concluded that male and female have little or no differences in flight capacity and that both within- and between- habitat are similar in number and magnitude for both sexes.

Conclusion: Consideration of aforementioned factors could likely increase the precision of estimating the seasonal population densities of male and female moths and improve lure and kill, as well as other management strategies. According to the results of this study and non-significant differences in marked female catches of Delta and Cylinder-shape trap, likewise priceless and effortless manufacturing of the last one, and precedent discussion, utilization of Cylinder-shape trap in mark-release-recapture studies of female and male Codling moths is recommended. Furthermore, a less expensive trap and reliable prediction from larger sticky bottom trap counts would facilitate more widespread Codling moth monitoring. Howbeit study of its efficiency by using pheromone and reassessment of action thresholds with new trap / lure combination remains to be more clarified.

4.5 Influence of apple cultivar on pheromone and Pear ester traps

In the continuum of the concept of R and K life history strategies, the Codling moth may be classified as strongly toward a K strategy. Among other characteristics, this include insect species whose limited niche in nature may be tolerable to wild hosts but which are major pests in the cultivations, where good productivity of high quality fruits is required. The status of a K-species as a pest may be increased when the mixing of cultivars results in the establishment of additional trophic relationships [11]. The early apples interplanted with late varieties are frequently very heavily infested [71].

There were over thirteen varieties of apple in the present study site. Entrapped moths quantity in the suspended traps on these varieties, indicated that marked-released male and female significantly influenced by diversity of varieties as well as feral male and female moths. Additionally all the fitted models affected by the date of the samplings, which hints the instability of varieties impact on the moths either inter-variety or intra-variety as well as spatio-temporally. Generally various characteristics of food plant including size [26], architecture [103], host volatiles [105], [61],

[168], [124] and [31], host density [107] and phenology (e. g. [17]) may governing this procedure. For example Blommers, 1994 demonstrated that the modern small-sized apple tree provides few hiding places for the insect, consequently influence the population dynamics through the vulnerability by the natural enemies. Based on the phenology of the host tree the quantity and quality of the volatiles modifies by the time, since the total amount of of farnesene present in the apples in correlation with fruit size [11] and [53]. Moreover, the ripening time of the varieties are not the same for example variety Gala is ripen in mid August whereas Golden Delicious and Jonagold is ripen in mid September, which verifies the reasonability of sampling date explanatory variable significance once more. Study of Myer et al. [124] on the Oriental Fruit Moth (Lepidoptera: Tortricidae), confirmed the seasonal and cultivar-associated variation in oviposition preference of this pest afresh. Susceptibility of the cultivars to infestation by Codling moth is correlated with the emissions of the host since Lisitsyna [112] in his study on 115 apple cultivars proved that early, unseason and late apple cultivars showed 6.5 %, 11.7 % and 11.8 % infestation respectively [112].

Considering the overall (deviance value / degree of freedom) the descending goodness of fit for the presented fitted models in our study could be categorized as the models of marked male (Table, 3.14), marked female (Table, 3.17), feral female (Table, 3.21) and feral male (Table, 3.11). Least square means demonstrated significant effects of varieties for different groups of moths distinctly (Tables, 3.12, 3.15, 3.18 and 3.23). Likewise, least square pair-wise comparison of the varieties bestowed on more detailed information alongside with varieties. Feral moths indicated proportionally further significant pair-wise differences which is a cue for additional distinct interaction of host varieties and feral moths in contrast to the marked moths. Although Elstar is another successful offspring of Golden Delicious, their differences was meaningful for all moths's groups too. Disagreement of the feral and marked moths responses probably has its origin in slothfulness of the laboratory mass produced population. There was no behavioral response to apple odors by males reared 45 generations on an artificial diet, although electroantennogram responses were positive [168]. Whilst the life history of the purchased pupae retained vague, we utilized generations fifth to eight in this study. Another explanation for dissimilarity of feral and marked moths, may lie on the marking process. Despite, empirical experiments enabled us to use proper amount of fluorescent powder which had no significant influence on longevity of the moths, there was no possibility to inspect the influence of marking on the reaction and orientation of the moths to food plant volatile.

Female moth either marked or feral were more subjected to affection by varieties as overall than female moths. Meanwhile this reveals that male and female moths influenced distinctly by the host plants, one possible explanation of that may refer to sexual dimorphism of the male and female moths response to the host emissions. Based on the study of Hern and Dorn, 1999 a marked sexual dimorphism was found to increasing dosages of α-farnesene. Females were attracted to low dosages (starting from 63.4 ng) and repelled by high dosages (ending at 12.688 ng). Both mated and virgin females responded similarly in kind but differently in degree, both attraction and repellency being more pronounced in mated females. Males were neither attracted nor repelled over a large dose range (63.4 to 12.688 ng) except the highest rate which was attractive. This situation probably refer to a stronger dependency of females on plant-derived volatiles [61]. Therefore, this dependency imply stronger distraction and/or attraction to the special hosts rather than others, while male moths wandering around. Meanwhile the assessment of volatile and pheromone-kairomone interaction in such a complicated condition is apparently difficult and demands further studies.

In the almost fitted models the nested explanatory variables were related to the interaction of variety, distance and/or height. Undoubtedly, every sources has its effective domains which is moderated by vicinity and distant. In the present study we operated outside (from the borders of orchards) and inside (from a central point) releases. Only marked female moths denotatively reacted to outward and inward dispersal accompanying with the variety Rubinette. Rubinette parentage is Golden Delicious and Cox's Orange Pippin and has a superb flavor. Impartial distribution of the host varieties and traps may cause non significance interactions of same class with other releasing points and varieties.

Utilizing of the Genmode procedure SAS software, facilitated the comparison of numerical explanatory variables with categorical one, furthermore least square elucidated all possible simple and nested effects. Alongside other information of this study, female moths and varieties relation may warranted considerable outputs and aftereffects. Female moths orientation toward the host is due to the oviposition since its behavioral adaptations in oviposition is host-related [133] and [11]. Therefore, cultivars Cmeo, Golden Delicious, Jonagold, Rubinette, Pinova and Melrose which were meaningfully correlated with female moths distribution, probably are more vulnerable than others.

Conclusion: Current study revealed that dispersal of the feral and marked-released male and female Codling moths influenced by host cultivars distinctly and decidedly. Despite studies carried out on the food plant volatiles prior this study, but the quantifying of these relationships and proposition of distinct model for marked and feral male and female moths, bring about the present findings peculiar. Outcomes of presented study may improve the prevention strategies regard to the resistance and vulnerability of the cultivars. Always "Prevention better than cure". Moreover may ameliorate pest management tactics through further clarifying individual and sex-related distribution of the Codling moth, proper and subtle control measures and consequently environmental rehabilitation.

4.6 Study of Codling moth dispersal with mark-recapture and diffusion model

Dispersal is vital for the long-term persistence of all insects, although some species are highly mobile and others largely sedentary according to their dispersal propensity [56], [34], [81] and the last authors in other study [82]).

One of the most useful theoretical approaches to quantifying insect dispersal and relating it to the insect population dynamics is provided by diffusion framework ([184], [167], [129] and [79]). The advantages of the diffusion framework related to its compact and precise summary of the spatial distribution process and its explicit and mechanistic connection to data [79].

4.6.1 Codling moth dispersal interpretation based on indirect diffusion coefficient estimation

Considering the overall models, suitability of three factors fitted models is more convincible than that of two factors model particularly for male moths (See Fig.3.24). It signifies that diffusion model elucidate dispersal of Codling moth more appropriately when height of flight was included in model. Height is an important consideration for understanding insect distribution and abundance [27].

Although the diffusion coefficient of female moths was superior at the first day, generally the diffusion coefficient of male moths was higher than female moths in the both models. This hints the quick dispersal and more mobility of male moths. For the supporting of this idea, we postulate that male moths should forage for the female moths, as well as every female moth possibly ruling similar to a mobile attractants that led to male's dispersal arising tendency. Additionally, disproportionate luring potential of pheromone (only catch male moths) and Pear ester traps (catch both male and female moths) perhaps influence the dispersal of male and female in an unequal manner. Previous studies on codlemone and Pear ester verifying this argument as well [86], [98], [92], [89], [22], [96] and [84]. Quick decline in the dispersal of the moths could be anticipated on fourth and fifth days after a sharp uprise. On one hand rapidly dispersed moths are attracted to the traps on the third day and therefor decreased the following population and/or find their couple and therefore pheromone emission disruption could not influence them effectively (e. g. [186]). Male moths dispersed faster than the female moths at the rest over period of dispersal next to the fifth day which probably due to the aforesaid reasons. Male moths more mobility could be plausible with their reaction to the female's pheromone and mating foraging of the male moths. However the body size, race ([82] and [81]), longevity, sex ([81] and [82]), mating status ([24] and [90]) pheromone and Pear ester attractiveness and traps efficiency [118], [83], [91], reaction to the food plant emissions ([17] and [107]) could be other factors which may more or less influence dispersal of male and female moths.

Moreover our findings are not congruent with the results of Schumacher et al. [157]. Based on long single flight (LSF) they concluded that male and female moths have little or no differences in flight capacity [157]. In this study we had only one observation in which the male moths recaptured 170 m farther than the releasing point at 1.2 m height suspended trap.

Regardless of the model type, the R^2 was relatively high in our experiments which evaluate how well the model fits data. It should mention that a good fit (high R^2) does not necessarily prove that the individuals move independently and at random. However, the individuals would have to display unusually strong social behavior or the environment would have to be carefully constructed to generate data in which the fit is good, but the insects may do not follow the diffusion assumptions. On the other hand, a poor fit to the data guarantees that the insects studied do not obey the conditions for diffusion. One possibility is that the individuals repel or attract each other, or move in some other way that involves cooperative behavior. Another possibility is that the insects are subject to some external influence, such as an attractant, or wind, so that the assumption of random motion is violated. In studies like the present study in which the insects are target of attractants, it is worthy of violation of assumption of random motion, but superiority of R^2 at the present case may hints satisfiable fitting of the models as well as random dispersal of the moths [150]. Probably appropriate spatial order and balanced distribution of the traps in addition to saturation of the attractants resulted a uniform spatial environment. Sheperd et al. [162] in their study on predaceous insects Big-eyed bugs, *Geocoris* spp., calculated R^2 value of 0.98 where they measured bug's spatial distribution seven days later after releasing [162]. Similar high values of R^2 acquired by Turchin and Thoeny [184]in the study of southern pine beetle quantitative dispersal with mark-recapture experiments, Tamaki et al. [177] in pea aphids dispersal and Suckling et al.[174] in *Epiphyas postvittana*(Walker) and *Planotortrix octo* Ugdale (Lepidoptera: Tortricidae) which entirely could be argued as approve and accuracy of our findings.

4.6.2 Direct and indirect fitted models attributes

Diffusion coefficient increasing trend parallel to the escalation of the distances is obviously rational in indirect model since the distanced trapped moths were more mobile and dispersed more quickly than others. Based on indirect model the annual diffusion coefficient of male and female moths indicated an increase tendency along distance escalation, additionally higher annual diffusion coefficient for female moths resulted in this model. A portion of this distinction probably related to the longevity of male and female moths that is contributed in the computing of annual diffusion coefficient. The same argue was for female population rate of spread. Largest estimation of the diffusion coefficient using this method was reported in other studies too. Smith et al. [169] reported largest diffusion coefficient for *Anoplophora glabripennis* (Cerambycidae) using direct method.

Therefor the differences of diffusion coefficient of direct and indirect methods is more or less inborn. Furthermore the Codling moth, *C. pomonella*, is considered a sedentary insect, and dispersal by flight in this species is believed to be primarily associated with reproductive and feeding activities [51] and [56]. Therefore large distances displacements of Codling moth appear to be out of potentiality of this pest which indirect models refer. Hence, great difference in the diffusion coefficient of direct and indirect methods probably postulate that indirect models were more appropriate for present performance. Such a great diffusion coefficient of direct model, implies swift and independent dispersion of the moths, which is not reliable for sedentary insects like Codling moth on one hand and high values of R^2 in our indirect models on the other hand. High values of R^2 hints that released insects diffused randomly and at constant rate [150].

4.6.3 Mortality and emigration

When we calculated values of K for the present data, the results were a few confusing. One of the reasons of a such low rate for K, is the innate traits of our experiments that insects were collected using attractant traps. Regard to the density and distribution of the traps (15 m distanced at eight directions and three heights) and influence of pheromone / keiremone emission and consequently intensifying capture chance of the moths, some parts of the population were caught even prior to entire life-span of an insect and taking in its potential dispersal. On the other hand insects from wide areas were draw inward, which may produce inward dispersal and even immigration instead of outward dispersal and emigration in the system. Codlemone-baited traps placed on trees in orchards's borders can catch more Codling moths because of moth immigration (Author observations and [98]). Jeanneret and Charmilot [73] emphasized on the same conclusion, meanwhile hinted that exchanges were significantly different from one margin to the other furthermore, there was no massive emigration or immigration of tortricid species from or into orchards in their study.

Undoubtedly we can postulate that factors which influence the dispersal of the moths and consequently affect the flight distance and height as well as population rate of spread are not limited to the flight distance and height. Once, recapture sampling at a high frequency over an extensive area may ”trap out” dispersing individuals. This may have partly contributed to more or less lower average dispersal distances of 36.03 m in the present study. This finding was verifying the findings of Turchin et al. [184] and Smith et al. [169] on southern pine beetle dispersal study. Along with, landscape heterogeneity especially variation in size, arrangement, architecture and host varieties volatile emission and its over growing season alteration are likely to have upshots on Codling moth dispersal (See section of variate influence on dispersal). Following examples are some examples to testimony of food plant characteristics influence. Levine et al. [107] emphasized on the role of plant dispersion and density, and clarified that significant differences in the probability of host plant attack were functions of overall plant dispersion within foraging habitats (patches) as well as the density and specific location of the host. Benzemer and Mills [17] found that walnut varieties and food plant continent has significant influence on population establishment of Codling moth. Vallat and Dorn [186] demonstrated that not only the plant emissions alters during the growing season, but also emission and its quantity firstly possess dimorphism tropism sexually, secondly has distinct influence in different quantities on the same gender.

We have shown that the diffusion model leads to powerful techniques for the analysis of dispersal data at least for one economically important insect. Use of the model allows one to determine whether the individuals move at random. If the motion is random, the parameters derived from the least squares analysis show how fast the individuals move and how fast individuals leave the sampling area, either through death or through emigration. If the attempt to use the model shows the motion is not random, the attempt itself provides information that is otherwise not available.

This study could be summarized by including the last four points. First, it provided an estimate of population spread by Codling moth, using estimated rates of reproduction and dispersal. Second, we quantified the association between various key factors and Codling moth movement for the first time using the diffusion model. Third, our approach provided an empirical method to assess factors influencing vertical and horizontal dispersal and fourth, we included additional parameter to the diffusion model which improved the predictive explanatory potential of this method for dispersal studies at least for a cosmopolitan and economically eminent insect.

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Submitted:

Gharekhani.G. H., C. P. W. Zebitz. 2009. Trade off trap structure in assessing the horizontal and vertical distribution of Codling moth *Cydia pomonella* L. (Lepidoptera: Tortricidae).

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